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ABSTRACT STANDARD TOPIC 21 - DISCRETE GLOBAL GRID SYSTEMS - PART 4 AXIS-ALIGNED ZONES

ABSTRACT SPECIFICATION TOPIC
Conceptual model

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Note

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CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF RECOMMENDATIONS

I ABSTRACT

Figure 1

This Abstract Specification extends the specification for Discrete Global Grid Systems (DGGS) to DGGS with Axis-Aligned Zones. This document specifies an Axis-Aligned DGGS Reference system as an extension of the DGGS Core Reference system and of Temporal DDGS Reference systems.

II KEYWORDS

The following are keywords to be used by search engines and document catalogues.

ogcdoc, OGC document, Discrete Global Grid System, DGGS, Axis-Aligned, Digital Earth, DGGS-core, Spatial Reference System, Global Data Structure, Geographic Information Systems, DE-9IM, standard, specification

III PREFACE

This document is consistent with ISO 19170-1:2021 Geographic Information — Discrete Global Grid Systems Specifications — Core Reference System and Operations, and Equal Area Earth Reference System.

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IV SECURITY CONSIDERATIONS

No security considerations have been made for this document.

V SUBMITTING ORGANIZATIONS

The following organizations submitted this Document to the Open Geospatial Consortium (OGC):

- Manaaki Whenua - Landcare Research, New Zealand
- Peking University Collaborative Innovation Center for Geospatial Big Data
- University of Calgary

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VII FOREWORD

This is a first edition of Part 4 of Topic 21. It extends OGC Abstract Specification Topic 21 Ed 2 (20-040) to encompass Axis-Aligned DGGS.

VIII INTRODUCTION

There are three ways to classify DGGS:

- The first classification of DGGS is based on dimensions, which includes 2D, 3D, 4D, … nD DGGS. Part 1 to Part 3 of ISO 19170 specified the first three types of DGGS.
- The second classification of DGGS is based on uniformity of grid's size (length, area, volume). One type is with equal size, the other is adaptive or with unequal sizes. The former forms Equal Area DGGS with 2D geometry (defined in ISO 19170 Part 1), and Equal Volume DGGS with 3D geometry (defined in ISO 19170 Part 2). The latter is adaptive Earth Surface DGGS or longitude and latitude DGGS in 2D shape, and diffusion type of DGGS in 3D shape.
- The third classification of DGGS is based on the coordinate reference system which defines DGGS. It could be divided into Axis-Aligned DGGS (AA DGGS) , Non-Axis-Aligned DGGS (Non-AA DGGS) and Hybrid DGGS (AA DGGS and non-AA Hybrid DGGS).

This standard specifies a set of consistent common classes for AA DGGS data model. The main reason is that AA DGGS can be constrained by certain conditions and frameworks, while it is difficult to set rules for non-AA DGGS and Hybrid DGGS that cannot be constrained.

The coordinate reference system is bound to the real world through a datum, which specifies the relationships between the real world and CRS (Coordinate Reference System) in dimension and direction. AA DGGS is bound to the real world through the coordinate reference system, and connect different dimensions through the coordinate reference system. Divided by Different axes (dimensions) (e.g. bisection), AA DGGS forms an independent subdivision structure corresponding to different levels in each axis direction. Using the orthogonal characteristics among axes of the coordinate reference system, subdivision of each coordinate axis forms the constellation of AA DGGS cells (zones). Each zone is assigned a unique address called zone identifier. Each zone identifier is associated with a typical location in a coordinate reference system defined by the ISO reference standard. AA DGGS described by geographical world is 4D in nature, including 3D space and time dimension. Therefore, a spatio-temporal data model with unified coordinate system, geometry, topology, identifier and reference system using identifier, is the premise of spatio-temporal AA DGGS.

AA DGGS is a typical classification method of DGGS. It classified DGGS from the perspective of coordinate reference system and describes a way to define DGGS from coordinate reference system. This is usually a geographic coordinate reference system, which includes the process of selecting coordinate reference system as datum, dividing coordinate axes of every dimensions step by step, intersecting different division levels of different coordinate axes to form DGGS, and using a unique identifier related to coordinate reference system to identify the zones of AA DGGS. Hence AA DGGS is defined as:

a) Different axes (dimensions) are divided separately (for example, bisection) to form an independent partition structure corresponding to different levels n in each axis direction

$S_{n,i}^{d}$

$$\begin{cases} R_d = \bigcup_i S_{n,i}^d \\ S_{n,i}^d \bigcap S_{n,j}^d = \varnothing \\ \exists\, i,\, j,\, S_{n+1,i}^d \bigcup S_{n+1,i+1}^d = S_{n,j}^d \end{cases} , d \in \{X, Y, Z, T, \cdots\}, i \neq j, n \geq 0 \tag{1}$$

a) The orthogonal property is maintained between different axes (dimensions), and the cross product is 0

$$\forall\, d_i,\, d_j \in \{X, Y, Z, T, \cdots\}, i \neq j, d_i \times d_j = 0 \tag{2}$$

a) The element G of AA-DGGS is formed by intersection of different axes (dimensions) and different levels of subdivision structure

$$G = S_{n_i}^{d_i} \bigcap S_{n_j}^{d_j} \bigcap S_{n_l}^{d_l} \bigcap \cdots \bigcap S_{n_k}^{d_k}, d_i, d_j, d_l,\ d_k \in \{X, Y, Z, T, \cdots\} \tag{3}$$

Features of AA DGGS include:

a) The number of axis considered by AA DGGS is aligned with the dimension. Generally speaking, different dimensions are orthogonal, thus the axes are also orthogonal.

b) The advantage of orthogonality is that the cross term is zero.

c) Orthogonality means the quadrature of all components with different subscripts is zero.

d) There are several classifications of orthogonal coordinate systems, such as:

e) Cartesian coordinate system, Two dimensional and 3D rectangular coordinate system, Polar coordinate system, Cylindrical coordinate system, Spherical coordinate system, Parabola coordinate system, Conic coordinate system, etc.

In addition, this standard also describes the relationship between AA DGGS and other types of DGGS, as well as the basic principles and ideas of mutual conversion and interoperability between different types of AA DGGS. This standard does not specify any specific AA DGGS model, basic coordinate reference system or coordinate reference system category, but is intended to allow a range of options to produce AA DGGS with compatible and interoperable function features.

This standard includes:

- Basic definition of AA DGGS
- Coordinate reference system of AA DGGS
- Tessellation structure of coordinate axes in AA DGGS
- Process of axis intersection to construct AA DGGS

- A general indexing method of AA DGGS
- Association between AA DGGS and other DGGS
- Specification of the interoperability between different types of AA DGGS, as well as with other non-AA DGGS and Hybrid DGGS
- Typical AA DGGS examples

1

SCOPE

1 SCOPE

This part of OGC Topic 21 / ISO 19170 supports the definition of:

- Axis-Aligned Reference System for DGGS

2

CONFORMANCE

2 CONFORMANCE

This standard defines a single requirements class, Axis-aligned DGGS, of http://www.opengis.net/spec/dggs/1.0/req/core/aa with a single pertaining conformance class, Axis-aligned Reference system, with URI http://www.opengis.net/spec/dggs/2.0/conf/aa/rs.

Conformance with this standard shall be checked using all the relevant tests specified in Annex A (normative) of this document. The framework, concepts, and methodology for testing, and the criteria to be achieved to claim conformance are specified in the OGC Compliance Testing Policies and Procedures and the OGC Compliance Testing web site.

All requirements-classes and conformance-classes described in this document are owned by the standard(s) identified.

3

NORMATIVE REFERENCES

3 NORMATIVE REFERENCES

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO: ISO 19107:2019, *Geographic information — Spatial schema*. International Organization for Standardization, Geneva (2019). https://www.iso.org/standard/66175.html

ISO: ISO 19111:2019, *Geographic information — Referencing by coordinates*. International Organization for Standardization, Geneva (2019). https://www.iso.org/standard/74039.html

ISO: ISO 19112:2019, *Geographic information — Spatial referencing by geographic identifiers*. International Organization for Standardization, Geneva (2019). https://www.iso.org/standard/70742.html

ISO: ISO 19156:2011, *Geographic information — Observations and measurements*. International Organization for Standardization, Geneva (2011). https://www.iso.org/standard/32574.html

ISO: ISO 19170-1:2021, *Geographic information — Discrete Global Grid Systems Specifications — Part 1: Core Reference System and Operations, and Equal Area Earth Reference System*. International Organization for Standardization, Geneva (2021). https://www.iso.org/standard/32588.html

4

TERMS AND DEFINITIONS

4 TERMS AND DEFINITIONS

For the purposes of this document, the following terms and definitions apply.

For the purposes of this document, the following terms and definitions apply.

This document uses the terms defined in Sub-clause 5.3 of [OGC06-121r9], which is based on the ISO/IEC Directives, Part 2, Rules for the structure and drafting of International Standards. In particular, the word “shall” (not “must”) is the verb form used to indicate a requirement to be strictly followed to conform to this standard.

4.1. Axis-Aligned DGGS AA DGGS ADMITTED

spatial reference system that uses a hierarchy of tessellations by partitioning earth space along each dimensional axis into grid cells. Each edge of an AA DGGS cell is defined solely by the coordinate value of one axis, resulting that each cell is surrounded by edges each of which is parallel to the axes other than the axis defining its position.

Note 1 to entry: DGGS generated by dividing the axes of general coordinate systems of GIS (Geographic Information Systems) and surveying such as geodetic coordinate system, geocentric coordinate system, longitude and latitude coordinate system, tangent plane coordinate system, etc. are AA DGGS.

Note 2 to entry: The cell edges (dividing lines) of AA DGGS are aligned with the coordinate axes which are mostly Euclidian or non-Euclidian orthogonal axes.

4.2. Non-Axis-Aligned DGGS non-AA DGGS ADMITTED

DGGS with zone’s edges are not aligned with axes of common orthogonal coordinate systems.

Note 1 to entry: DGGS on earth surface with cell shapes of hex, tri, diamond are non-AA DGGS.

Note 2 to entry: The coordinate axes of most non-AA DGGS are non-orthogonal in Euclidian or non-Euclidian space.

4.3. AA and non-AA Hybrid DGGS   Hybrid DGGS ADMITTED

DGGS which is Axis-Aligned in some dimensions and non-Axis-Aligned in other dimensions.

Note 1 to entry: Most of these hybrid DGGS are 3D or 4D. Most commonly seen hybrid systems use non-AA structures for the first two dimensions, such as hex-, tri- and diamond- shaped non-AA DGGS (Clause 4.2). For the 3rd dimension (altitude), geometrically it’s very difficult to build a non-AA structure. The orthogonal axis in the third dimension is usually used. The fourth (temporal) dimension must have an orthogonal axis, as time and geometry shape are completely independent.

4.4. Coordinate axis

one of the fixed reference lines of a coordinate system

4.5. Coordinate reference system

coordinate system that is related to an object by a datum. (Clause 4.7)

Note 1 to entry: Geodetic and vertical datums are referred to as reference frames.

Note 2 to entry: For geodetic and vertical datums (Clause 4.7), the object will be the Earth. In planetary applications, geodetic and vertical reference frames may be applied to other celestial bodies.

Source: ISO 19111:2019, Clause 3.1.9

4.6. Coordinate system

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

Source: ISO 19111:2019, Clause 3.1.11

4.7. datum

reference frame

parameter or set of parameters that realize the positions of the origin, the scale, and the orientation of a *coordinate system* (Clause 4.6)

Source: ISO 19111:2019, Clause 3.1.15

4.8. Axis

straight line through a body or figure that satisfies certain conditions

4.9. X-axis

horizontal axis in a plane coordinate system

4.10. Y-axis

vertical axis in a plane coordinate system

4.11. Z-Axis

third axis in a 3D coordinate system

5

CONVENTIONS

5 CONVENTIONS

5.1. UNIVERSAL RESOURCE IDENTIFIERS

The normative provisions in this specification are denoted by the URI

http://www.opengis.net/spec/dggs/2.0

All requirements and conformance tests that appear in this document denoted by partial URIs are relative to this base.

5.2. UNIFIED MODELLING LANGUAGE NOTATION

In this document, the conceptual schema for describing discrete global grid systems are presented in the Unified Modeling Language (UML). ISO 19103 Conceptual schema language presents the specific profile of UML used in this document.

In the UML diagrams in this document, color indicates classes from other standards. The use of color for each standard is consistent across all diagrams. Each diagram has a key to the standards referred to in that diagram and their colors.

5.3. ATTRIBUTE AND ASSOCIATION ROLE STATUS

In this document conceptual schema in Clauses 6…8 are defined by tables. In these tables:

- attributes and association roles are given an **Obligation** status:
  - **M:** mandatory — this attribute or association role shall be supplied.
  - **C:** conditional — this attribute or association role shall be supplied if the condition (given in the description) is true. It may be supplied if the condition is false.
  - **O:** optional — this attribute or association role may be supplied.
- the **Maximum Occurrence** column in the tables indicates the maximum number of occurrences of attribute values that are permissible, with * indicating no upper limit.

- non-navigable associations are not included in the UML diagrams or tables.

The tables provide a summary of the UML diagrams, in particular association roles, attributes, operations, and constraints that are inherited from another class unchanged are not described in the tables. In the event of any discrepancies between the UML diagrams and text, the UML shall prevail.

5.4. ABBREVIATED TERMS

AA	axis-aligned
AARS	axis-aligned reference system
CRS	coordinate reference system
DGGS	discrete global grid system
HTM	hierarchical triangular mesh
ISO	International Organization for Standardization
MODIS	Moderate Resolution Imaging Spectroradiometer
OGC	Open Geospatial Consortium
STARR	spatio-temporal adaptive resolution encoding
UML	Unified Modeling Language
URI	Universal Resource Identifiers
1D	one-dimensional
2D	two-dimensional
3D	three-dimensional
4D	four-dimensional

6

DGGS SPECIFICATIONS OVERVIEW

6 DGGS SPECIFICATIONS OVERVIEW

6.1. PACKAGE OVERVIEW

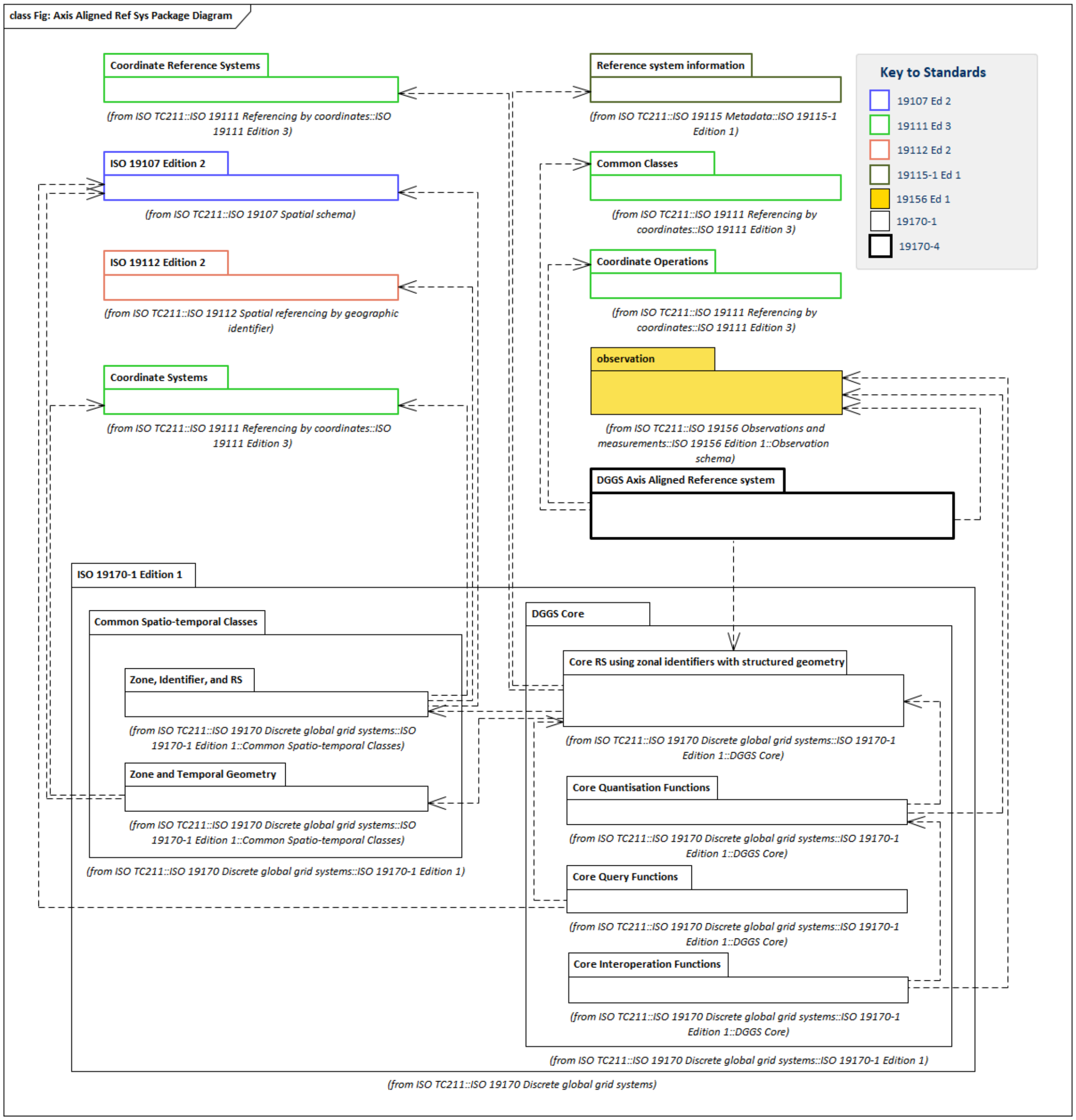
The specification for axis-aligned discrete global grid systems is described in this document in the form of a UML model with supplementary defining tables and text. The Axis-Aligned DGGS contains one UML package, as shown in Figure 1.

a) DGGS Axis-Aligned Reference System Package contains

   1) DGGS axis-aligned reference system.

Each box represents a package and contains the package name. Each arrowed line shows the dependency of one package upon another package (at the head of the arrow).

Figure 2 — DGGS Axis-Aligned Reference System Package Diagram



Packages are grouped in a hierarchy of sub-packages, with modules containing interfaces at the leaves of the hierarchy. In the UML diagrams that follow, interface names are often shown as \<module-name\>::\<interface-name\>. For reference, Table 1lists all the module names that are referred to in the diagrams and names the standard they come from.

Table 2 — Module names used in UML diagrams in this document

STANDARD NAME	MODULE NAME

ISO 19107:2019 Spatial Schema Ed 2		Edge
		Geometry
		Node
		Topology
ISO 19111:2019 Referencing by Coordinates Ed 3		Common Classes
		Coordinates
		Coordinate Operations
		Coordinate Reference System
		Coordinate Systems
ISO 19112:2019 Spatial referencing by geographic identifier Ed 2		ISO 19112 Edition 2
ISO 19115-1:2014 Metadata Ed 1		Reference system information
ISO 19156:2011 Observation and Measurements Ed 1		Observation
ISO 19170-1 Discrete Global Grid Systems Ed 1	Common Spatio-temporal Classes	Temporal Geometry and Topology
		Zonal Geometry and Topology
		Temporal RS using Identifiers
		Spatial Location
		Zonal RS using Identifiers
	DGGS Core	Core RS using Zonal Identifiers with Structured Geometry
		Core Quantization Functions
		Core Topological Query Functions
		Core Interoperation Functions
		Interoperation Query
		Interoperation Broadcast
	Equal-Area Earth DGGS	Equal-Area Earth RS
		Equal-Area Tessellation
		Equal-Area Cell
	Axis-Aligned RS with all zone edges parallel to the base CRS's axes	Axis-Aligned RS
		Axis-Aligned Tessellation

Axis-Aligned Cell

Conformance classes for the DGGS Axis-Aligned Reference system are described in Annex A.

One product conformance class is also defined for Axis-Aligned DGGS, that brings the module together as a system.

7

DGGS AXIS-ALIGNED REFERENCE SYSTEM AND FUNCTIONS PACKAGE

7 DGGS AXIS-ALIGNED REFERENCE SYSTEM AND FUNCTIONS PACKAGE

7.1. DGGS AXIS-ALIGNED REFERENCE SYSTEM MODULE

The following clauses specifies the axis-aligned reference system (AARS) class for a DGGS specification.

For a DGGS that is compliant with the DGGS Core to be an Axis-Aligned DGGS it shall satisfy the requirements described in this clause.

The data model supports DGGS AARS based on either *static* and *dynamic* Datums. Care needs to be taken when implementing DGGS with static datums. Static reference systems are by their nature only intended for use on one tectonic plate, however the definition for a DGGS always has a global domain. This apparent conundrum is resolved in two ways:

a) **Orientation:** Noting that some static reference systems have one or more points on the Earth's surface where the underlying mathematics is poorly behaved, orient the EA_BaseUnitPolyhedron so that areas, centroids, vertices, and edges can be computed; and,

b) **Precision:** On the tectonic plate where the reference frame is static choose the level of DGGS precision to suit the intended use of the DGGS (typically in the range of millimetres to 10s of metres), and in areas of the Earth on plates that are moving with respect to the static reference frame choose the level of DGGS precision to reflect the larger of the constraints imposed by the mathematics and by plate tectonics (typically in the of range 10s to 100,000s of metres).

Figure 3, Figure 4, & Figure 5 show the class structure for the reference frame of an AA DGGS specification and how the classes relate to each other.

Figure 3 — Context for Axis-Aligned Reference System

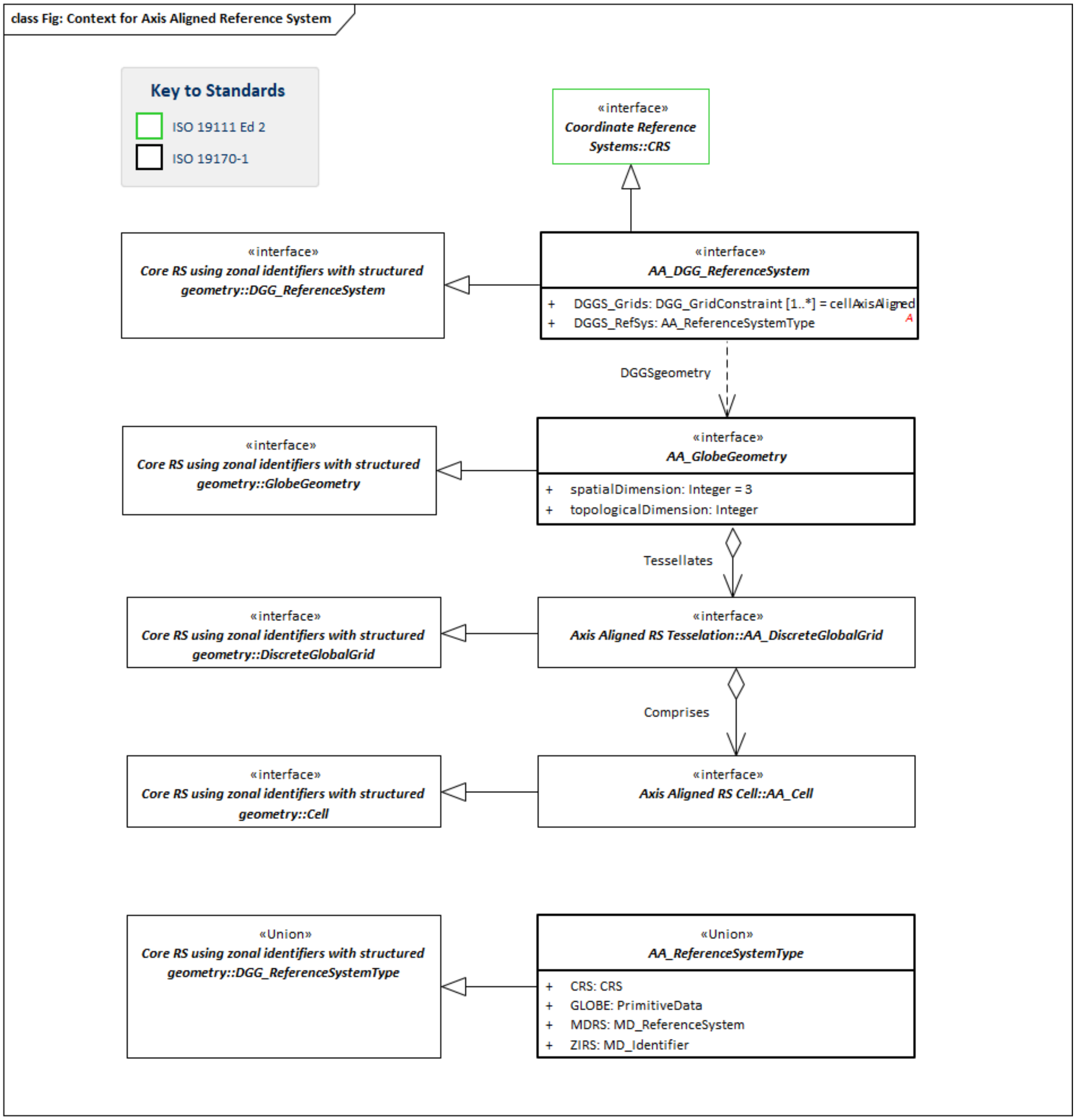
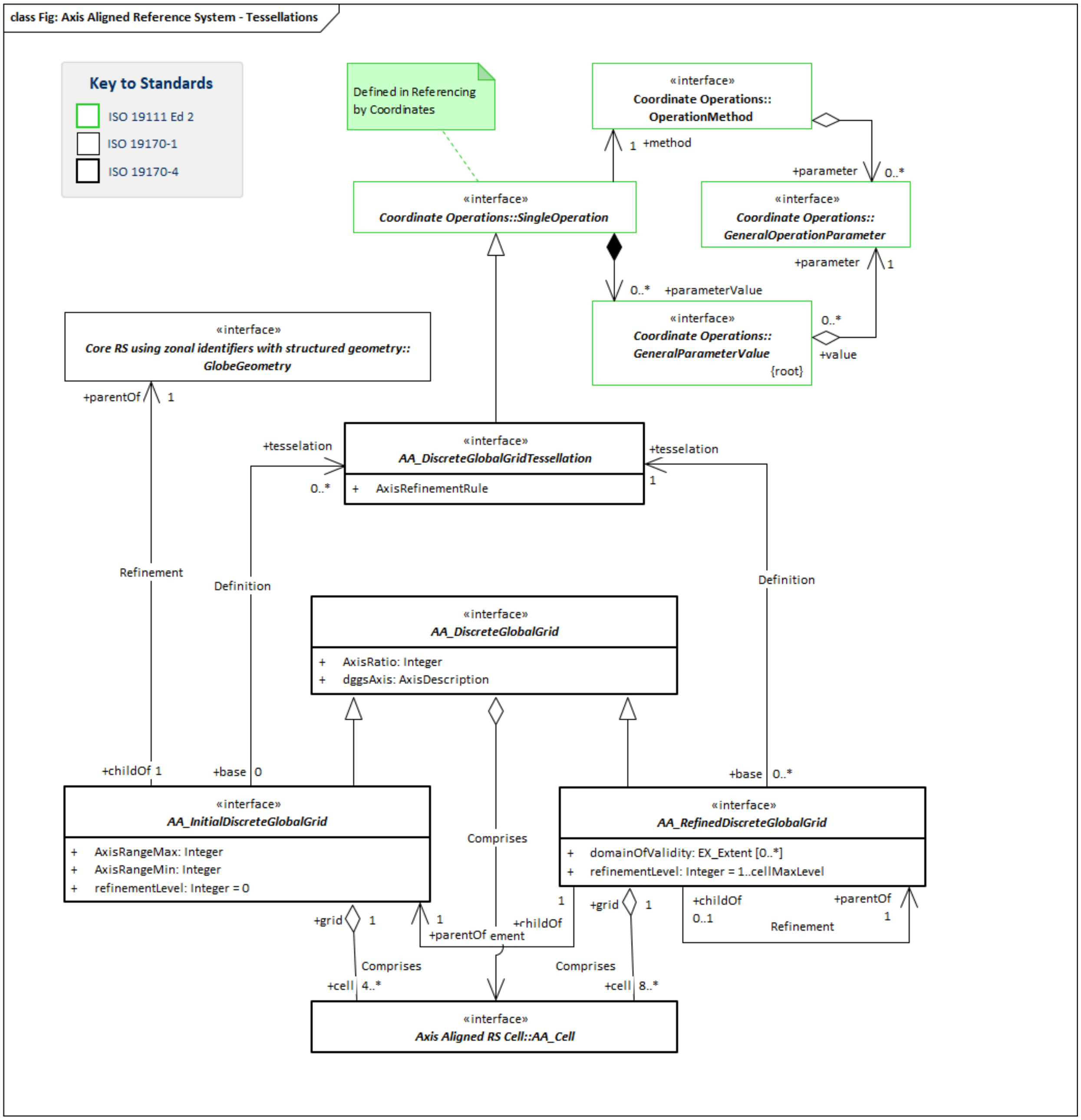
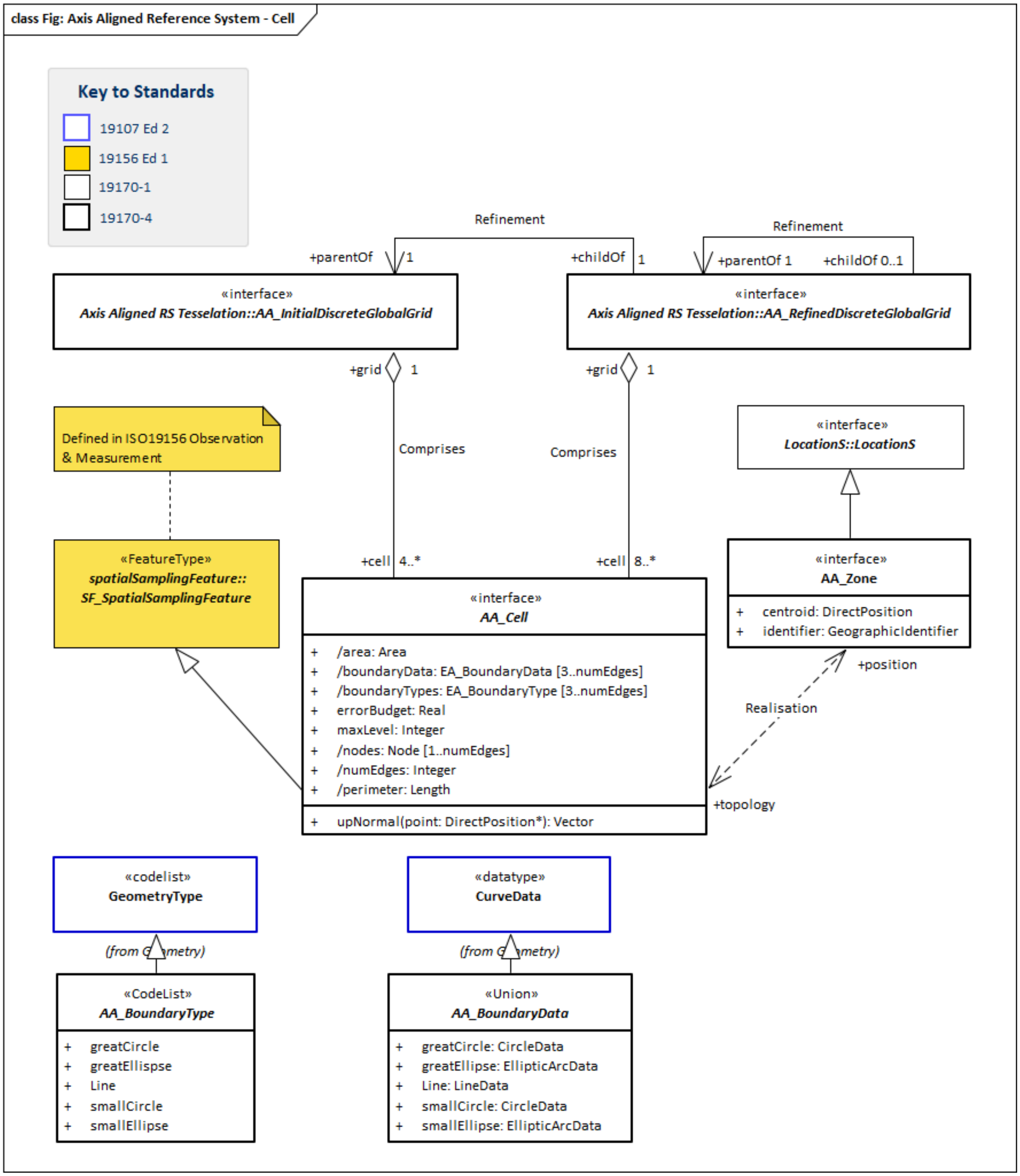


Figure 4 — Axis-Aligned Reference System Tessellations



NOTE: cf Clause 7.2 for definitions of tables in Figure 4

Figure 5 — Axis-Aligned Reference System Cells



NOTE: cf Clause 7.2 for definitions of tables in Figure 5

REQUIREMENT 1:

www.opengis.net/spec/DGGS/2.0/req/aa/rs/harmonised_model

REQUIREMENT 1:

All reference system classes SHALL comply with classes in the axis-aligned reference system data model in Figure 3, Figure 4, & Figure 5 and definitions in Table 3…Table 6.

7.2. DEFINING TABLES

a) Table 3 — Elements of Axis-Aligned RS::AA_DGG_ReferenceSystem

b) Table 4 — Elements of Axis-Aligned RS::AA_GlobeGeometry

c) Table 5 — Elements of Axis-Aligned RS::AA_ReferenceSystemType

d) Table 6 — Elements of Equal-Area Tessellation::AA_DiscreteGlobalGrid

e) Table 7 — Elements of Axis-Aligned Tessellation::AA_DiscreteGlobalGridTessellation

Table 3 — Elements of Axis-Aligned RS::AA_DGG_ReferenceSystem

NAME:	**AA_DGG_REFERENCESYSTEM**					
Definition:	Defining characteristics of a RS using Zonal Identifiers with Structured Geometry for an Axis-Aligned DGGS.					
Stereotype:	Interface					
Inheritance from:	DGG_ReferenceSystem					
Abstract:	true					
Associations:	(none)					
Public attributes:	*Name*	*Definition*	*Derived*	*Obligation*	*Maximum occurrence*	*Data type*
	DGGS_ Grids	List of characteristics that constrain the grid cells in this DGGS in decreasing order of priority. cellEquiSized shall be the first value.	+	M	*	DGG_GridConstraint (code list)
	DGGS_ RefSys	Reference system metadata.	+	M	1	AA_ReferenceSystemType (union data type)
Constraints:	(none)					

Table 4 — Elements of Axis-Aligned RS::AA_GlobeGeometry

NAME:	**AA_GLOBEGEOMETRY**					
Definition:	Parent geometry specifying the geometry, dimensionality and domain of the globe for this DGGS in the spatial dimension. Geometry of the surface of an earth reference model or the whole earth.					
Stereotype:	Interface					
Inheritance from:	GlobeGeometry					
Abstract:	true					
Associations:	Association with:			Obligation	Maximum occurrence	Provides:
	AA_DiscreteGlobalGrid (feature type)			M	*	grid
Public attributes:	*Name*	*Definition*	*Derived*	*Obligation*	*Maximum occurrence*	*Data type*
	spatialDimension	AA_GlobeGeometry shall have a spatialDimension of 3 regardless of the temporal dimension.	+	M	1	Integer
	topologicalDimension	AA_GlobeGeometry have a topologicalDimension of 2 or 3, corresponding to the dimension of axis in the space.	+	M	1	Integer
Constraints:	(none)					

Table 5 — Elements of Equal-Area Earth RS::AA_ReferenceSystemType

NAME:	**AA_REFERENCESYSTEMTYPE**					
Definition:	Defining metadata elements of the base CRS for a DGGS Axis-Aligned RS					
Stereotype:	Union					
Inheritance from:	DGG_ReferenceSystemType					
Abstract:	true					
Associations:	(none)					
Public attributes:	*Name*	*Definition*	*Derived*	*Obligation*	*Maximum occurrence*	*Data type*
	CRS	Metadata required to reference coordinates, Includes CRS ID and coordinate Epoch for dynamic CRS.	+	M	1	DerivedGeodeticCRS

	GLOBE	SurfaceData for the chosen AA_GlobeGeometry that specifies geometry, spatial, and topological dimensionality and domain of the globe for this DGGS.	+	M	1	SurfaceData
	MDRS	Reference system information describing this whole DGGS.	+	M	1	MD_ReferenceSystem
	ZIRS	Identifier for the spatial RSUsingZonalIdentifiers used by the DGGS.	+	M	1	MD_Identifier
Constraints:	(none)					

Table 6 — Elements of Equal-Area Tessellation::AA_DiscreteGlobalGrid

NAME:	**AA_DISCRETEGLOBALGRID**					
Definition:	Super class for AA_InitialDiscreteGlobalGrid and AA_RefinedDiscreteGlobalGrid					
Stereotype:	Interface					
Inheritance from:	DiscreteGlobalGrid					
Generalization of:	AA_InitialDiscreteGlobalGrid, AA_RefinedDiscreteGlobalGrid					
Abstract:	true					
Associations:	Association with:			Obligation	Maximum occurrence	Provides:
	EA_Cell (feature type)			M	*	cell
Public attributes:	*Name*	*Definition*	*Derived*	*Obligation*	*Maximum occurrence*	*Data type*
	dggsAxis	dggsAxis for AA DGGS are used to tessellate the grid in each axis. The number of axis equals to the dimensions of the grid cell.	+	M	1	AxisDescription
	AxisRation	AxisRatio represents the tessellation rule of the AA DGGS.	true	M	1	Integer
Constraints:	(none)					

Table 7 — Elements of Axis-Aligned Tessellation::AA_DiscreteGlobalGridTessellation

NAME:	AA_DISCRETEGLOBALGRIDTESSELLATION
Definition:	The AA_DiscreteGlobalGridTessellation method implements the DGGS_Grids constraint, DGGS_Refinement strategy and DGGS_RefinementRatio, to create a child AA_RefinedDiscreteGlobalGrid from a parent AA_DiscreteGlobalGrid.
Stereotype:	Interface
Abstract:	true
Associations:	(none)
Public attributes:	(none)
Constraints:	(none)

7.3. AXIS

The axis-aligned reference system is formed by partitioning earth space along each dimensional axis into multi-hierarchy grid cells. The axes used for tessellation in an axis-aligned DGGS reference system are from basic coordinate reference systems for surveying and mapping, such as geodetic coordinate system or geographical coordinate system. The orthogonal axes of the coordinate reference system shall be determined.

REQUIREMENT 2:
www.opengis.net/spec/DGGS/2.0/req/aa/rs/axis
An Axis Aligned Reference System specification SHALL define axes from basic coordinate reference systems for surveying and mapping.

7.4. DIMENSION

The axis-aligned reference system may be 2D for the surface of the earth, and be extended in elevation to three dimensions or higher. The tessellation of some or all dimensions shall be axis-aligned.

REQUIREMENT 3:
www.opengis.net/spec/DGGS/2.0/req/aa/rs/dimension
An Axis-Aligned Reference System specification SHALL specify its dimension.

7.5. CELL

7.5.1. 2D Polygon

For an 2D axis-aligned DGGS, the cells formed on the surface of the earth are usually quadrilaterals and triangles. For example, in the AA DGGS based on longitude and latitude, most cells are quadrilateral with edges parallel to the longitude or latitude line, and cells around the two poles are triangle. Simple 2D cells have the properties that:

a) Edges that meet only at the vertices;

b) Exactly two edges meeting at each vertex;

c) Exactly the same number of edges and vertices; and,

d) Enclosing a region which always has a measurable area

REQUIREMENT 4:
www.opengis.net/spec/DGGS/2.0/req/aa/rs/cell/simple/2D_polygon
An 2D Axis-Aligned Reference System specification SHALL define cells that are simple polygons.

7.5.2. Edge

The cell edges in an Axis-Aligned Reference system specification are generated through axis-aligned tessellations, the number of edges is as twice as the number of axes and each edge is parallel to the corresponding axis.

The range of coordinate values on each edge of a cell is determined by the range of coordinate values of the axis and the refinement ratio.

REQUIREMENT 5:
www.opengis.net/spec/DGGS/2.0/req/aa/rs/cell/edge
An Axis-Aligned Reference System specification SHALL define the cell edge that are parallel to the axis.

7.5.3. Center

Each DGGS cell can be referenced at its center. This is because the centroid is the only location that will provide a representative point that behaves consistently with shape and is invariant under orientation. In an axis-aligned reference system, the coordinate of the center of each cell can be determined by the midpoint values at the axes which the edges are parallel to.

REQUIREMENT 6:
www.opengis.net/spec/DGGS/2.0/req/aa/rs/cell/center
An Axis Aligned Reference System specification SHALL define the cell center based on the midpoint at the axes.

7.5.4. Address

Cells are addressed using geodetic identifiers to represent the related zones. Under this document each cell of an AA DGGS specification shall have a unique cell address assigned using one or more of indexing methods across the reference system domain.

REQUIREMENT 7:
www.opengis.net/spec/DGGS/2.0/req/aa/rs/cell/address
An Axis Aligned Reference System specification SHALL use a spatial referencing method to assign a unique spatial identifier (or index) to each cell across the entire DGGS Domain.

7.5.5. Geometric Parameters

For use of axes of the common coordinate reference systems, it is easier for an axis-aligned reference system to calculate some important geometric parameters such as cell area, cell volume, and the cell vertex coordinate due to the availability of coordinates.

The coordinates of cell vertices can usually be directly obtained from the related axis values. Geometric parameters of a cell can be calculated by coordinates of the vertices of the cell. The geometry of each axis is consistent for all cell. The area (volume), intersection angle and edge of a cell can be calculated by the values on the axes.

REQUIREMENT 8:
www.opengis.net/spec/DGGS/2.0/req/aa/rs/cell/geometric_parameters
An Axis Aligned Reference S ystem specificatio__n SHALL define the calculation of geometric parameters based on the values of on the axes.

7.6. TESSELLATION

7.6.1. Tessellation Overview

An AA DGGS tessellation is a result of the multi-hierarchy tessellation of the axes. Each axis is partitioned independently and has its tessellation pattern and ratio, which results in the grid cell surrounded by edges each of which is parallel to the axes other than the axis defining it.

REQUIREMENT 9:
www.opengis.net/spec/DGGS/2.0/req/aa/rs/tessellation
An Axis Aligned Reference System specification SHALL define the tessellation method as the axis-aligned tessellation.

7.6.2. Tessellation Sequence

An AA reference system comprises a discrete sequence of grid cells generated from a recursively axis-aligned partition to refine the cells, so that each cell has a progressively finer resolution.

REQUIREMENT 10:
www.opengis.net/spec/DGGS/2.0/req/aa/rs/tessellation/sequence
An Axis Aligned Reference System specification SHALL define tessellation operations that generate a sequence of discrete global grids with progressively smaller resolutions

A

ANNEX A (NORMATIVE) CONFORMANCE CLASS ABSTRACT TEST SUITE

A

ANNEX A (NORMATIVE) CONFORMANCE CLASS ABSTRACT TEST SUITE

A.1. DGGS AXIS-ALIGNED REFERENCE SYSTEM PACKAGE

REQUIREMENT TEST A.1: AXIS-ALIGNED — REFERENCE SYSTEM — AXIS	
Abbreviation	conf/aa/rs/axis
Type	Basic
Requirement	Clause 7.3, Requirement 2: http://www.opengis.net/spec/DGGS/2.0/req/aa/rs/axis
Reference Clause	Clause 7.3
Test Purpose	To verify the axes of an Axis-Aligned Reference system specification are from the basic coordinate reference systems for surveying and mapping.
Test Method	Inspect documentation for the Axis-Aligned Reference System specification.

REQUIREMENT TEST A.2: AXIS-ALIGNED — REFERENCE SYSTEM — DIMENSION	
Abbreviation	conf/aa/rs/dimension
Type	Basic
Requirement	Clause 7.4, Requirement 3: http://www.opengis.net/spec/DGGS/2.0/req/aa/rs/dimension
Reference Clause	Clause 7.4
Test Purpose	To verify an Axis-Aligned Reference system specification has a specified dimension.

REQUIREMENT TEST A.2: AXIS-ALIGNED — REFERENCE SYSTEM — DIMENSION	
Test Method	Inspect documentation for the Axis-Aligned Reference System specification.

REQUIREMENT TEST A.3: AXIS-ALIGNED — REFERENCE SYSTEM — CELL — SIMPLE — 2D POLYGON	
Abbreviation	conf/aa/rs/cell/simple/2D_polygon
Type	Basic
Requirement	Clause 7.5.1, Requirement 4: http://www.opengis.net/spec/DGGS/2.0/req/aa/rs/cell/simple/2D_polygon
Reference Clause	Clause 7.5.1
Test Purpose	To verify that all cells of a 2D Axis-Aligned Reference system specification have shapes that are simple polygons on the surface model of the Earth.
Test Method	Inspect documentation for the Axis-Aligned Reference System specification.

REQUIREMENT TEST A.4: AXIS-ALIGNED — REFERENCE SYSTEM — CELL— EDGE	
Abbreviation	conf/aa/rs/cell/edge
Type	Basic
Requirement	Clause 7.5.2, Requirement 5: http://www.opengis.net/spec/DGGS/2.0/req/aa/rs/cell/edge
Reference Clause	Clause 7.5.2
Test Purpose	To verify that the edges of cells in an Axis-Aligned Reference system specification are generated through axis-aligned tessellations, the number of edges is as twice as the number of axes and each edge is parallel to the corresponding axis.
Test Method	Inspect documentation for the Axis-Aligned Reference System specification.

REQUIREMENT TEST A.5: AXIS-ALIGNED — REFERENCE SYSTEM — CELL— CENTER	
Abbreviation	conf/aa/rs/cell/center

REQUIREMENT TEST A.5: AXIS-ALIGNED — REFERENCE SYSTEM — CELL— CENTER	
Type	Basic
Requirement	Clause 7.5.3, Requirement 6: http://www.opengis.net/spec/DGGS/2.0/req/aa/rs/cell/center
Reference Clause	Clause 7.5.3
Test Purpose	To verify that the center of each cell in an Axis-Aligned Reference system specification are defined by the midpoint values of the axes.
Test Method	Inspect documentation for the Axis-Aligned Reference System specification.

REQUIREMENT TEST A.6: AXIS-ALIGNED — REFERENCE SYSTEM — CELL— ADDRESS	
Abbreviation	conf/aa/rs/cell/address
Type	Basic
Requirement	Clause 7.5.4, Requirement 7: http://www.opengis.net/spec/DGGS/2.0/req/aa/rs/cell/address
Reference Clause	Clause 7.5.4
Test Purpose	To verify that an Axis-Aligned Reference system specification has a method to assign a unique spatial identifier (or index) to each DGGS cell.
Test Method	Inspect documentation for the Axis-Aligned Reference System specification.

REQUIREMENT TEST A.7: AXIS-ALIGNED — REFERENCE SYSTEM — CELL — GEOMETRIC PARAMETERS	
Abbreviation	conf/aa/rs/cell/geometric_parameters
Type	Basic
Requirement	Clause 7.5.5, Requirement 8: http://www.opengis.net/spec/DGGS/2.0/req/aa/rs/cell/geometric_parameters
Reference Clause	Clause 7.5.5
Test Purpose	To verify that the geometric parameters for an Axis-Aligned Reference system specification can be calculated by coordinates of the vertices of the cell, and the area (volume), intersection angle and edge of a cell can be calculated by the values of on the axes.

REQUIREMENT TEST A.7: AXIS-ALIGNED — REFERENCE SYSTEM — CELL — GEOMETRIC PARAMETERS	
Test Method	Inspect documentation for the Axis-Aligned Reference System specification.

REQUIREMENT TEST A.8: AXIS-ALIGNED — REFERENCE SYSTEM — TESSELLATION	
Abbreviation	conf/aa/rs/tessellation
Type	Basic
Requirement	Clause 7.6.1, Requirement 9: http://www.opengis.net/spec/DGGS/2.0/req/aa/rs/cell/tessellation
Reference Clause	Clause 7.6.1
Test Purpose	To verify that an Axis-Aligned Reference system specification has part or all dimensions that are partitioned by axis-aligned tessellation and in the specification, each axis is partitioned independently and has its tessellation pattern and ratio.
Test Method	Inspect documentation for the Axis-Aligned Reference System specification.

REQUIREMENT TEST A.9: AXIS-ALIGNED — REFERENCE SYSTEM — TESSELLATION — SEQUENCE	
Abbreviation	conf/aa/rs/tessellation/sequence
Type	Basic
Requirement	Clause 7.6.2, Requirement 10: http://www.opengis.net/spec/DGGS/2.0/req/aa/rs/cell/tessellation/sequence
Reference Clause	Clause 7.6.2
Test Purpose	To verify that an Axis-Aligned Reference system specification defines multi-hierarchy tessellation of the axes with progressively finer scales that can support data at multiple levels of spatial scales.
Test Method	Inspect documentation for the Axis-Aligned Reference System specification.

B

ANNEX B (INFORMATIVE) EXAMPLE APPLICATION OF AXIS-ALIGNED DGGS

B

ANNEX B (INFORMATIVE) EXAMPLE APPLICATION OF AXIS-ALIGNED DGGS

About the concept of AA, the core is that the boundary of DGGS is parallel to the coordinate axes of the general GIS and mapping coordinate system, geodetic coordinate system, geocentric coordinate system, longitude and latitude coordinate system, tangent plane coordinate system and so on. According to this definition, the boundary of the grid, such as longitude and latitude grid, earth 3D grid, spatial-temporal grid, etc., is aligned with these coordinate axes, which are mostly Euclidean or non-Euclidean orthogonal axes. On the basis of meeting all the advantages of DGGS, AA DGGS embodies the following superiorities:

a) From the point view of the reference system, AA DGGS is completely consistent with the axis coordinates, moreover, it can be equivalent to axis coordinate under certain precision.

b) The position itself is usually defined by coordinates, hence the position defined by AA is easy to be understood by human.

c) For information integration, it can be directly transformed from coordinates, and is easily compatible with the range of map sheets.

d) AA is quite easily to segment the remote sensing images.

e) It's more consistent to adopt the concept of AA for extensions to 3D or 4D, as axis is inevitable in this case.

Typical AA DGGS and their applications are described below in combination with 2D, 3D and 4D DGGS.

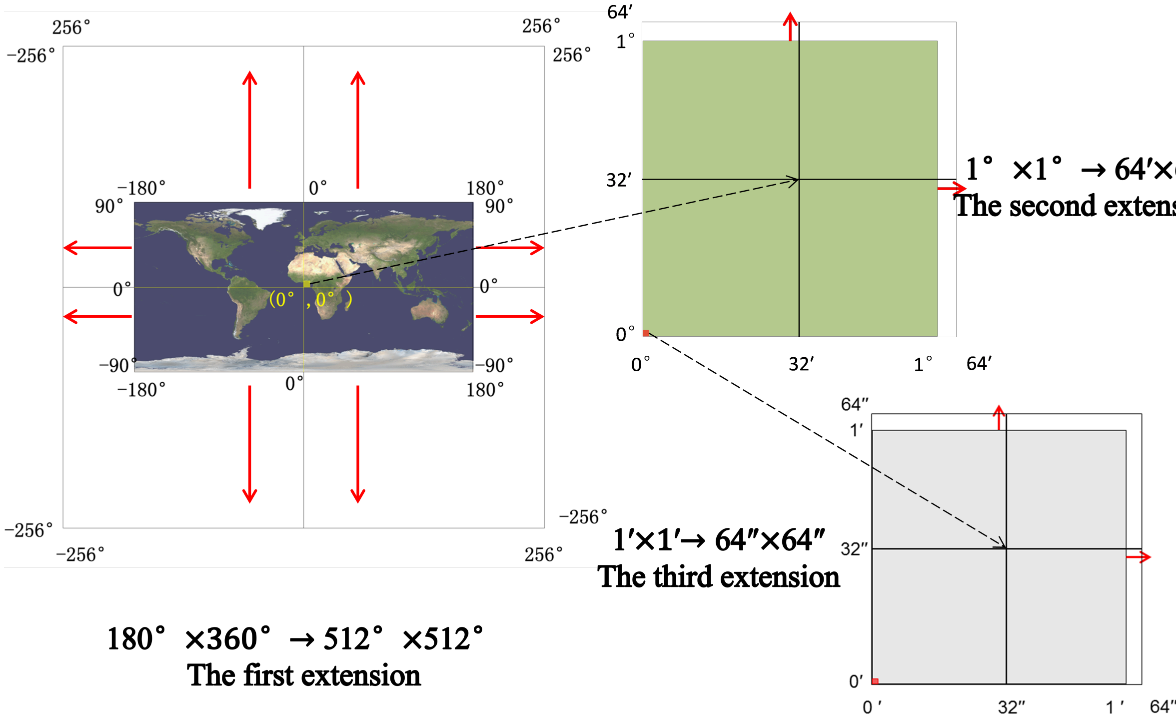
B.1. 2D-AA DGGS: GEOSOT

B.1.1. Introduction[1]

The GeoSOT (Geographical coordinate Subdividing grid with One dimension integer coding on a 2^n Tree) is a geospace reference grid of earth surface, and it's based on the latitude and longitude axes, and it's a kind of typical 2D-AA DGGS.

Through dividing the Earth three times (expand the earth (180° × 360°) into 512° × 512°, then each 1° expand into 64′ and each 1′ expand into 64″, see Figure B.1), quadtree subdivisions at the degree, minute, and second levels are obtained and the GeoSOT is congruent and aligned; the largest subdivision cell in the highest level (Level 0) can represent the whole Earth's surface, while the smallest subdivision cell in the lowest level (Level 32) can represent centimeter scales. The eight basic grids of 4°, 2°, 1°, 2′, 1′, 2″, 1″ and 0.5″ are also included.

Figure B.1 — The three main divisions of the GeoSOT (Geographical coordinate Subdividing grid with One dimension integer coding on a 2^n Tree) subdivision.



GeoSOT involves 32 levels and the origin is the intersection of the prime meridian and the equator. The latitudes are formed by lines with equal lengths at equal intervals, while longitude lines of equal lengths are perpendicular to latitudes at equal intervals. The ratio of longitude to latitude length is 1:2. The North and South Poles are parallel to latitudes and equal in length. The ranges of latitude and longitude are 180° and 360°, respectively.

Level 0 is defined as the 512° × 512° grid where the center point and the origin coincide in geographical coordinate space. Its grid code is "G", (signifying "Globe") and the regional location is the whole global area.

Level 1 is defined as the four cells (256° × 256° each) equally divided over Level 0 Its grid code is "Gd", where "d" stands for 0, 1, 2, or 3. For example, the regional location of G0 is the Northeast Hemisphere region.

Following this logic, Level 2 is obtained by quadtree division of Level 1, and so on up to Level 9. Levels 1–9 are each termed GeoSOT degree-level grids.

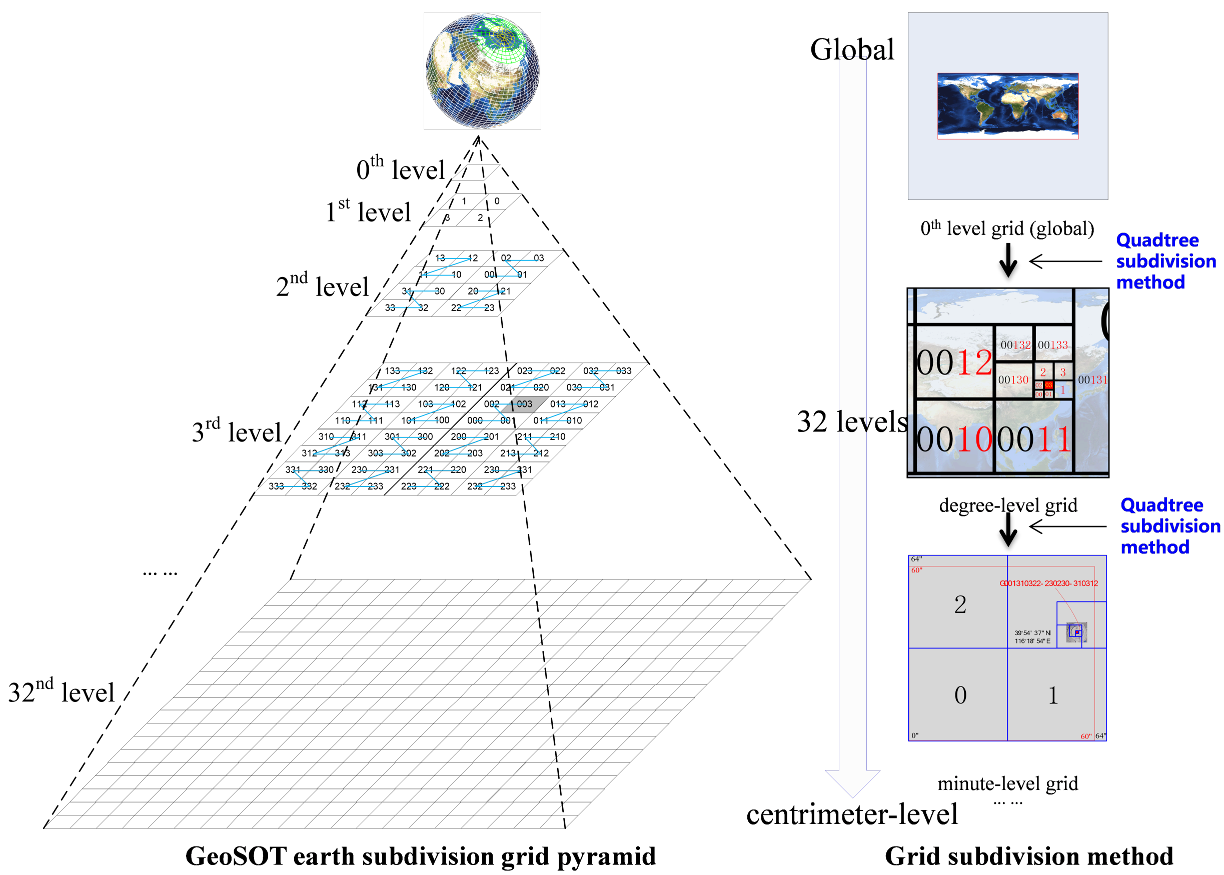
Levels 10–15 are rooted in the minute-level grid (Level 9, 1° × 1° grid or 60′ × 60′ grid), and they have the same codes. The grid size is extended from 60′ to 64′. GeoSOT subdivision grids are obtained by performing quadtree divisions of the extended Level 9 grid.

Levels 16–21 are rooted in the second-level grid (Level 15, 1′ × 1′ grid or 60″ × 60″ grid), and they have the same codes. The grid size is extended from 60″ to 64″. GeoSOT subdivision grids are obtained by performing quadtree divisions of the extended Level 15 grid.

Grids smaller than a second (levels 22–32) can be obtained by dividing the previous level into four equal cells.

According to the above definitions, GeoSOT grids are divided into 32 levels, with the greatest covering the entire global space and the smallest at the centimeter-level. These 32 levels divide Earth's surface evenly into multi-leveled grids that form the global quadtree system (Figure B.2). The ratio of the upper to the lower levels is approximately 4:1 and the change is uniform.

Figure B.2 — The global 2^n integer quadtree subdivision after extending latitude and longitude three times.



B.1.2. Application

B.1.3. Identification for Geospatial Big Data

Geospatial big data refers to the earth big data which contains the meanings of space. These geospatial big data have the characteristics of huge quantity, variety, complex data structure and intensive computing. How to effectively store, manage, share and mine effective information from them has become an urgent problem to be solved.

As all geospatial big data contain spatial meanings, we could add location attributes to data attributes according to their spatial meanings. Location attributes might be directly included in the existing data attributes, such as the location attributes of the shooting area in the remote sensing satellite images, and the location attributes of the text published in the social network. In addition, location attributes may be implied in the data objects, such as the contents of text and video which implies the location meanings. Therefore, location attributes can be used as the basic attributes of spatial big data.

The development of a unified spatial location identification system is of great significance to the management and application of geospatial big data. Firstly, a set of unified spatial location identification methods is constructed to express the spatial location attributes contained in big data itself. Secondly, with the help of spatial location identification, the K-dimensional association between different objects can be reduced to 1D association. Finally, based on the unified spatial location identification, it provides a set of quantitative records of geographical locations, which is conducive to the measurement and calculation of the degrees of geographical spatial associations between different objects. Thus, identification coding, dimension reduction, calculation and measurement, could lay the foundations for geospatial big data analysis.

B.1.4. Data Organization for Remote Sensing Earth Observations

Remote sensing earth observation system involves many types of satellites, including remote sensing satellites, surveying and mapping satellites, positioning and navigation satellites, meteorological satellites, marine satellites, etc. At present, the specifications of different types of satellite data organization in different departments are different (scene, strip, etc.). The data specifications of different departments such as surveying and mapping, meteorology, oceanography, are mostly inconsistent, which makes it difficult for information sharing and joint application among departments. At the same time, block specifications of the observation data generated by the same sensor in different data processing processes (from data receiving, primary processing, advanced processing, to application display, and product distribution) are not consistent, which increases a lot of additional processing workload, and also it restricts the timeliness of the applications of spatial information products to a certain extent.

Based on the important inclusive characteristics of GeoSOT geospatial reference grid and the existing main grids of various departments, the development of a unified block specification of remote sensing earth observation data can unify the existing multi-source heterogeneous remote sensing data, improve the convenience of cross-departmental spatial information exchange, sharing and splicing, and lay a better foundation for the joint applications of spatial information[2]. Relevant research and experiments show that, with the use of the grid organization strategy of remote sensing earth observation data, the spatial query efficiency is more than 10 times higher than Oracle Spatial, Geohash and so on. Moreover, there are no omitted querying results, and the average query accuracy is as high as 94.6%[3]. This method can provide support for the effective sharing and accurate service of remote sensing earth observation data. It has been applied in a satellite data center in China, whose existing data management system has been upgraded with this low-cost, efficient and feasible solution.

B.2. 3D-AA DGGS: GEOSOT-3D

B.2.1. Introduction[4]

GeoSOT-3D divides the earth's 3D space into 32 levels of grids, and the grid generation is recursively carried out according to the levels which are nested. From the first level of grid, each grid of each level continues to be divided into eight sub-grids until the 32nd level of grid. Each grid has a globally unique grid code. According to the regulations of GeoSOT-3D, the division range of the earth's 3D space height dimension is based on the earth's reference ellipsoid, which extends to 6, 302, 106.723m underground and 528, 680, 171.125m above the ground according to the earth's height direction. The geographic coordinate system and earth reference ellipsoid used in GeoSOT-3D grid generations follow China Geodetic Coordinate System 2000 (CGCS2000), which is a typical AA DGGS.

The starting position of GeoSOT-3D subdivision is at the intersection (O point) of the earth reference ellipsoid, the primary meridian plane and the equatorial plane, as could be seen from Figure B.3 (a). Based on the 0-level grid composed of longitude, latitude and elevation, a multi-level 3D spatial grid system of the earth is formed by the solid octree partitions on three directions of longitude, latitude and earth height. The sphere is divided by means of longitude difference and latitude difference, and the division levels of geodetic height are consistent with those of earth reference ellipsoid. Each grid of the same level should be equal at the same height, and the height should match the grain size in the latitude direction of the grid formed by the corresponding level of the equator of the corresponding contour plane. The relationship between the grid height of the same level and the grid latitude granularity at the equator of the corresponding contour plane is shown in Figure B.4. In order to realize the recursive mesh generation step by step and form grid cells of integral degree, integral minute and integral second, it is necessary to expand the space partition area to an integer power of 2, that is, extending the longitude coordinates from [-180°，180°] to [-256°，256°] and the latitude coordinates from [-90°，90°] to [-256°，256°], and the virtual elevation range is [-256，256], as shown in Figure B.3(b).

Figure B.3 — GeoSOT-3D earth 3D spatial grid subdivision

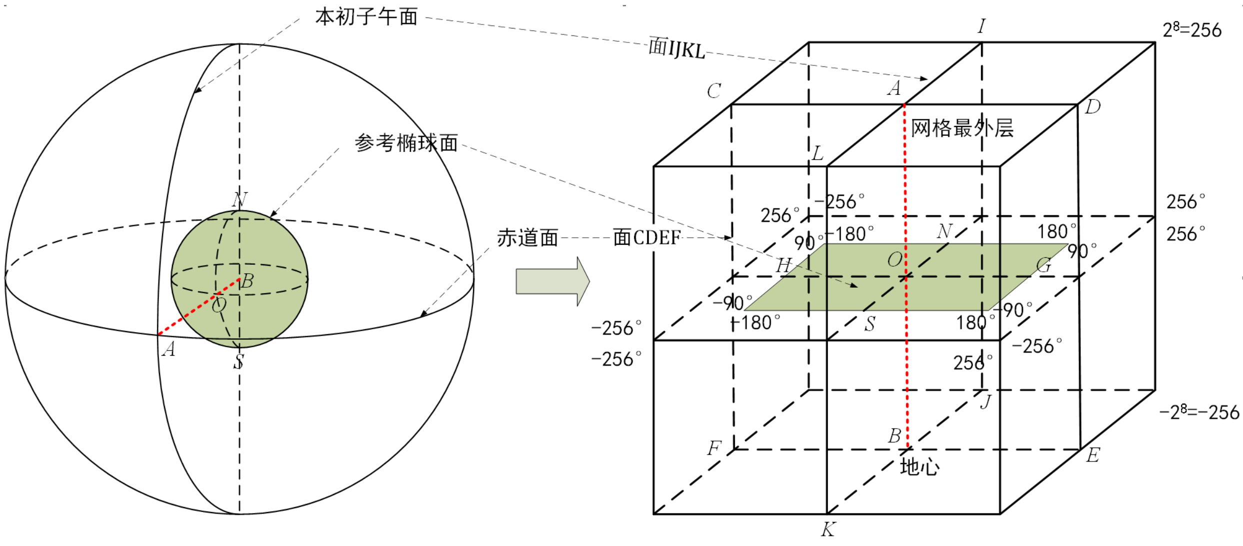
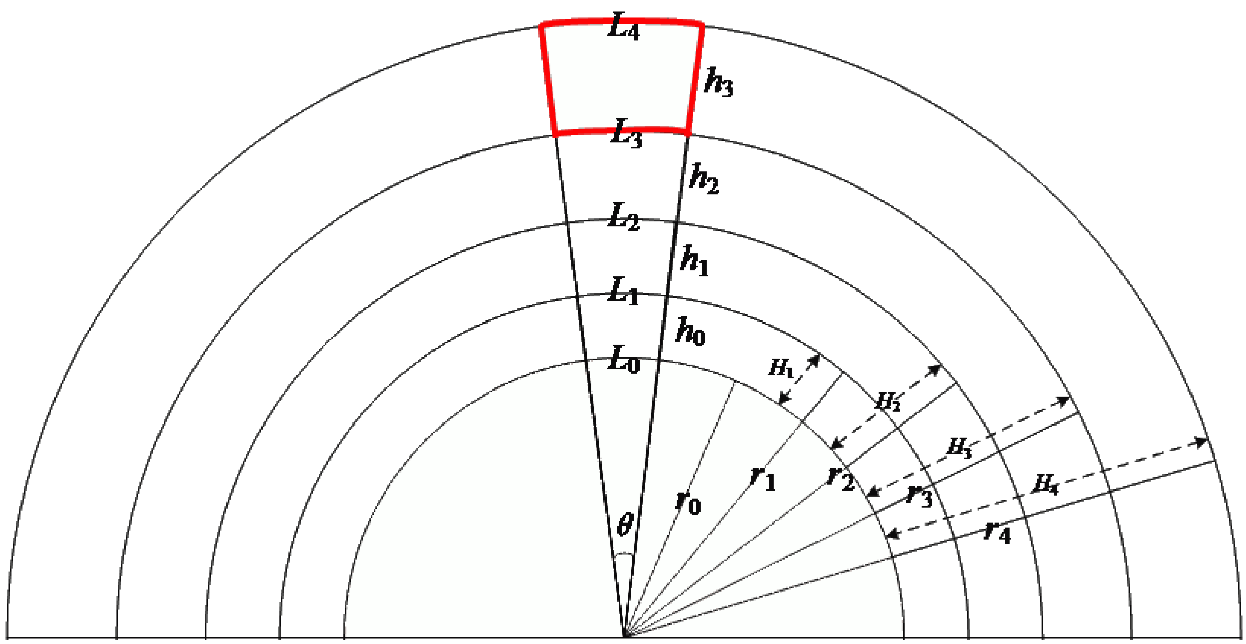


Figure B.4 — Schematic diagram of the relationship between grid granularity in height domain and equatorial grid granularity in corresponding contour plane



Example : L_i—the length of the grid on the contour plane, the grain size in the equatorial direction H_i—grid geodetic height h_i—grid height, geodetic high direction granularity r_i—the distance from the grid to the center of the earth on the equatorial plane, r_0 is the long half axis of the earth θ—longitude (latitude) span difference corresponding to grid

B.2.2. Application

B.2.3. Grid Coding Technology for New Navigation and Positioning

Compared with the traditional longitude and latitude positioning method, navigation and positioning grid coding can not only identify the spatial position in the process of navigation and positioning, but also express the regional range of spatial objects. At present, the application of grid coding in navigation and positioning has been tried worldwide. For example, the national geographic grid (USNG) of the United States has been displayed in the navigation terminal for auxiliary longitude and latitude identification, and MapCode is widely used in vehicle navigation in Japan.

GeoSOT-3D is used to develop a new grid code for navigation and positioning, which is used to organize and express navigation data. At present, China's Beidou Satellite Navigation System has deployed it as the National Standard of navigation and positioning grid coding, that is \< Beidou Grid Location Code \> (GB / T 39400-2020). This set of standards is a discrete, multi-scale regional location identification and measurement system developed on the basis of GeoSOT-3D. The core of this system is to use a new method to divide the earth space from the center of the earth to 520, 000 km above the ground into trillions of grids with different sizes and the highest accuracy of 1.5 cm, and to give each grid a unique global integer identification code, so as to realize the discretization and digital expression of any spatial position, support the objective description and efficient calculation of aerospace, aviation, land, ocean and underground space, which has great scientific and practical significances.

B.2.4. Construction of True 3D Digital Earth System

The volume elements of GeoSOT-3D earth subdivision system are filled in the altitude of 520000 km above the ground to the earth's center, and each scale of volume element seamlessly fills the whole earth 3D space. Therefore, any space, sky, earth and underground target can be expressed in true 3D with corresponding volume element or patch codes, so as to realize the unified management on the earth space reference grid. By establishing a true 3D representation model of the earth's 3D object, each entity can record the attribute information of the corresponding object, such as humidity, temperature and concentration. The digital earth skeleton formed by GeoSOT-3D has the grid design of the earth's 3D space. Hence, compared with the existing earth surface digital earth systems such as Google Earth and WorldWind, it is more direct and convenient for the effective expression, organization and management of the real 3D of the space, sky and earth data at all levels.

B.3. 4D-AA DGGS

B.3.1. Introduction

The core of 4D-AA DGGS is the fourth dimension, that is, the time dimension. The first three dimensions are 3D DGGS. The fourth time dimension is divided along the time coordinate axis and orthogonal to the coordinate axis of the first three spatial dimensions (such as latitude, longitude and geodetic height). The resulting DGGS must be a typical AA DGGS. Based on the coordinate axis of time dimension, the fourth dimension is divided as follows.

Time subdivision is a kind of multi-granularity time slicing and coding, which is a beneficial supplement to time label identification and has the consistency of time and time interval identifications. The time division is divided along the UTC time coordinate axis of the Gregorian Calendar, and the time range is from 2^{m-47} B.C. to 2^{m-47}-1 A.D. (where m = 64, taking 64bit computer as an example). The granularity range of time division coding is as large as 2^{m-47} year time granularity and as small as 1 μ s time granularity, with a total of 64 granularity levels. In this model, the initial time domain is selected from 65536 B.C. to 65535 A.D., and 17 recursive bisection operations are performed on this time domain to obtain a time period with a time granularity of 1 year. In the limited time domain (from 65536 BC to 65535 AD), the maximum precision is limited to 1 microsecond, and the virtual expansion processing is carried out for seven times: year, month, day, hour, minute, second and millisecond. In the above seven levels, the granularity of time segment is virtually expanded to the integer power of 2, and then the recursive bisection can ensure the integer property of the granularity of time segment at each level in the process of subdivision[5]. The generated grid and code can correspond to the common time units, which has higher practical value.

B.3.2. Application

4D-AA DGGS is mainly used for spatio-temporal information retrieval. Its core is spatio-temporal integration, which focuses the complete integration of spatio-temporal dimensions. It does not deal with time and space differentiation, but uses the same way to deal with time and space dimensions. Representative examples include: GeoMesa (2019) combines Geohash geocoding with time stamp strings to construct index keys, and uses 35-bit Geohash coding to cross with “yyyymmddhh” string to represent about 150-meter square and 1-hour time interval, so that the index weight of spatial dimension and time dimension are equal. Van et al. proposed the corresponding index mechanism in HBase based on STCode[6]. The spatio-temporal adjacent data objects will have the same prefix after STCode encoding, so as to be stored together in HBase. This method can support fast update of data objects and efficient spatio-temporal query. Similarly, Guan et al. extended the Geohash coding algorithm, which is widely used in key value storage structure, to encode longitude, latitude and time into a short and unique string to satisfy the fast updates of trajectory data index[7]. Through the experiment in MongoDB, it is verified that this method has higher query efficiency than Geohash + timestamp composite index structure. In the management of remote sensing big data, Kwo et al. proposed a spatio-temporal adaptive resolution encoding (STARR)[8]. In STARR, space and time are used as a fusion data structure to construct spatio-temporal index, and space is encoded in the form of hierarchical triangular mesh (HTM). However, time is still encoded by time interval, which has been applied in Terra / MODIS data management. Yang et al. proposed GeoSOT-ST[9], a spatio-temporal integration subdivision organization model, designed spatio-temporal grid generation and coding method, as well as a subdivision voxel relationship calculation method, which provides the underlying support for the complete integration of spatio-temporal dimensions and spatio-temporal data management.

C

ANNEX C (INFORMATIVE) REVISION HISTORY

C

ANNEX C (INFORMATIVE) REVISION HISTORY

Table C.1 — Revision History

DATE	RELEASE	EDITOR	PRIMARY CLAUSES MODIFIED	DESCRIPTION [COLS= ”9,9,12,14,46”]
2020-05-30	0.0.1	Robert Gibb	All	Set up initial Word template
2020-09-08	0.0.2	Fuhu Ren， Chengqi Cheng, Xiaochong Tong, Jin Ben, Tengteng Qu, Rui Wang.	All	Preliminary draft
2021-02-03	0.0.3	Fuhu Ren， Chengqi Cheng, Xiaochong Tong, Jin Ben, Tengteng Qu, Rui Wang.	Introduction, 6.1, 7.1,7.2, Annex B, Bibliography	Added clauses in Introduction; Modified Figure 1,2,3; Added Table 1,2,3,4,5,6; Added clauses in 7.2; Added Annex B and Bibliography
2021-06-30	0.0.3	Robert Gibb	all	Conversion to a single metanorma asciidoc file; first editorial pass — abbreviations, terms and definitions, hyphen usage; and load asciidoc file into gitlab repository for tracking subsequent changes.

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