[Ouranos 4D Spatio-temporal ID]

Definition of Spatial ID and Spatial Voxel

Ministry of Economy, Trade and Industry
Ministry of Land, Infrastructure, Transport and Tourism
New Energy and Industrial Technology Development Organization
Information-technology Promotion Agency

Preface - Positioning of this document

The Ouranos Ecosystem is an initiative promoted by the Ministry of Economy, Trade and Industry in Japan to collaborate and utilize data across companies and industries.

In the Ouranos Ecosystem, "Ouranos 4D Spatio-temporal ID" (abbreviated as Spatio-temporal ID) serves as an index for easily integrating, retrieving, and freely distributing a wide variety of spatial information (including temporal information).

"Spatio-temporal ID" is a combination of "Spatial ID," which is an identifier in three-dimensional space, and "Temporal ID," which is an identifier in the time axis.

Since the specification of Temporal ID is currently being formulated, this document describes the specification of Spatial ID.

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1. Introduction

1.1. Overview of Spatial ID

In order to use spatial information effectively and expand its use, it is necessary to improve interoperability and distribute information efficiently. For this purpose, a common framework is required to distribute spatial attribute information independent of the form of the data.

Spatial ID is an identifier that uniquely identifies a specific spatial region on the earth. The unit of a spatial region is a rectangular parallelepiped (Hereinafter referred to as “spatial voxel ”) that divides three-dimensional space into rectangular grids. By recursively dividing spatial voxels, it is possible to define spatial voxels of various sizes ranging from a global scale to several tens of centimeters. A globally unique identifier, Spatial ID, is assigned to each spatial voxel.

The Spatial ID can be used as an index by relating the Spatial ID to information about the geographic features that exist within the region of each spatial voxel. By using spatial voxel as the spatial unit when distributing each information, information distribution based on a unified standard becomes possible, and retrieval and integration of each information becomes easy. In addition, by abstracting each information in units of Spatial ID, it is possible to grasp the general situation of the space.

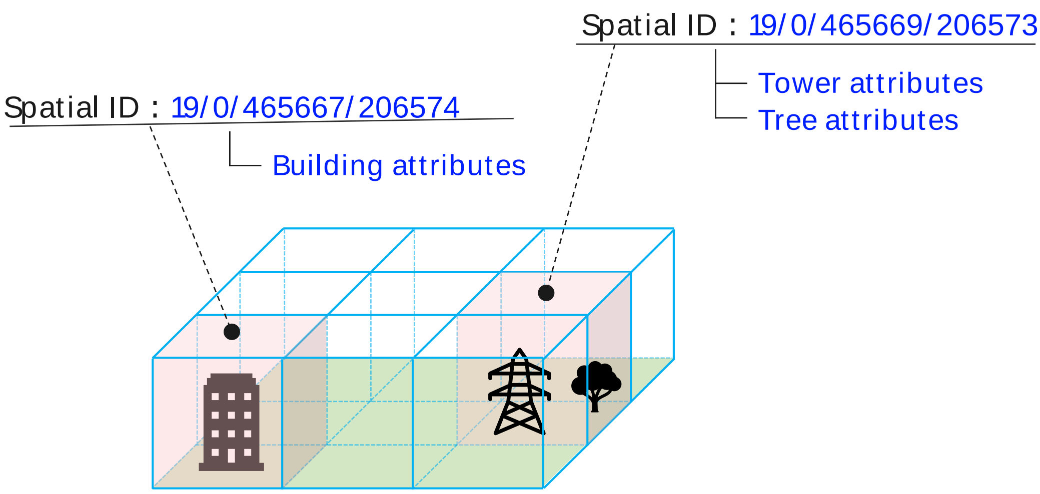


Figure 1 Image of Spatial ID

1.2. Significance and Usability of Spatial ID

(1) Significance of Spatial ID

Spatial ID has characteristics such as handling 3-dimensional space, sharing ID numbering rules, being able to calculate IDs by computation, and being hierarchical. By using Spatial ID, interconnectivity can be ensured. Significance can be roughly classified into three categories. Based on these characteristics and meanings, concrete benefits will be generated according to each use case. Each item is explained below.

i. Characteristics of spatial ID

- Three-dimensional Spatial ID system
  While ID management of geospatial information in two horizontal dimensions is currently the mainstream, Spatial ID manages three-dimensional Spatial ID by adding height direction.
- Standardization of ID numbering rules
  Users use the same ID numbering rules that uniquely identify a specific spatial area.
- Identification of ID by calculation
  Spatial ID can be calculated from physical location information.
- Hierarchical ID system
  Spatial ID has a hierarchical structure, has parent-child relationships among the hierarchies, and can change the granularity of the spatial voxel depending on the use case.

ii. Significance of using Spatial ID

- Ensuring interconnectivity
  Using Spatial ID as an index makes it easy to search and integrate spatial attribute information based on different criteria.
- Flexible use of spatial Information
  It can be used flexibly, for example, by changing the granularity of the Spatial ID (Spatial voxel) or by abstracting and sorting the attached attribute information to maintain confidentiality depending on the use case.
- Lightweight information processing and communication load
  By controlling the amount of information by selecting the granularity of the area depending on the use case, the amount of information processing and communication can be reduced. This makes it easy to handle large-scale spatial attribute information and to perform information processing and communication with devices with small machine power such as mobile terminals and IoT devices.

(2) Potential use of Spatial ID

Spatial ID that can identify a unique location can be associated with a variety of spatial information with different specifications. This is expected to lead to the advancement of existing services and the creation of new services using spatial attribute information in spaces such as the air, the ground, the underground, the indoor, and the sea. For example, use cases will be created such as infrastructure facility inspection and material transportation using drones in the air, safe operation of autonomous vehicles on the ground, construction site support using robots and indoor navigation using AR in the indoor, and visualization of underground objects and advanced excavation work in the underground.

Figure 2 shows examples of data to be related to Spatial ID and use cases under development and actual proof for each use space: the air, the ground, and the underground.

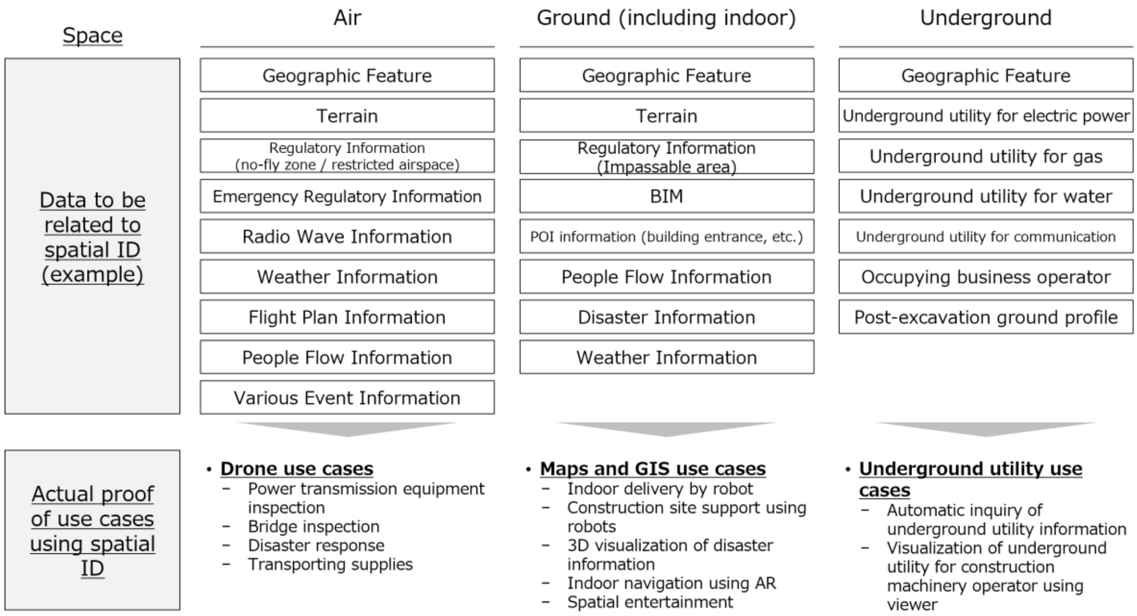


Figure 2 Data to be related to Spatial ID by use space and actual proof of use cases

2. Spatial Voxel

2.1. Concept of Spatial Voxel

The spatial area of each rectangular parallelepiped obtained by dividing every space on the earth, including the air, the ground, the underground, the indoors, and the sea, into a rectangular grid is called a "spatial voxel." "Spatial ID" is assigned to each spatial voxel, which can uniquely identify its position even if the spatial information is based on different specification.

Spatial voxels have the following structure.

- The highest hierarchical level is set to zoom level 0, and the spatial voxel is divided into 8 segments each time the zoom level is increased.
- The spatial voxel of the upper zoom level and the spatial voxel of the lower zoom level divided from it have a parent-child relationship.
- There are no overlapping spatial voxels at the same zoom level.

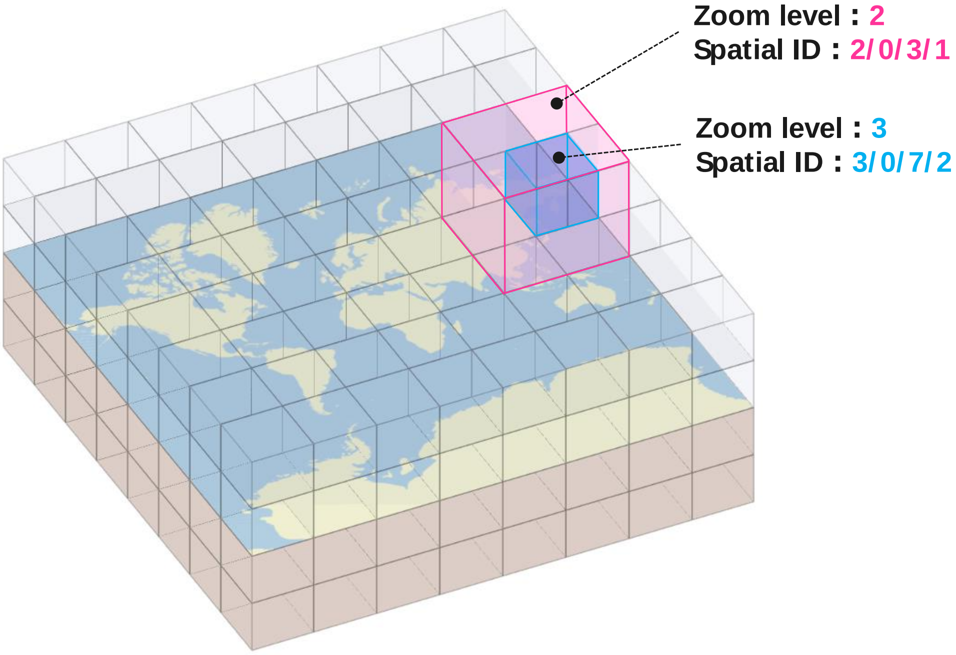


Figure 3 Image of spatial voxels and Spatial ID

2.2. Basic Elements of Spatial Partitioning Methods with Spatial Voxels

There are three basic elements to define a spatial voxel partitioning method. The following sections describe each element in detail.

(1) The height basis for placing spatial voxels
(2) Horizontal spatial partitioning method
(3) Vertical spatial partitioning method

In deciding the spatial partitioning method, the following were taken into consideration: affinity with generally distributed geospatial information and related services, convenience of voxel shape and size, and global availability.

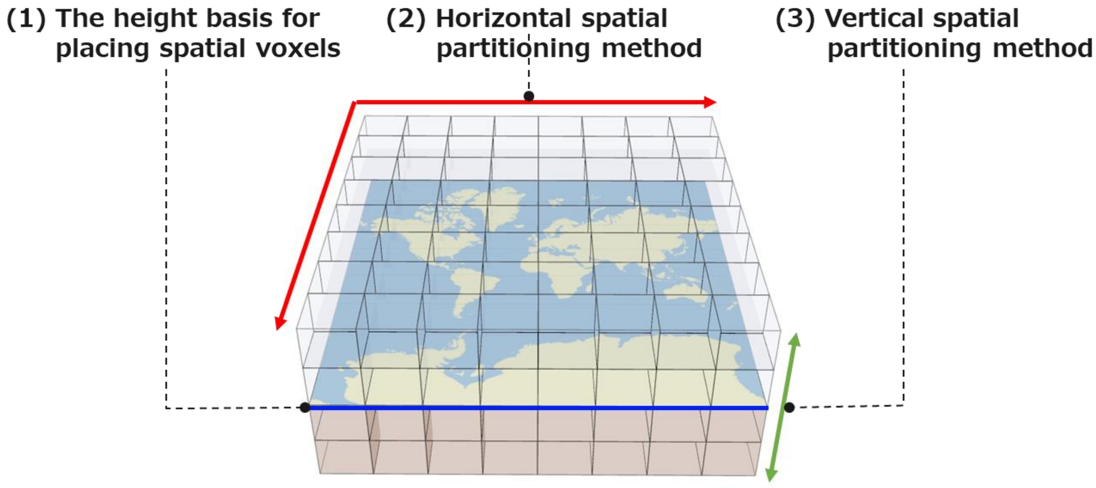


Figure 4 Basic elements of the spatial partitioning scheme

(1) The height basis for placing spatial voxels

i. Reference plane for placing spatial voxels

The reference plane for placing spatial voxels in 3D space on the earth is a geoid (plane with equal potential energy due to the earth's gravity), and the spatial voxels are placed in a coordinate space with a plane with an elevation of 0 m as a flat plane.

The height value of the spatial voxel corresponds to the elevation value (Orthometric Height), and the spatial attribute information created based on the elevation can be directly related to the spatial voxel.

$$h=H+N$$

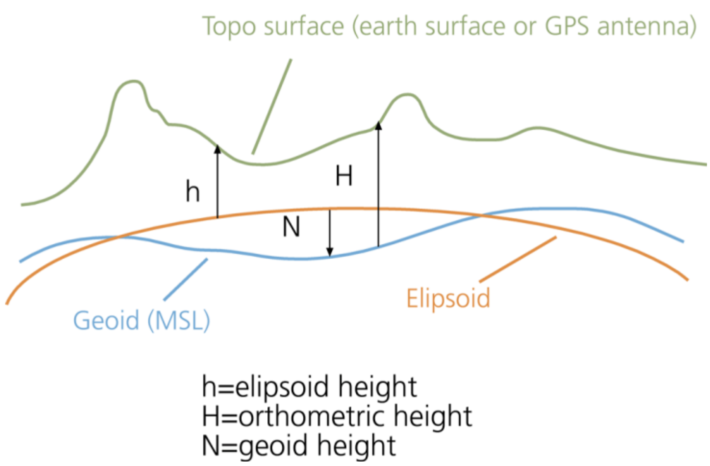


Figure 5 Relationship between ellipsoid height, geoid height and orthometric height

Source: Witold Fraczek, Esri Applications Prototype Lab

https://www.esri.com/news/arcuser/0703/geoid1of3.html

ii. Geoid model

The "geoid model" is used as the data to obtain the elevation from the ellipsoid height obtained by satellite positioning. The geoid model is used depending on the country or region, and the basis of the height should be specified as metadata. In Japan, Japan Geoid 2011 (which assumes the mean sea level of Tokyo Bay as 0 m) is the standard height reference plane.

(2) Horizontal spatial partitioning method

i. Horizontal spatial partitioning

Horizontal spatial partitioning is based on a rectangular area of the earth using the Web Mercator projection *.

The target area of the earth is as follows.

Longitude (X): 180 degrees west longitude to 180 degrees east longitude

Latitude (Y): 85.0511 degrees south latitude to 85.0511 degrees north latitude

The above area is set to zoom level 0, and 4 divisions (Divide east-west direction in two, divide north-south direction in two) are repeated each time the zoom level increases by 1. This partitioning method is the same as XYZ tiles (Slippy map tilenames) adopted by many Web map services.

* The Web Mercator projection method is only used to obtain the latitude and longitude coordinates of the divided grid, and any map projection method may be used for the map used in the spatial information infrastructure. The Spatial ID is calculated based on the latitude and longitude coordinates.

ii. Geodetic system

The geodetic system of the map used for horizontal partitioning shall be the World Geodetic System (Japan Geodetic System 2011 (JGD2011) or WGS84). If necessary, the geodetic system adopted in the application area is specified as metadata of the data related to the Spatial ID.

iii. Assigning x and y indexes

The x-index for longitude (east-west direction) and the y-index for latitude (north-south direction) are assigned as identification numbers for each divided grid.

x-index value

Left-most columns: x = 0, right-most columns: x = 2 ^ Zoom level – 1

(Increments from 0 of the left-most columns to the next one on the right)

y-index value

Top rows: y = 0, Bottom rows: y = 2 ^ Zoom level – 1

(Increments from 0 of the top-most rows to the next one on the bottom)

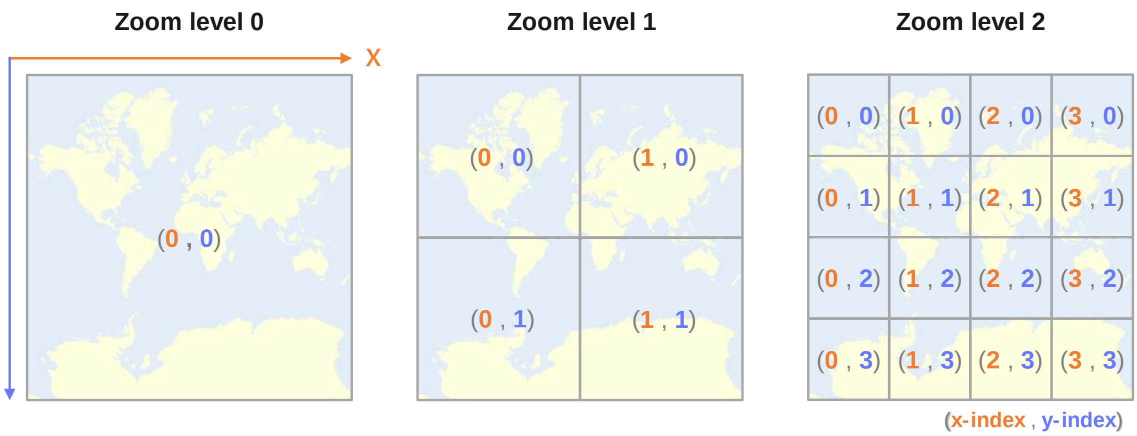


Figure 6 Horizontal partitioning and index assignment

(3) Vertical spatial partitioning method

i. Vertical spatial partitioning

Vertical spatial partitioning is based on the positive and negative height ranges. Each range is as follows.

Positive height range (elevation): 0 m to 33,554,432 m

Negative height range (elevation): -33,554,432 m to 0 m

The above positive height range and negative height range are set to zoom level 0, and equal division is repeated every time the zoom level increases by 1.

ii. Assigning an f-index

A f-index is assigned to each range divided in the vertical direction. For each additional zoom level, the positive direction assigns a value incremented by 1 from 0 in the positive direction. The negative direction assigns a value decremented by 1 from -1 in the negative direction.

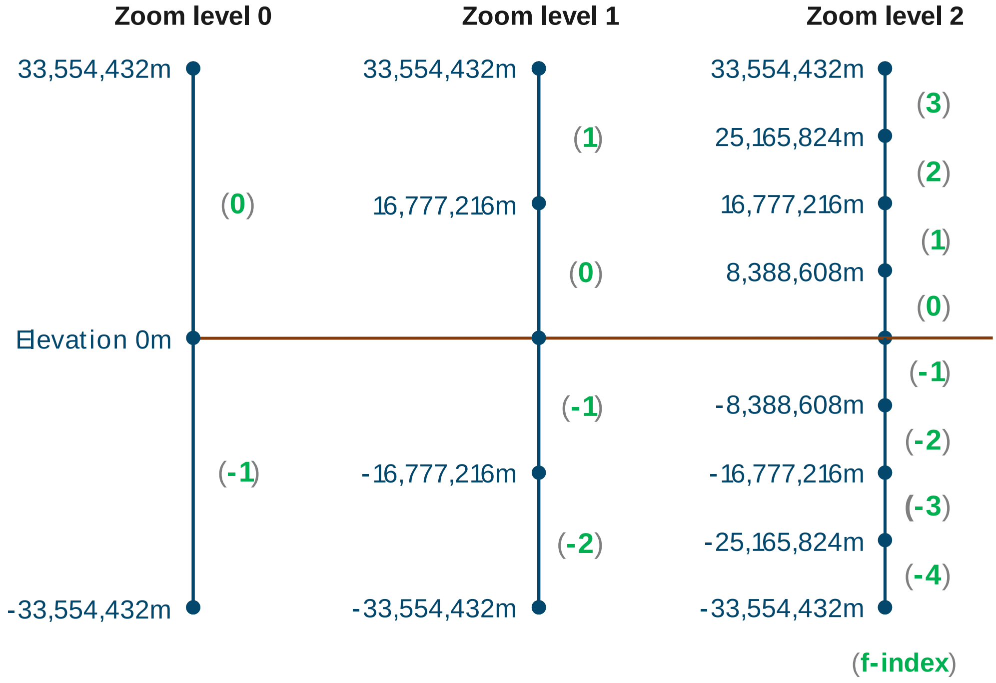


Figure 7 Vertical divisions and assigning Indexes

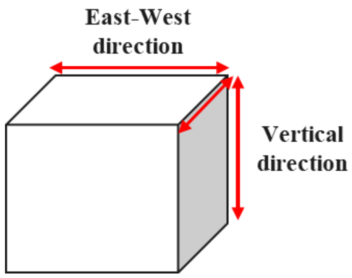
* Elevation values that serve as split points are included in the upper index.
Example) The f-index of 8,338,608 m at zoom level 2 is 1.

2.3. Zoom Level and Size of Spatial Voxels

A spatial voxel is divided into 8 segments each time the zoom level increases by 1 from zoom level 0, decreasing in size. Examples of the horizontal (east-west and north-south directions) and vertical sizes of spatial voxels at zoom level 0-26 are shown below. Zoom levels 27 and higher can also be defined.

Table 1 Examples of spatial voxel sizes at zoom level 0~26

Zoom Level	Horizontal East-West direction (m)	Horizontal North-South direction (m)	Vertical direction (m)
0	40,075,016.68	40,075,016.68	33,554,432.00
1	20,037,508.34	20,037,508.34	16,777,216.00
2	10,018,754.17	10,018,754.17	8,388,608.00
3	5,009,377.09	5,009,377.09	4,194,304.00
4	2,504,688.54	2,504,688.54	2,097,152.00
5	1,252,344.27	1,252,344.27	1,048,576.00
6	626,172.14	626,172.14	524,288.00
7	313,086.07	313,086.07	262,144.00
8	156,543.03	156,543.03	131,072.00
9	78,271.52	78,271.52	65,536.00
10	39,135.76	39,135.76	32,768.00
11	19,567.88	19,567.88	16,384.00
12	9,783.94	9,783.94	8,192.00
13	4,891.97	4,891.97	4,096.00
14	2,445.98	2,445.98	2048.00
15	1,222.99	1,222.99	1024.00
16	611.50	611.50	512.00
17	305.75	305.75	256.00
18	152.87	152.87	128.00
19	76.44	76.44	64.00
20	38.22	38.22	32.00
21	19.11	19.11	16.00
22	9.55	9.55	8.00
23	4.78	4.78	4.00
24	2.39	2.39	2.00
25	1.19	1.19	1.00
26	0.60	0.60	0.50



The distances in the east-west and north-south directions in the above table indicate distances at 0 degrees of latitude, and the distances become shorter at higher latitudes.

The vertical distances are the same for all longitudes and latitudes as shown in Table 1.

The east-west distance of the spatial voxel at each latitude can be calculated by the following formula:

East-west distance = Equatorial radius * 2 * PI * cos (latitude)/2 ^ Zoom level

(The equatorial radius for geodetic systems JGD2011 and WGS84 is 6,378,137 m.)

Source: OpenStreetMap

https://wiki.openstreetmap.org/wiki/Zoom_levels

For reference, the following shows the spatial voxel sizes at zoom level 16-26 for cities in Japan (Naha, Tokyo and Sapporo).

Table 2 Examples of spatial voxel sizes at zoom level 16~26 for Naha, Tokyo, and Sapporo

Naha
(Naha City Hall)
Latitude: 26.21 degrees north

Zoom Level	Horizontal		Vertical direction (m)
	East-West direction (m)	North-South direction (m)	
16	548.98	546.01	512.00
17	274.49	273.00	256.00
18	137.24	136.50	128.00
19	68.62	68.25	64.00
20	34.31	34.13	32.00
21	17.16	17.06	16.00
22	8.58	8.53	8.00
23	4.29	4.27	4.00
24	2.14	2.13	2.00
25	1.07	1.07	1.00
26	0.54	0.53	0.50

Tokyo
(Tokyo Metropolitan Government Building)
Latitude: 26.21 degrees north

Zoom Level	Horizontal		Vertical direction (m)
	East-West direction (m)	North-South direction (m)	
16	497.22	495.01	512.00
17	248.61	247.51	256.00
18	124.31	123.75	128.00
19	62.15	61.88	64.00
20	31.08	30.94	32.00
21	15.54	19.11	16.00
22	7.77	7.73	8.00
23	3.88	3.87	4.00
24	1.94	1.93	2.00
25	0.97	0.97	1.00
26	0.49	0.48	0.50

Sapporo
(Sapporo City Hall)
Latitude: 26.21 degrees north

Zoom Level	Horizontal		Vertical direction (m)
	East-West direction (m)	North-South direction (m)	
16	447.48	445.86	512.00
17	223.73	222.92	256.00
18	111.86	111.46	128.00
19	55.93	55.73	64.00
20	27.97	27.87	32.00
21	13.98	13.93	16.00
22	6.99	6.97	8.00
23	3.50	3.48	4.00
24	1.75	1.74	2.00
25	0.87	0.87	1.00
26	0.44	0.44	0.50

※ If the east-west distance between the top edge (north side) and bottom edge (south side) of the horizontal plane of the spatial voxel is different, indicate the distance of the bottom edge.

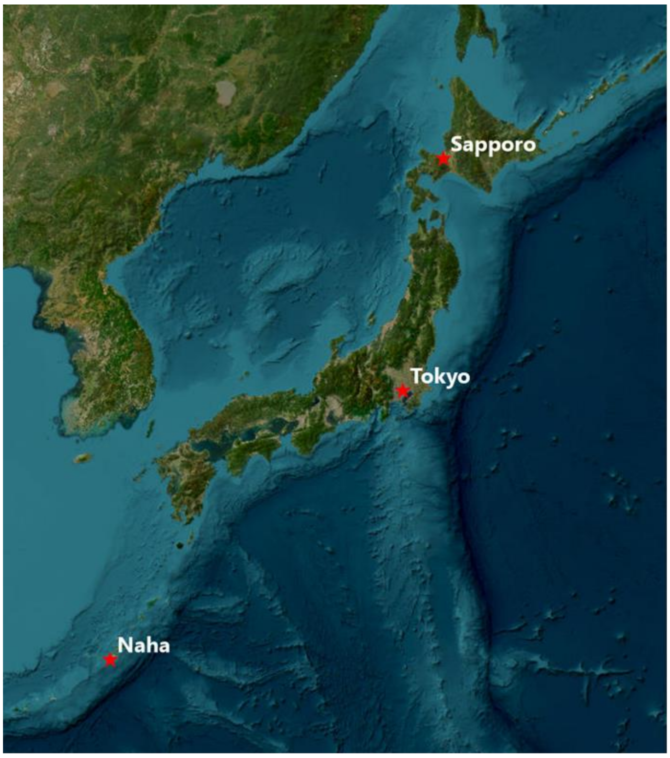


Figure 8 Locations of Naha, Tokyo, and Sapporo

3. Spatial ID

3.1. Spatial ID Format

A Spatial ID consists of z, f, x, and y elements, which are connected by forward slashes (/).

Elements that make up a Spatial ID

{z}: Zoom level

{f}: Elevation (vertical direction) index

{x}: Longitude (east-west direction) index

{y}: Latitude (north-south direction) index

Array of Spatial ID

{z}/{f}/{x}/{y}

Example: 20/1/931369/413142

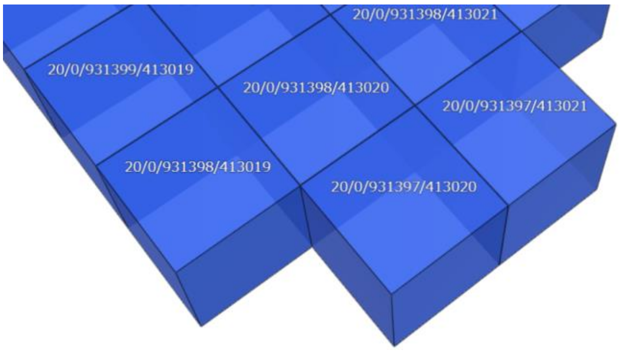


Figure 9 Image showing the Spatial ID of spatial voxels

3.2. Formulas for Calculating Each Element of Spatial ID

The formulas for calculating each element (f, x, y) of Spatial ID from longitude, latitude, elevation, and zoom level are as follows.

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lng: Longitude [Decimal Degree]

lat: Latitude [Decimal Degree], lat_rad: Latitude [Radians]

h: Elevation $[m]$

z: Zoom Level

$$n = 2^z$$

$$Z = 25 \text{ (The zoom level at which the voxel height is 1m)}$$

$$H = 2^Z \ [m]$$

$$f = floor\left(n * \frac{h}{H}\right)$$

$$x = floor\left(n * \left(\frac{lng + 180}{360}\right)\right)$$

$$y = floor\left(\frac{n}{2} * \left(1 - \frac{\log\left(\tan(lat\_rad) + \left(\frac{1}{\cos(lat\_rad)}\right)\right)}{\pi}\right)\right)$$

Source: UN Vector Tile Toolkit
https://github.com/unvt/zfxy-spec

3.3. Spatial ID Format for Data without Heigh Value

In spatial data, there are many two-dimensional data (E.G., demographics, zoning, land use) without height value. When these data are related to Spatial IDs, the following ID format excluding the f-index is applied because the f-index indicating elevation is not necessary.

Array of Spatial ID corresponding to data without height value

{z}/{x}/{y}

Example: 20/931369/413142

This is the same array as XYZ tiles numbers in web map services such as Geographical Survey Institute Maps.

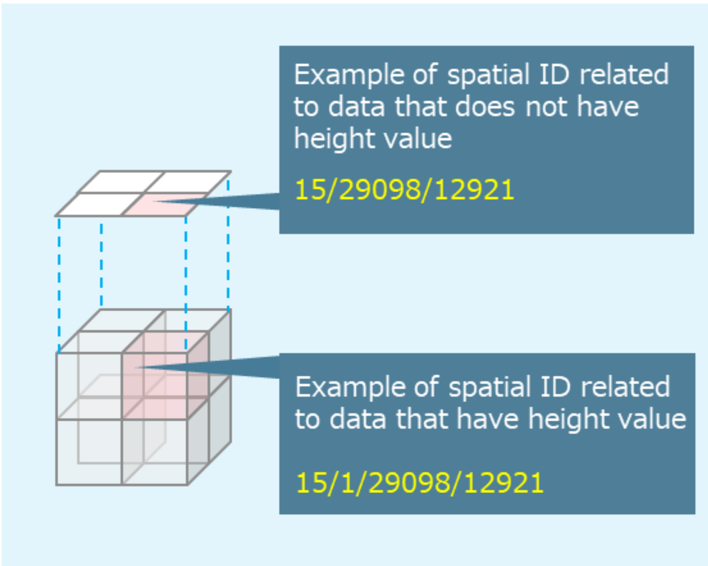

Figure 10 Example of Spatial ID corresponding to data without height value

4. Attribute Information

4.1. Basic Concept of Assigning Attributes to Spatial Voxels

By relating information such as a geographic feature existing in each spatial voxel to the Spatial ID and using the Spatial ID as an index, a spatial unit in distributing each information can be defined as a spatial voxel. This makes it possible to distribute information based on uniform standards, and makes it easy to search and integrate information. In addition, by abstracting each information by a Spatial ID unit, the general situation of the space can be grasped.

The relationship between each spatial voxel and features may be one-to-one, one-to-many, or many-to-one. Although these relationships are not defined as data schemas, the basic concepts for assigning and associating information in each relationship are as follows.

(1) When the relationship between spatial voxel and features is one-to-one

When one spatial voxel contains one feature, attribute information of the feature is related to the spatial voxel. In addition, a Spatial ID is assigned to the attribute of the feature.

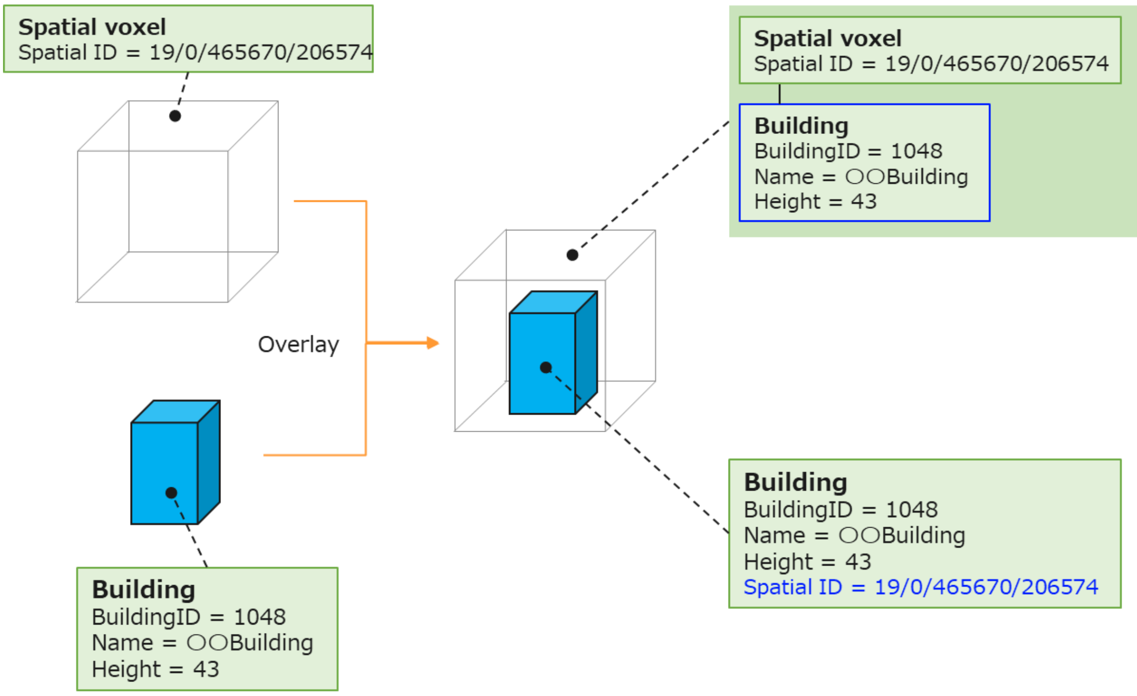

Figure 11 Example of relating spatial voxel and feature data (one-to-one)

(2) When the relationship between the spatial voxel and the feature is one-to-many

When one spatial voxel contains multiple features, attribute information of each feature is related to the spatial voxel. When numerical information is included in the attribute of the feature, statistical information (Count, maximum value, minimum value, average value, etc.) is also assumed to be added. In addition, a Spatial ID is assigned to the attribute of each of the features.

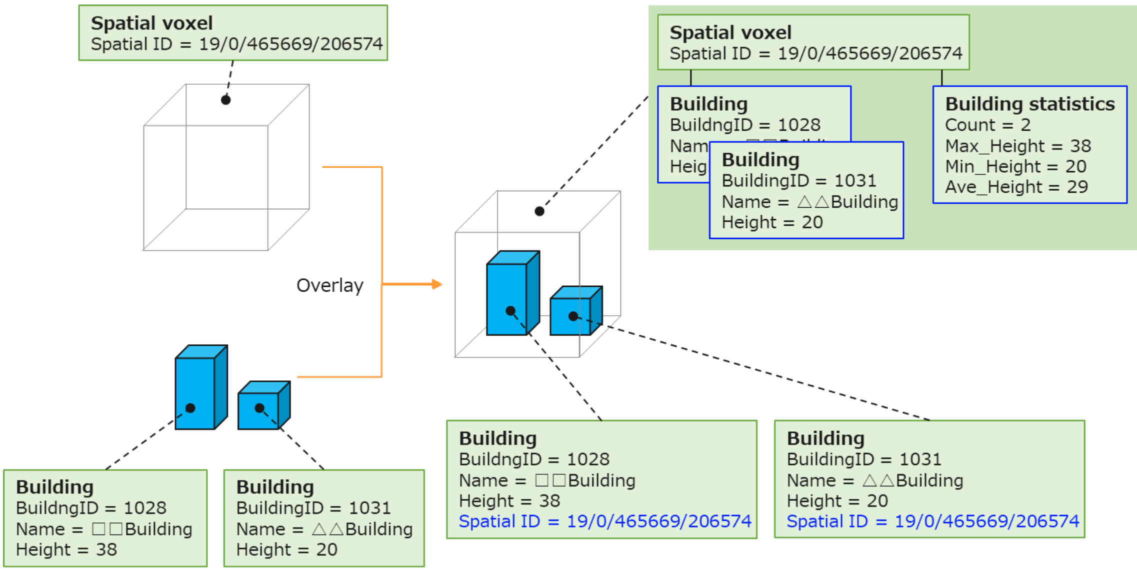

Figure 12 Example of relating spatial voxels and feature data (one-to-Many)

(3) When the relationship between the spatial voxels and the feature is many-to-one

When one feature overlaps multiple spatial voxels, attribute information of the same feature is related to the multiple spatial voxels. In addition, the Spatial IDs of all spatial voxels including the feature are assigned to the attributes of the feature.

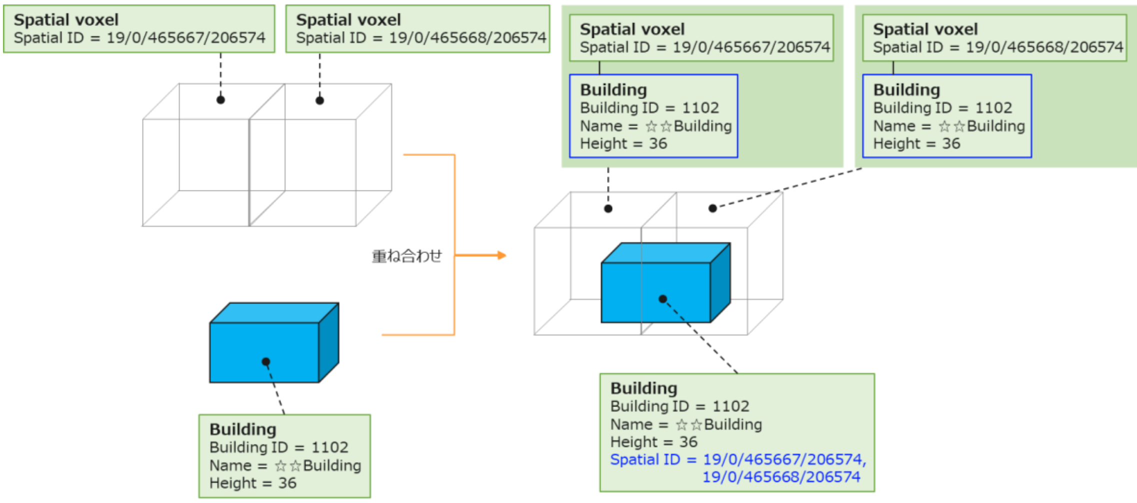

Figure 13 Example of relating spatial voxels and feature data (Many-to-one)

4.2. Handling of Temporal Information

The data of the feature may include temporal information (year/month/day/time) as attributes. Temporal information includes instant information and period information. In the instant information, the situation (including prediction) of the feature at a certain point in time is indicated together with the time (e.g., weather information). In the period information, the existing period or validity period of the feature are indicated by the start time and end time (e.g., road construction information). By relating temporal information to the ID of the

3D space, it becomes possible to manage and search using space and time.

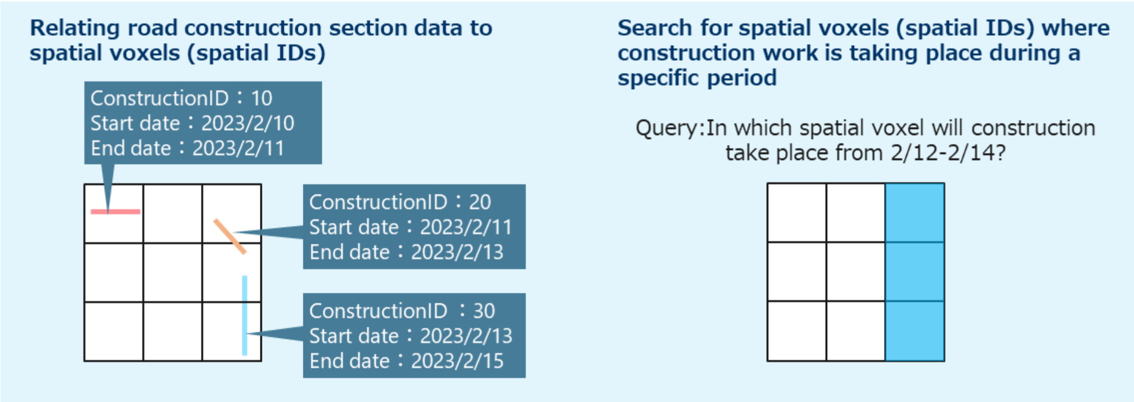

Figure 14 Examples of using temporal information

4.3. Example of Using Spatial Voxels

(1) Selection of zoom level when relating information of feature to spatial voxels

The zoom level for relating information of feature to spatial voxels can be selected arbitrarily. The optimum zoom level is determined depending on the purpose of use and the accuracy required. It is also possible to relate a single type of feature dataset (e.g. building data) to a mixed spatial voxels at multiple zoom levels.

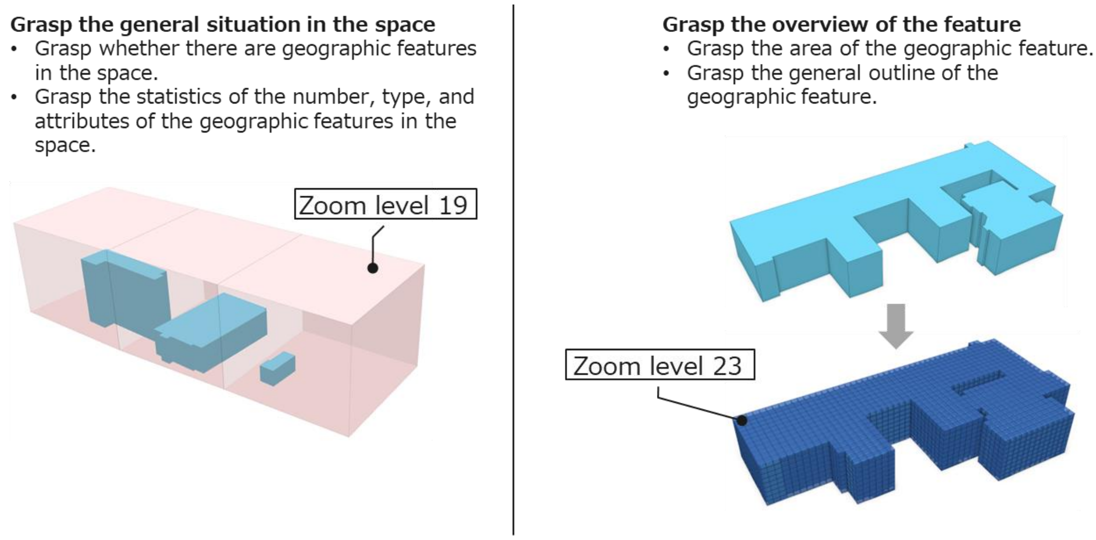

Figure 15 Examples of setting zoom level

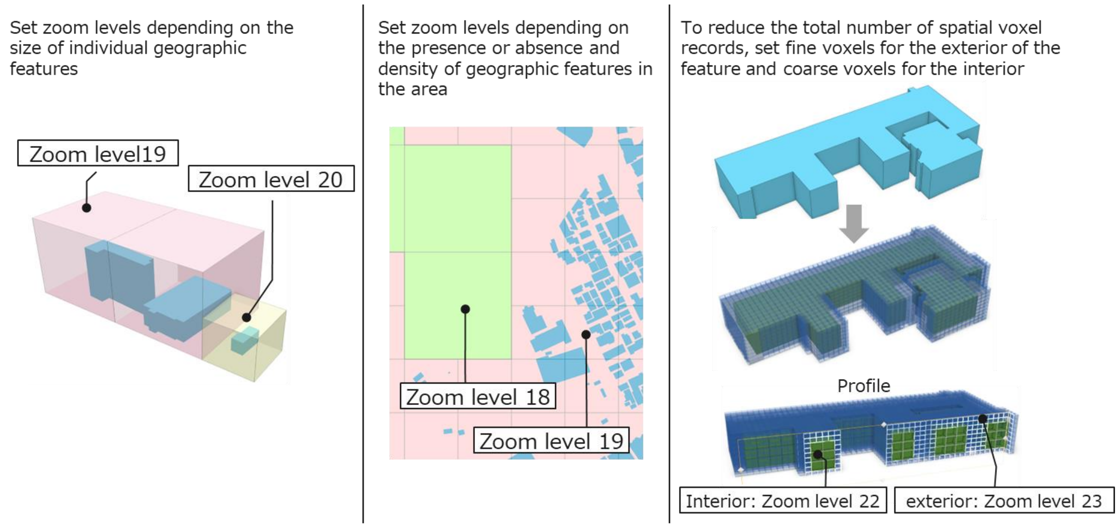

Figure 16 Examples of setting multiple zoom levels together

(2) Role of a spatial voxel as an index of feature data

Spatial voxel can serve as an index when distributing information of feature. For example, by requesting a certain Spatial ID, information of feature included in the spatial voxel of the Spatial ID is delivered.

APPENDIX Glossary

Glossary	Meaning	General Terms
Feature	An object that is directly or indirectly related to a position on the earth. [1] Natural environment (e.g., rivers), natural phenomena (e.g., weather), man-made objects (e.g., buildings), man-made boundaries (e.g., administrative district), etc.	X
Attribute information	Information that describes the characteristics of the feature (e.g., building use, building area, number of stories, structure, etc.).	X
Metadata	Descriptive information about the data, not the data itself. [2] (Although there are other definitions for metadata, definition above is used in this document.)	X
Spatial ID	An identifier with a code assigned to a spatial voxel so that it can be uniquely located even if the 3D spatial information is based on different specification.	
Spatial Voxel	The spatial region of each rectangular parallelepiped obtained by dividing every space on the earth, including the air, the ground, the underground, the indoors, and the sea, into a rectangular grid.	
Geodetic System	The rules for measuring positions on the earth and the coordinates that follow them. [3]	X
Japan Geodetic System 2011 (JGD2011)	The geodetic system currently used by Japan. It is based on the International Terrestrial Reference System (ITRF), which is a global geodetic system that can be used throughout the world. [3]	X
WGS84	A global geodetic system established and maintained by the United States. [4]	X
XYZ tiles	A specification that defines the earth as a flat square and distributes data by dividing it into tiles at each zoom level.	X
Geographical Survey Institute Maps	A web map of Japan as captured by the Geospatial Information Authority of Japan, including topographic maps, photographs, elevations, topographic classifications, and disaster information. [5]	X
height basis	A reference plane for locating spatial voxels in three-dimensional space on the earth.	
Geoid	A plane of equal potential energy due to the earth's gravity (the isopotential surface of gravity). [6]	X
Geoid Model	A basis for determining elevation using satellite positioning. [12]	X
Japanese Geoid 2011	Geoid model of Japan (excluding some isolated islands) released by the Geospatial Information Authority of Japan in April 2014.	X
Ellipsoid height	The height from the surface of a model of the earth represented by an ellipsoid of revolution.	X
ZFXY	Spatial ID in the form of zoom level (z), f-index, x-index, and y-index	
Zoom level	The level at which a 3D space is divided into spatial voxels. No division is zoom level 0, eight divisions are zoom level 1, and each division increases by one, decreasing the size of each spatial voxel.	
f-index	The elevation (vertical direction) number of the spatial voxel.	
x-index	The Longitude (east-west direction) number of the spatial voxel.	
y-index	The Latitude (north-south direction) number of the spatial voxel.	
Spatial attribute information	Data that represents the real world for each purpose.	

Source

[1] the Geospatial Information Authority of Japan "Operational Guidelines for JSGI 2.0)"
https://www.gsi.go.jp/GIS/stdind/stdindpdf/jsgi_guide.pdf

[2] the Geospatial Information Authority of Japan "Practical Application of Geospatial Information (JPGIS)"
https://www.gsi.go.jp/GIS/jpgis-wj_about.html

[3] the Geospatial Information Authority of Japan "Japan's Geodetic System"
https://www.gsi.go.jp/sokuchikijun/datum-main.html

[4] the Geospatial Information Authority of Japan "Questions and Answers on Global Geodetic System Transition"
https://www.gsi.go.jp/LAW/G2000-g2000faq-1.htm

[5] Geospatial Information Authority of Japan "How to use Geospatial Information Authority of Japan"
https://maps.gsi.go.jp/help/intro/

[6] Geospatial Information Authority of Japan "Geoid modeling"
https://www.gsi.go.jp/buturisokuchi/grageo_geoidmodeling.html