Introduction to Discrete Global Grid Systems (DGGS)

ENGO551 Advanced Geospatial Topics

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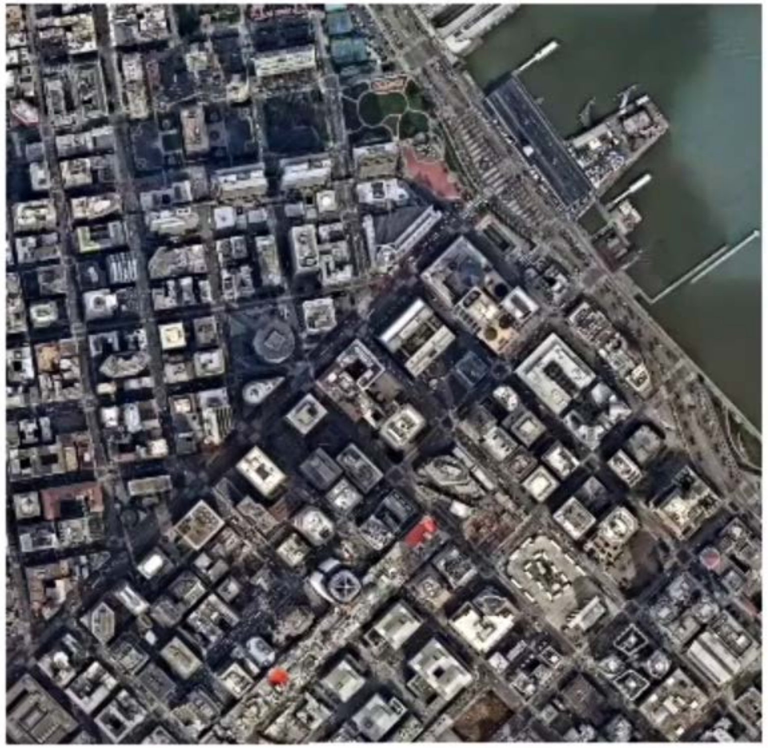
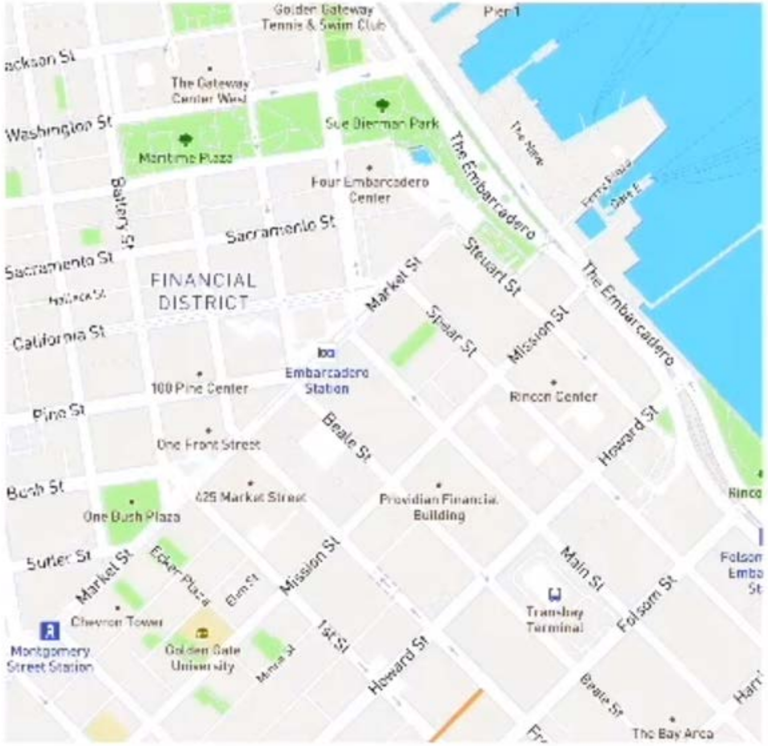
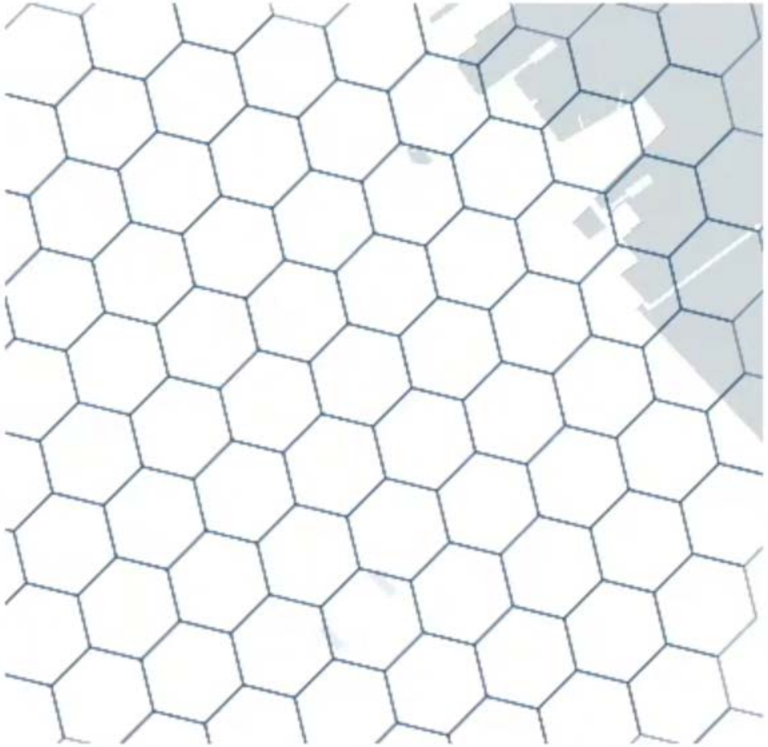
Jan 21, 2026

Geographic Grid Systems

Washington DC ↴







Real world
Hard to model
Elements without a consistent structure

Map
A common abstraction
But still messy..

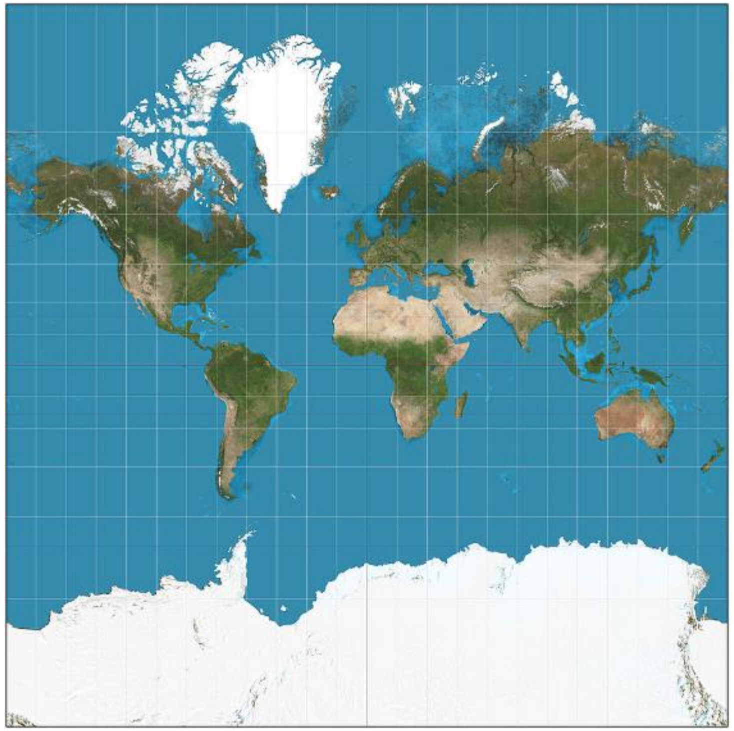
Grid
Clean mathematical space
Algorithms (aggregation/convolution/etc)

❖ *https://www.youtube.com/watch?v=wDuKeUkNLkQ&list=PL_gA0HNvT3FcEe2ABQg5HC9muDR-feGXp&index=3*

Why DGGS…?

Graticule

Inconsistent cell unit



Web Mercator Tiles

Inconsistent cell unit

Not a global domain

Discrete Global Grid Systems (DGGS)

✓

- *https://commons.wikimedia.org/wiki/File:Division_of_the_Earth_into_Gauss-Krueger_zones_-_Globe.svg*
- *https://en.wikipedia.org/wiki/File:Mercator_projection_Square.JPG*

Understanding of DGGS

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“A Spatial Reference System that uses a Hierarchical Tessellation of cells to Partition and Address the Globe. DGGS are characterized by the properties of their Cell Structure, Geo-encoding, Quantization Strategy and associated Mathematical Functions.”

❖ *https://docs.ogc.org/as/15-104r5/15-104r5.html*

Discrete -- a finite number of cells
Global -- a grid that completely covers the Earth’s surface
Grid -- a tessellation of space into a uniform arrangement of cells
System -- a grid that can be subdivided into smaller cells

❖ *Bowater and Stefanakis, 2018*

Five elements of constructing a DGGS

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1. Basic solid - A base regular polyhedron

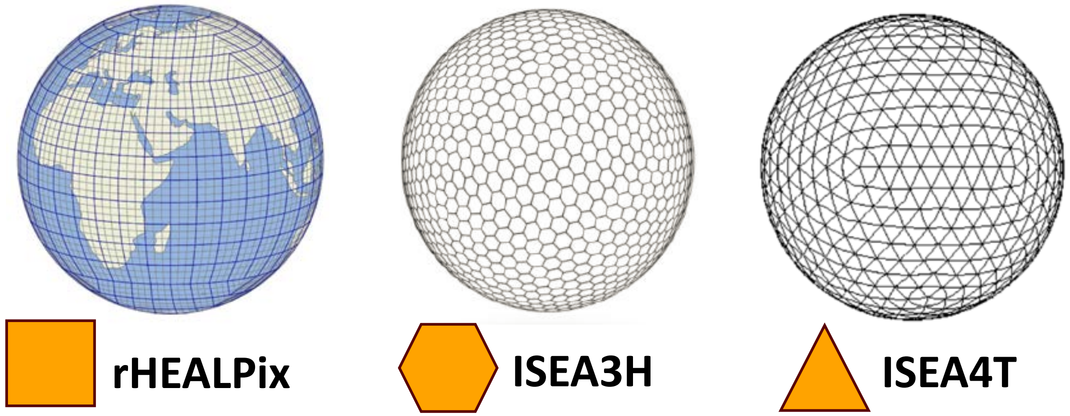
2. Orientation - A fixed orientation of the base regular polyhedron relative to the Earth

3. Cell geometry and aperture related - A hierarchical spatial partitioning method defined symmetrically on a face (or set of faces) of the base regular polyhedron

4. Transformation/Projection - A method for transforming that planar partition to the corresponding spherical/ellipsoidal surface

5. Cell reference point - A method for assigning points to grid cells

❖ *Sarh et al., 2003*

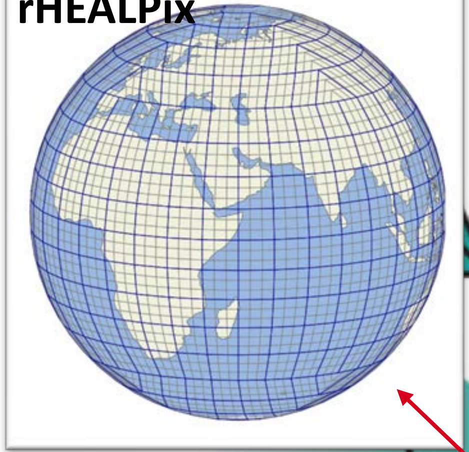


Five elements of constructing a DGGS

Basic solid

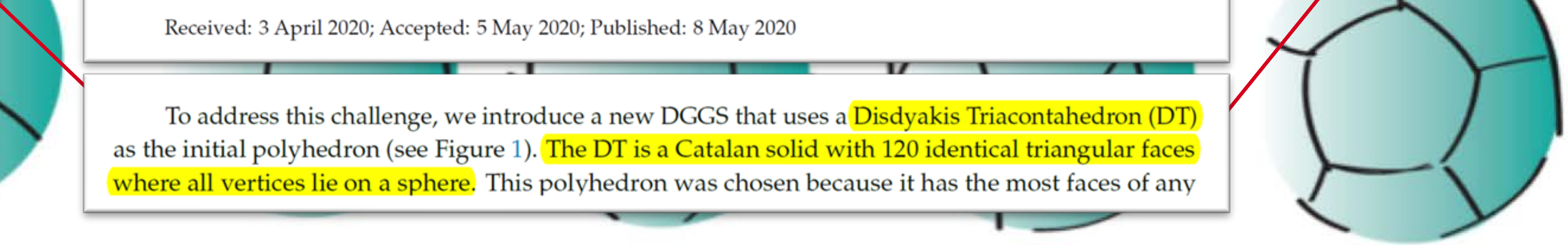
The 5 Platonic Solids

rHEALPix



QTM

ISEA4T



International Journal of *Geo-Information*

MDPI

Article

Disdyakis Triacontahedron DGGS

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To address this challenge, we introduce a new DGGS that uses a Disdyakis Triacontahedron (DT) as the initial polyhedron (see Figure 1). The DT is a Catalan solid with 120 identical triangular faces where all vertices lie on a sphere. This polyhedron was chosen because it has the most faces of any

tetrahedron **cube** **octahedron** **icosahedron** **dodecahedron**

- *http://docs.opengeospatial.org/as/15-104r5/15-104r5.html*
- *Hall et al., 2020*

Five elements of constructing a DGGS

Orientation

Take a spherical icosahedron as an example…

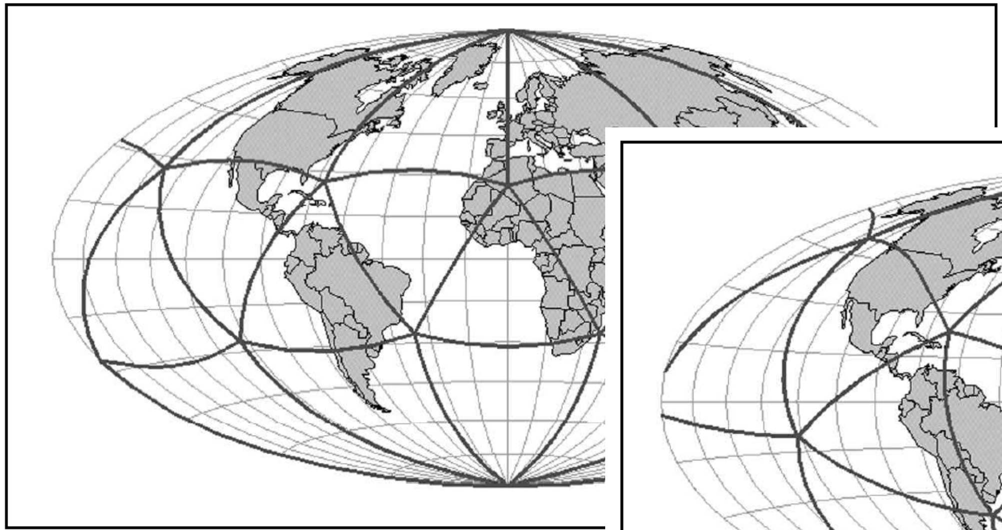

Figure 3a. Spherical icosahedron (in Mollweide p
at poles and an edge aligned with the prime meri
about the equator.

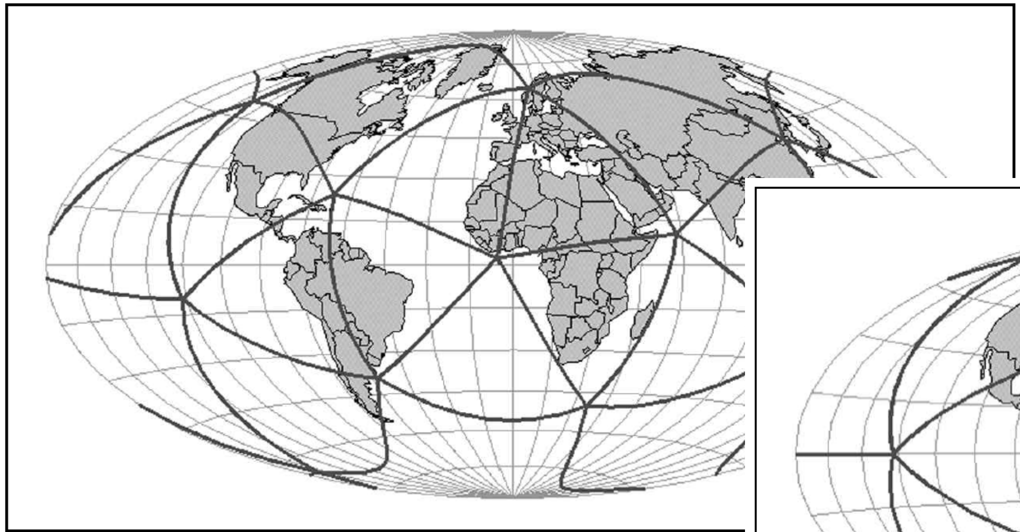

Figure 3b. Spherical icosahedron (in Mollweide projection)
Dymaxion orientation. Note that all vertices fall in the ocean

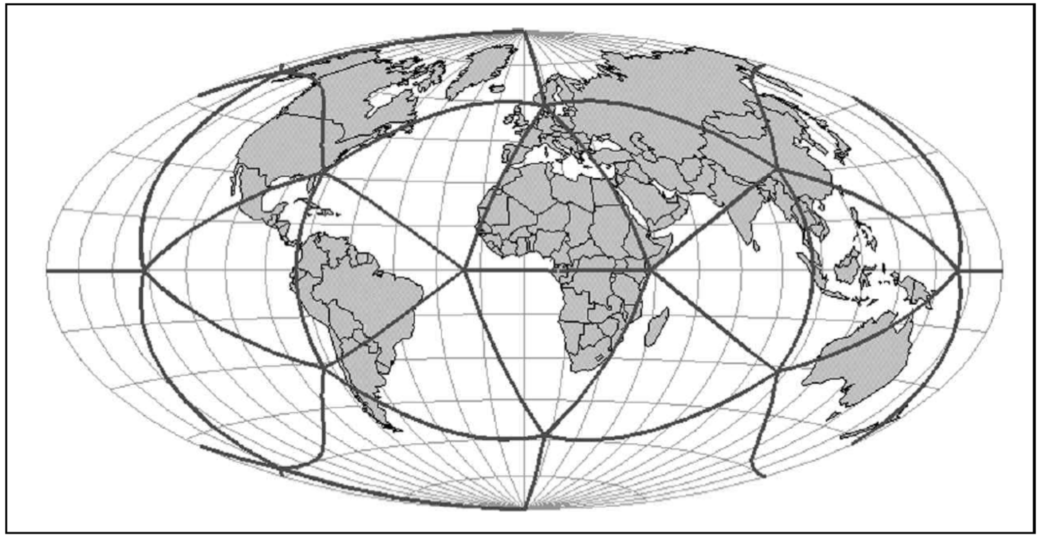

Figure 3c. Spherical icosahedron (in Mollweide projection) oriented for symmetry about equator by placing poles at edge midpoints. Note the symmetry about the equator and the single vertex falling on land.

❖ *Sarh et al., 2003*

Five elements of constructing a DGGS

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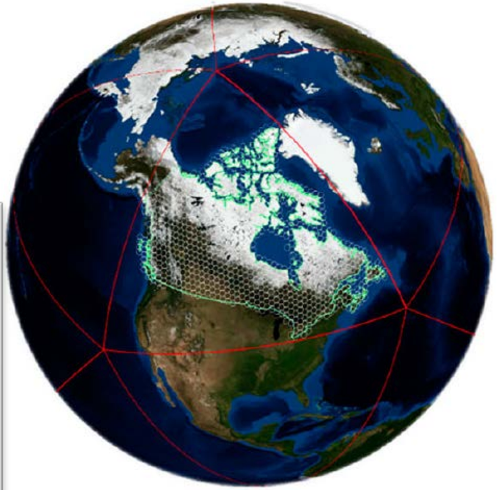
Orientation

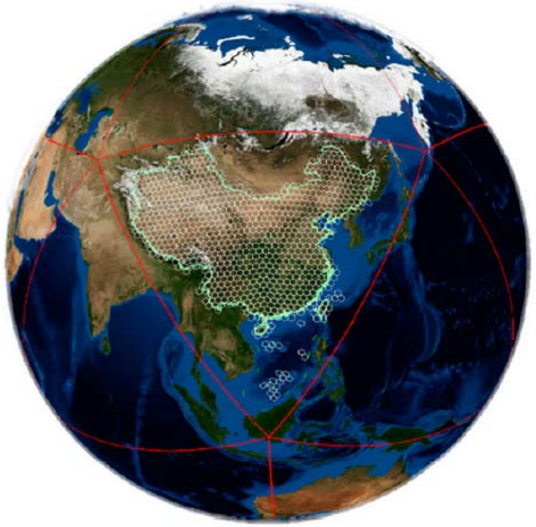
A novel method of determining the optimal polyhedral orientation for discrete global grid systems applicable to regional-scale areas of interest

Jianbin Zhou, Jin Ben, Rui Wang, Mingyang Zheng, Xiaochuang Yao & Lingyu Du

To cite this article: Jianbin Zhou, Jin Ben, Rui Wang, Mingyang Zheng, Xiaochuang Yao & Lingyu Du (2020): A novel method of determining the optimal polyhedral orientation for discrete global grid systems applicable to regional-scale areas of interest, International Journal of Digital Earth, DOI: 10.1080/17538947.2020.1748127

To link to this article: https://doi.org/10.1080/17538947.2020.1748127

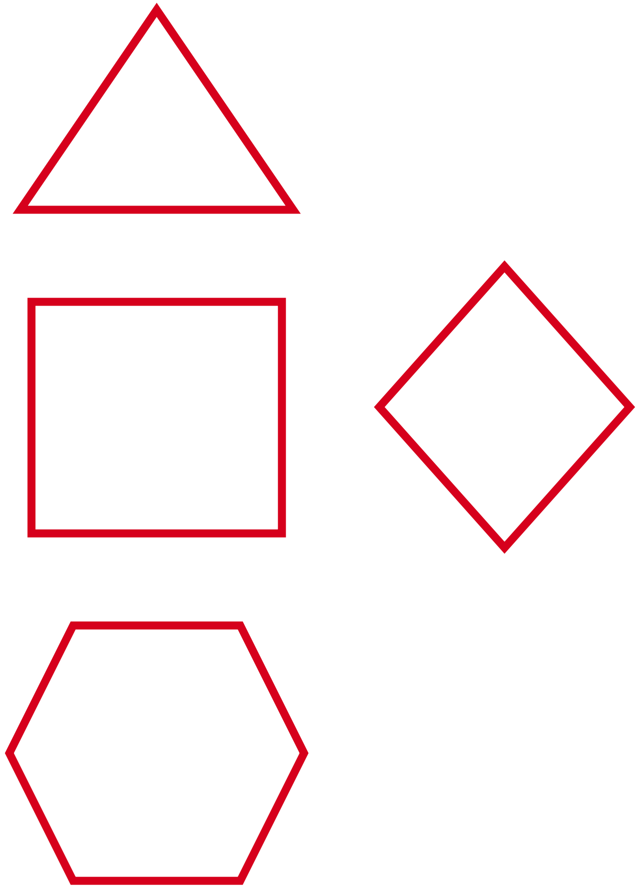


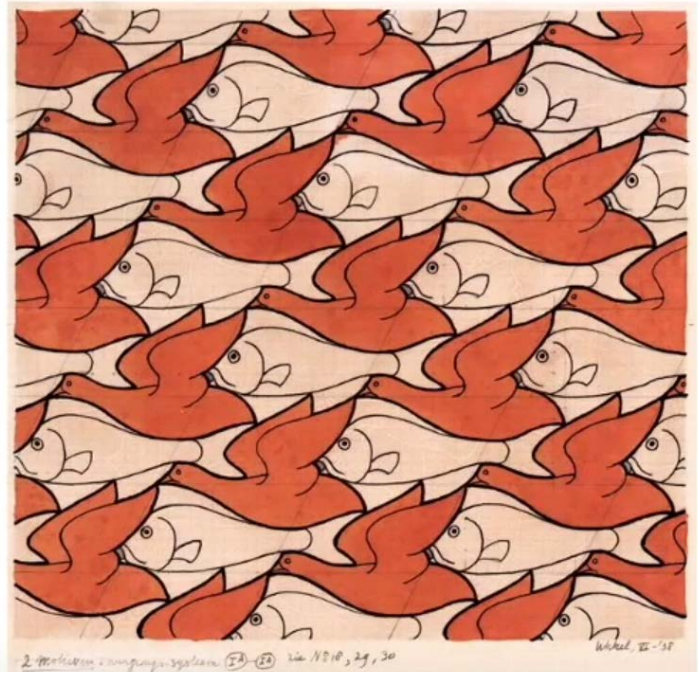


❖ *Zhou et al., 2020*

Five elements of constructing a DGGS

<u>**Cell geometry and aperture related**</u>





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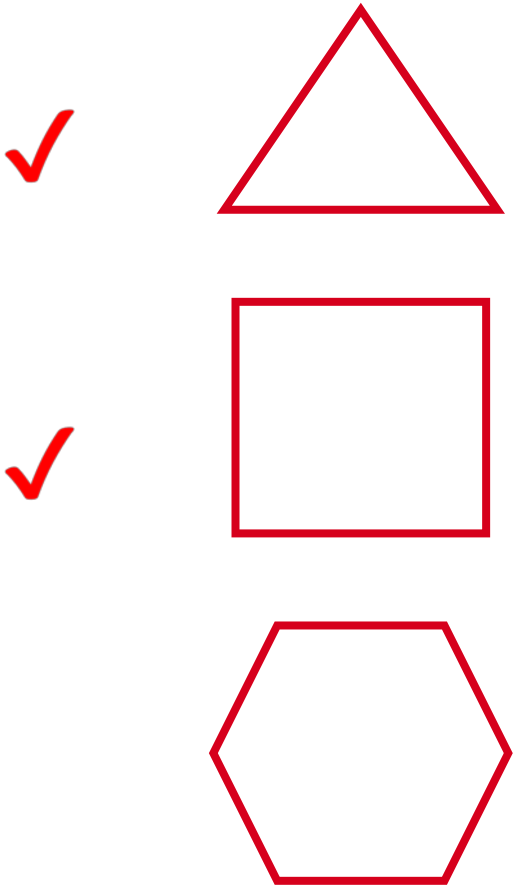
Five elements of constructing a DGGS

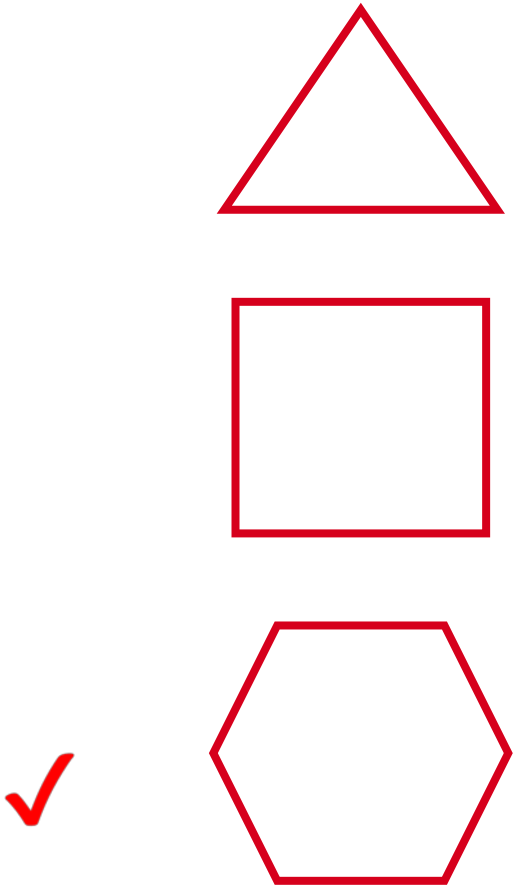
Cell geometry and aperture related



- Simple, regular geometry, spherical tiling
- Optimally compact/space-filling
- Uniform adjacency
- Hierarchical relationships

Five elements of constructing a DGGS

Cell geometry and aperture related

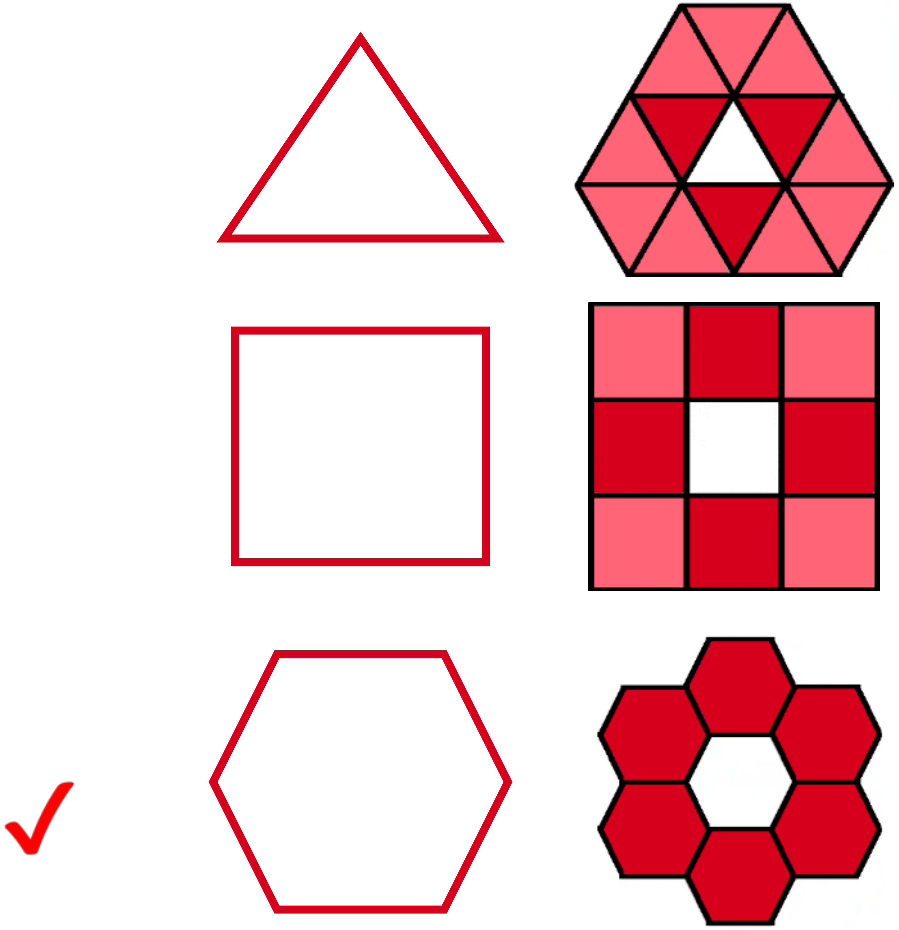


- Simple, regular geometry, spherical tiling
- Optimally compact/space-filling
- Uniform adjacency
- Hierarchical relationships

Compared to square grids at the same resolution, they can reduce the number of required cells by ~13%.

Five elements of constructing a DGGS

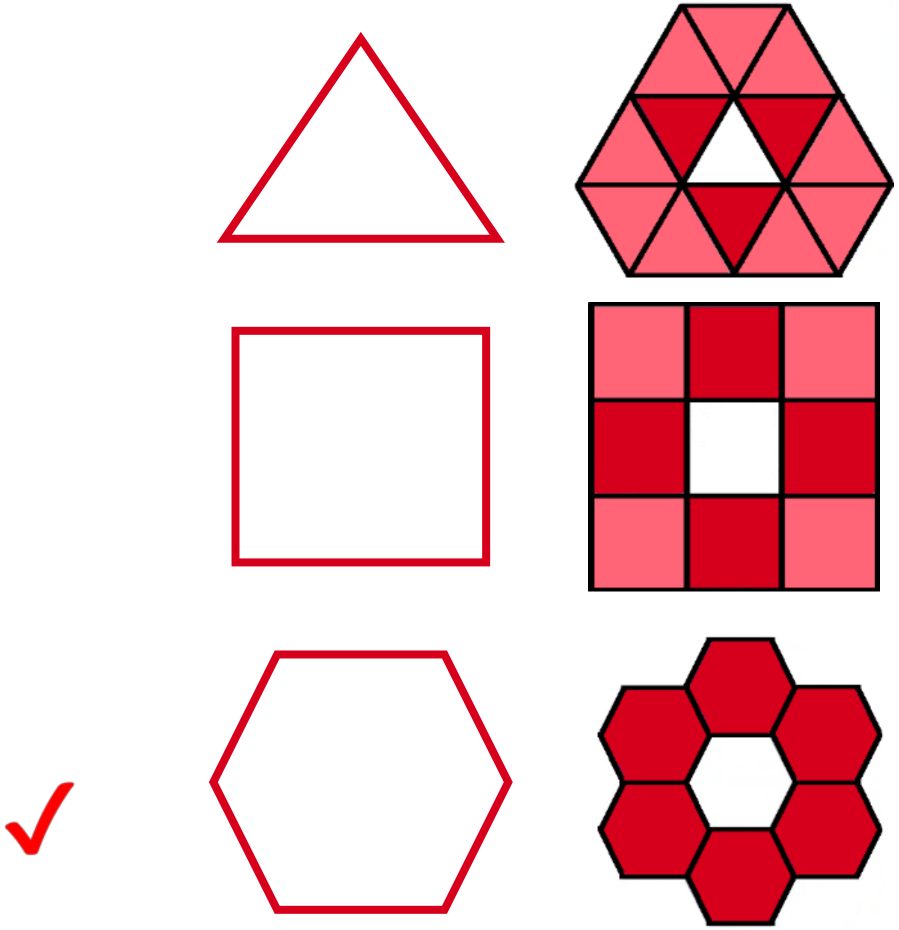
Cell geometry and aperture related



- Simple, regular geometry, spherical tiling
- Optimally compact/space-filling
- Uniform adjacency
- Hierarchical relationships

Five elements of constructing a DGGS

Cell geometry and aperture related



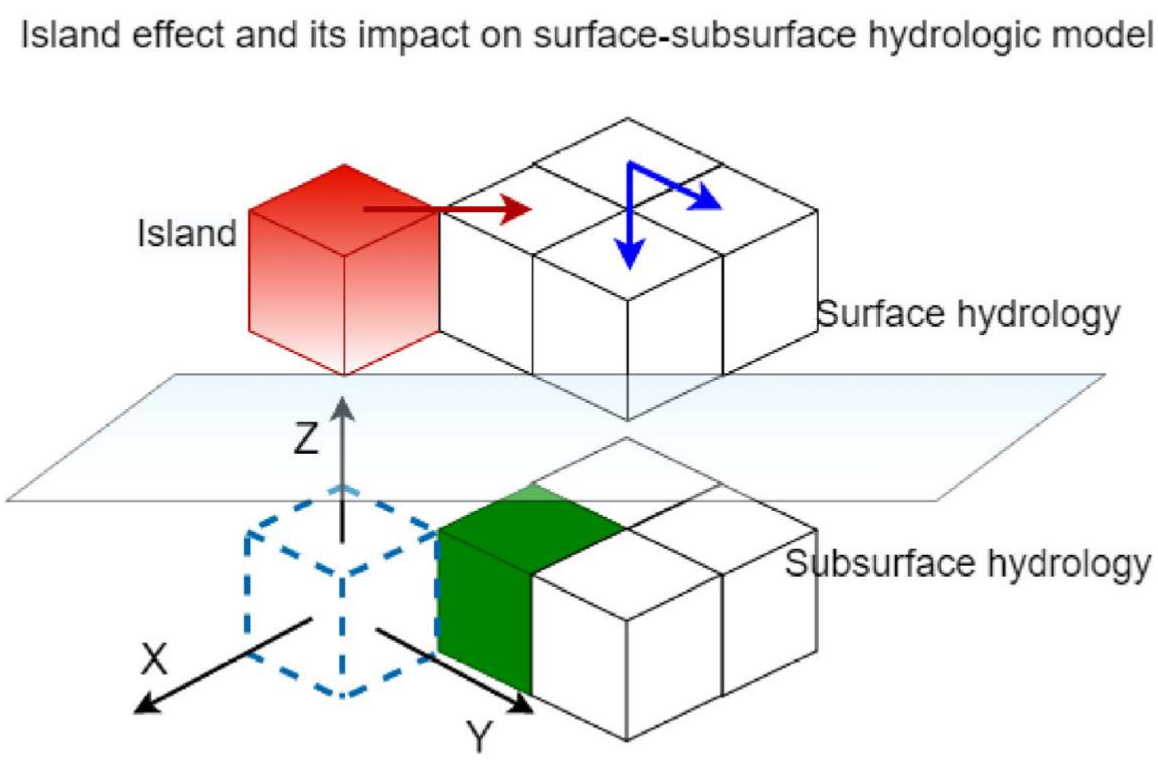
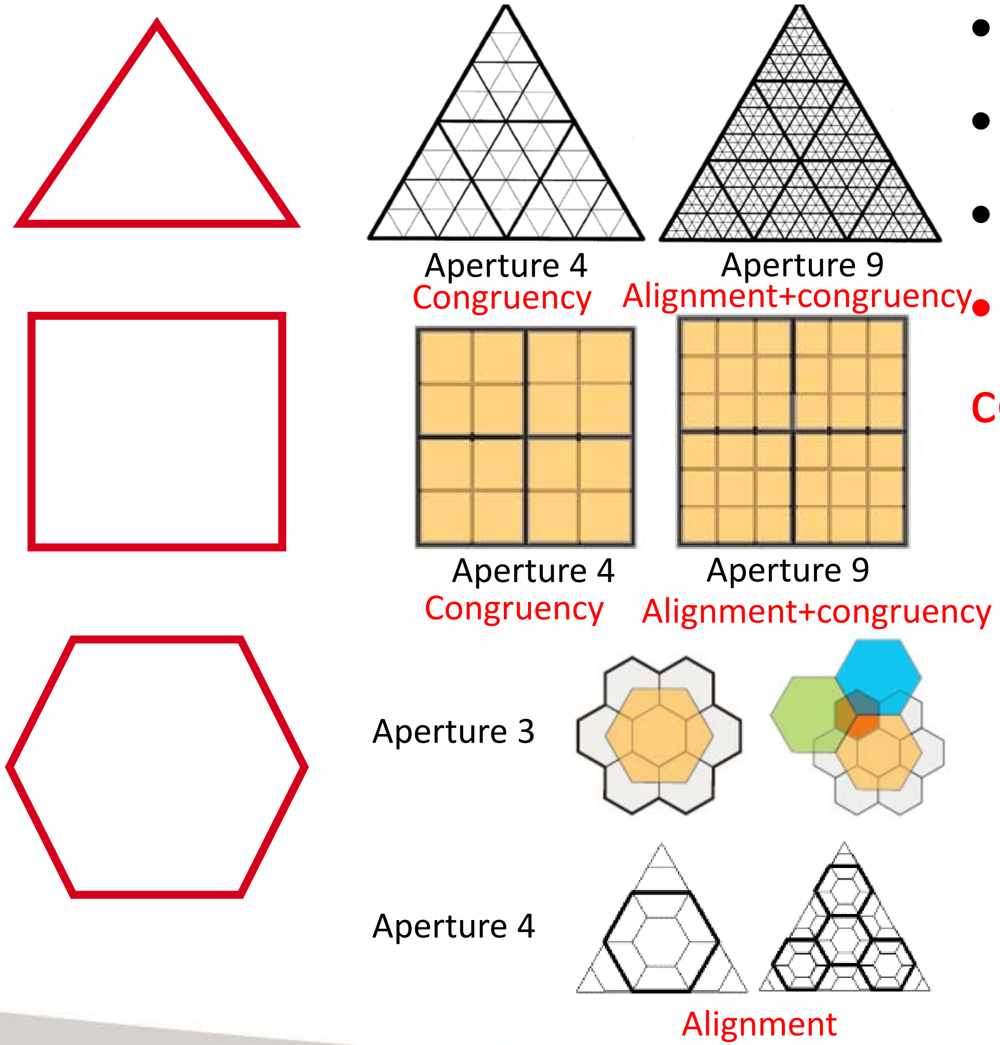


Fig. 1. Illustration of the island effect and its impact on coupled surface–subsurface hydrologic models. The red cube/cell is an island in the surface hydrology model and is connected through a diagonal path (red arrow). The blue arrows illustrate the differences between direct and diagonal neighbors. The dashed cube underneath the red cube cannot be modeled in a Cartesian grid-based subsurface hydrologic model because only the top face is connected with the red cube. The green cube is often not considered a "neighbor" of the dashed cube in the subsurface hydrologic models (Harbaugh, 2005; Langevin et al., 2017). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

❖ *Liao et al., 2020*

Five elements of constructing a DGGS

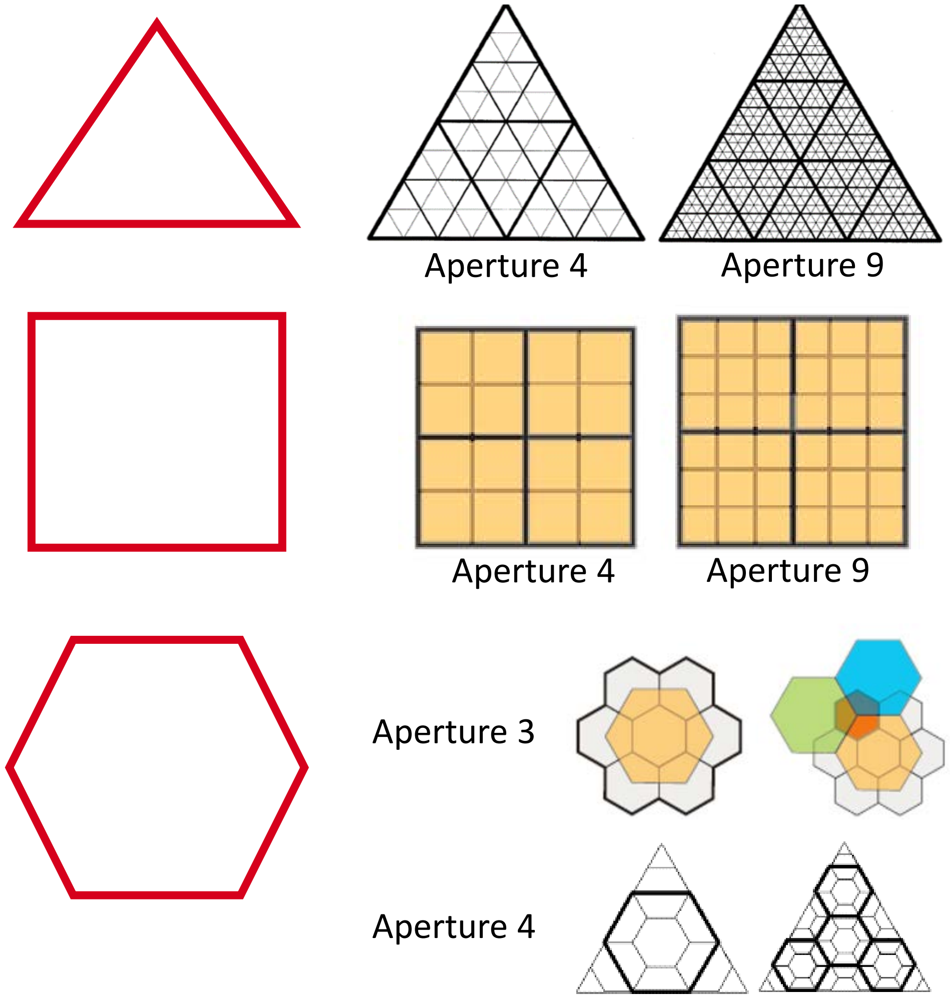
Cell geometry and aperture related



- Simple, regular geometry, spherical tiling
- Optimally compact/space-filling
- Uniform adjacency
- Hierarchical relationships (alignment and congruency)
  - Aperture is the refinement factor of a DGGS, meaning how many child cells each parent cell is subdivided into at the next resolution level.
  - Alignment is the property that the centroid of a parent cell coincides with the centroid of one of its child cells at the next finer resolution.
  - Congruency is the property that a parent cell can be subdivided into an integer number of child cells that fully cover it, with no overlaps and no gaps.

Five elements of constructing a DGGS

Cell geometry and aperture related



- Simple, regular geometry, spherical tiling
- Optimally compact/space-filling
- Uniform adjacency
- Hierarchical relationships (alignment and congruency)

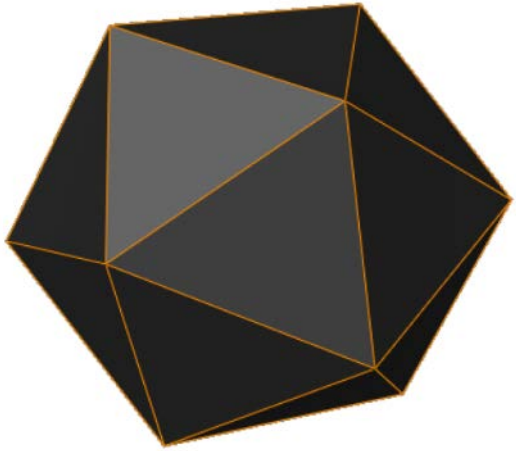
➢ monotonic convergence

The representing centroid is infinitely closer to the point to be modeled at a finer resolution

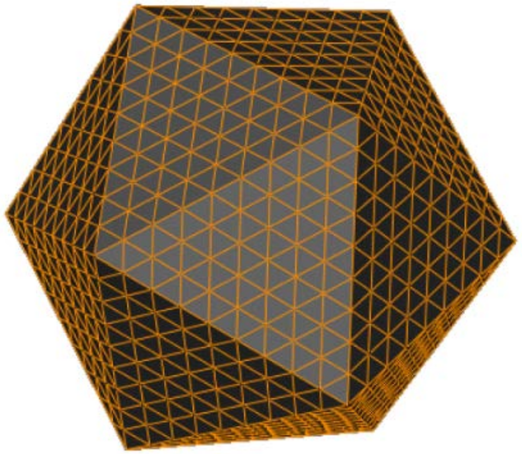
Five elements of constructing a DGGS

Transformation

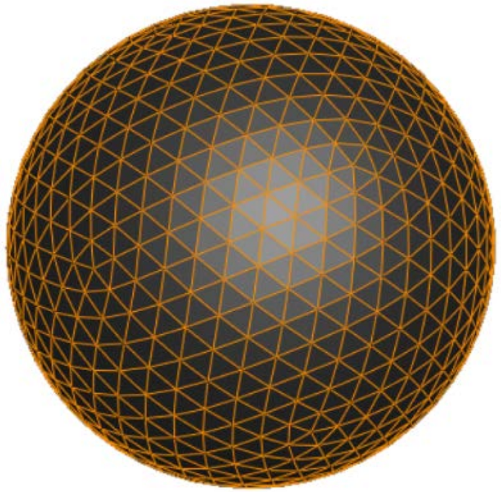
Method 1. Polyhedron projection



Planar faces of a polyhedron



Refined to an arbitrary resolution



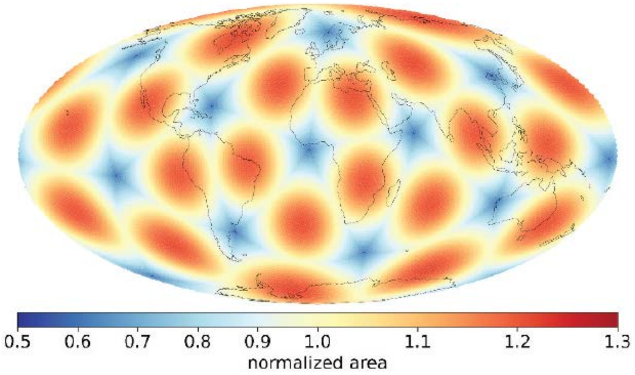
Project planar cells to spherical cells

Five elements of constructing a DGGS

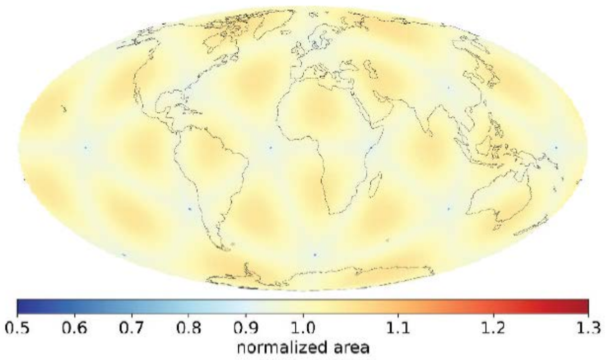
Transformation

We want equal-area grids!

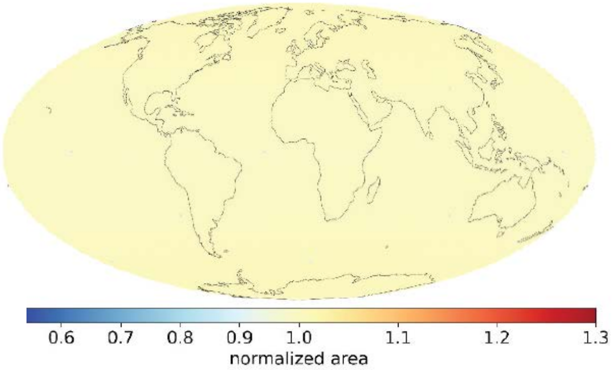
- Gnomonic projection (not equal area, cell shapes are well-preserved, used by Uber's H3)
- Fuller's Dymaxion projection (not equal area, somewhere between the Gnomonic projection and Snyder's equal area projection)
- Snyder's equal area polyhedral projection
- Rearranged hierarchical equal area isolatitude pixelization (rHEALPix, combines the Lambert cylindrical equal-area projection for the equatorial region and the Collignon equal-area projection for the poles)



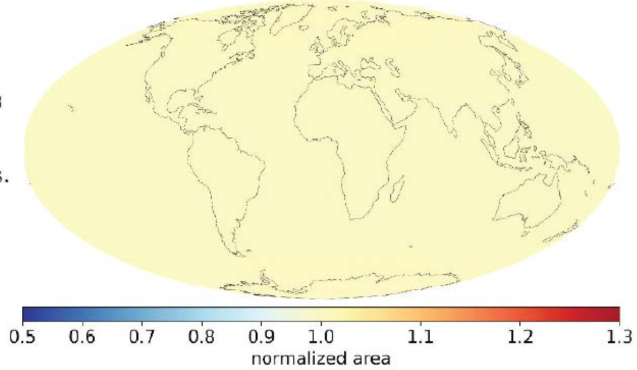
(a) Distribution of H3 area distortions.



(a) Distribution of DGGRID FULLER7H area distortions.



Distribution of DGGRID ISEA7H area distortions.



(a) Distribution of rHEALPix area distortions.

- *White et al., 1998*
- *Kmoch et al., 2022*

Five elements of constructing a DGGS

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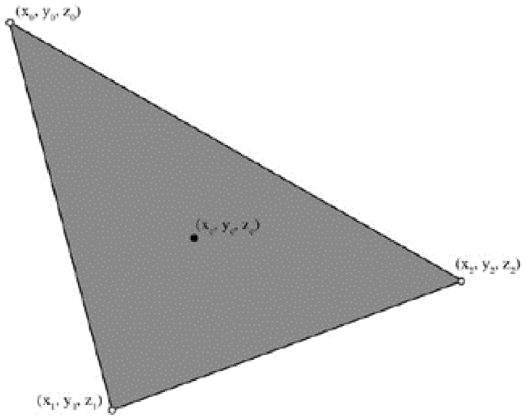
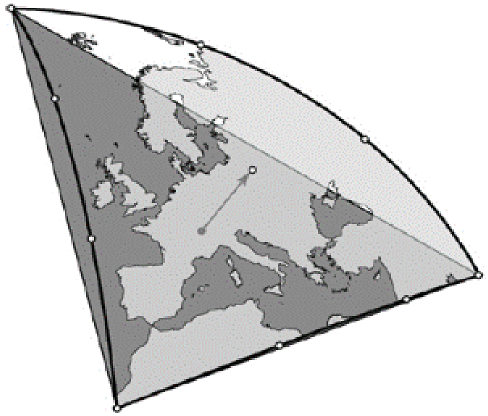
Transformation

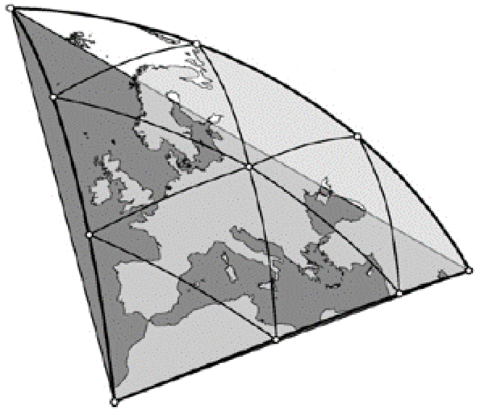
Method 2. Small-circle-based direct surface tessellations



Find center of planar faces



Project center point to sphere and split face sides with equal intervals



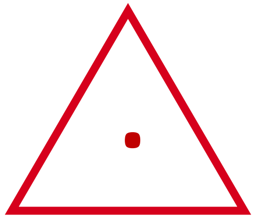
Connect points with arcs

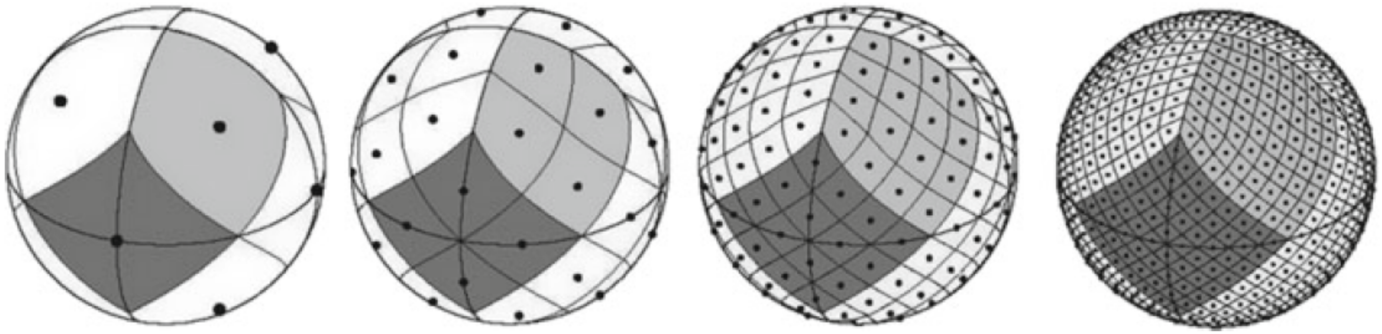
- *Song et al., 2002*
- *Sahr et al., 2003*

Five elements of constructing a DGGS

Cell reference point

- Each DGGS Cell must be referenced at its centroid.
- A centroid is the geodesic center of the surface area of a DGGS cell, which is also the only choice offering a systematic and consistent reference point for all cells regardless of their shapes.





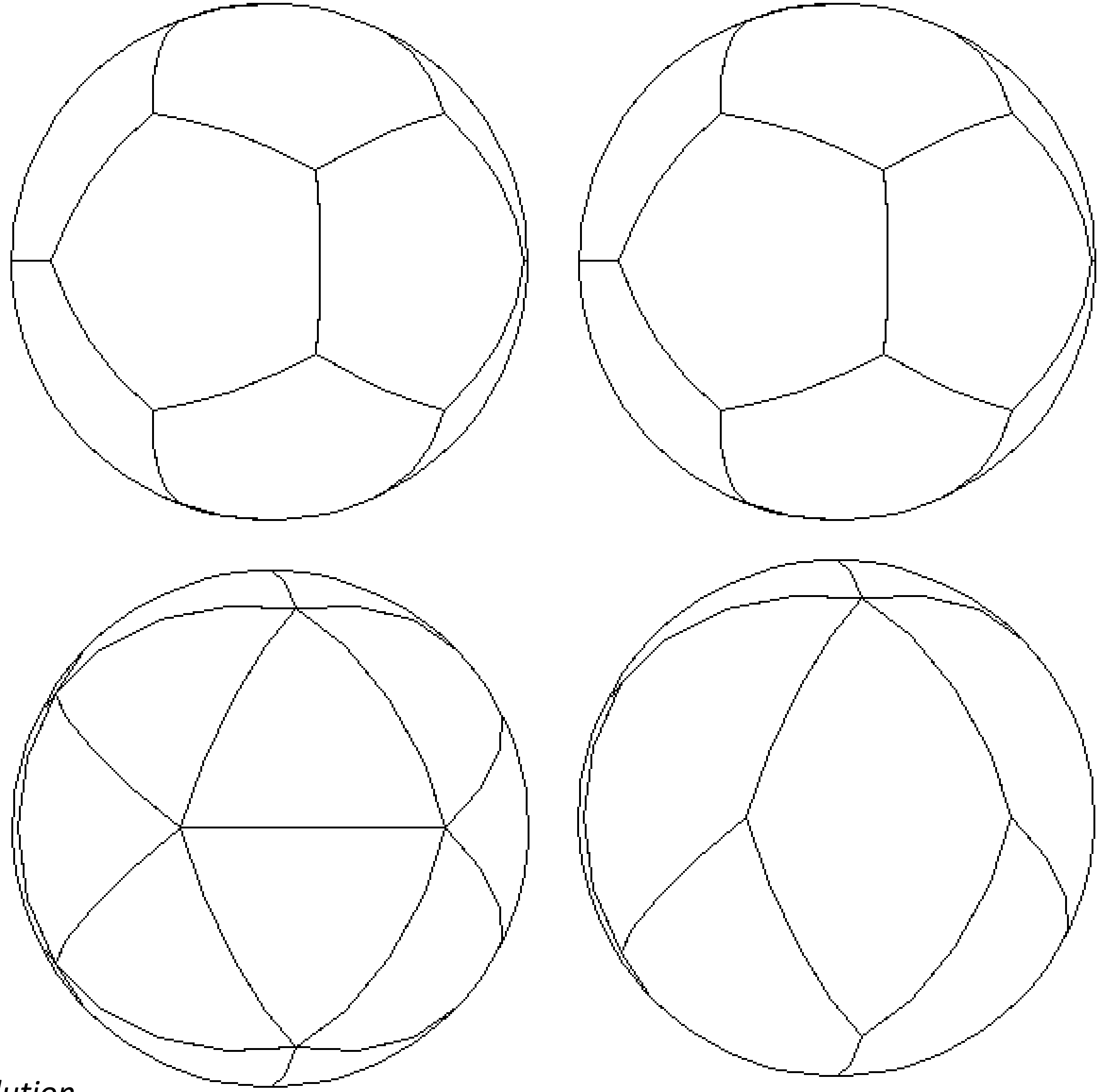
❖ *Gorski et al., 2005*

Other considerations of implementation

Nested resolution levels

Grid systems consist of a series of related grids at increasingly fine resolutions.

- **Single resolution computational grids are NOT sufficient to constitute a DGGS.**
- **Spatial data structures used to organize map tiles or optimize rapid spatial search CANNOT be considered to qualify as a DGGS in and of themselves.**



- *https://www.discreteglobalgrids.org/dggs-resolution*
- *http://docs.opengeospatial.org/as/15-104r5/15-104r5.html*

Other considerations of implementation

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Equal-area cells

- Equal area cells provide global grids with spatial units that (at multiple resolutions) have an equal probability of contributing to an analysis.

- Equal area cells also help to minimize the confounding effects of area variations in spatial analyses where the curved surface of the earth is the fundamental reference frame.

- With equal area partitioning, spatial analysis can be replicated consistently anywhere on the Earth independent of resolution or scale.

- Equal-area polyhedron projection OR small-circle-based direct surface tessellations

❖ *https://docs.ogc.org/as/15-104r5/15-104r5.html*

Other considerations of implementation

Unique index for each cell

- **A DGGS shall use a spatial referencing method to assign a unique spatial reference or index to each DGGS cell across the entire DGGS Domain.**

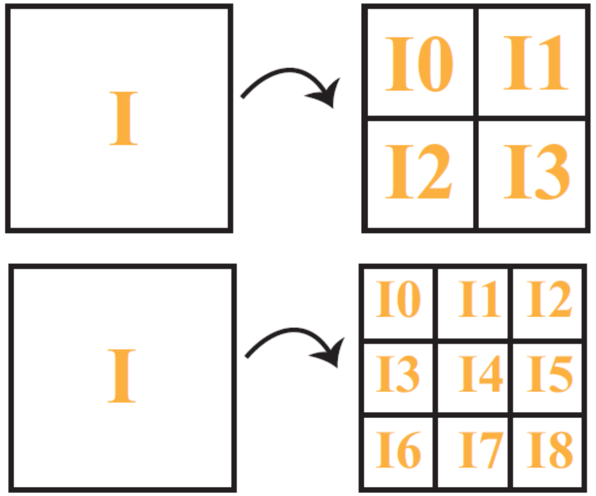
- **A DGGS shall define a unique index to address each cell across all defined spatial resolutions.**

- **This requirement sets the stage for data integration, information queries, and largely determines the efficiency of the DGGS.**

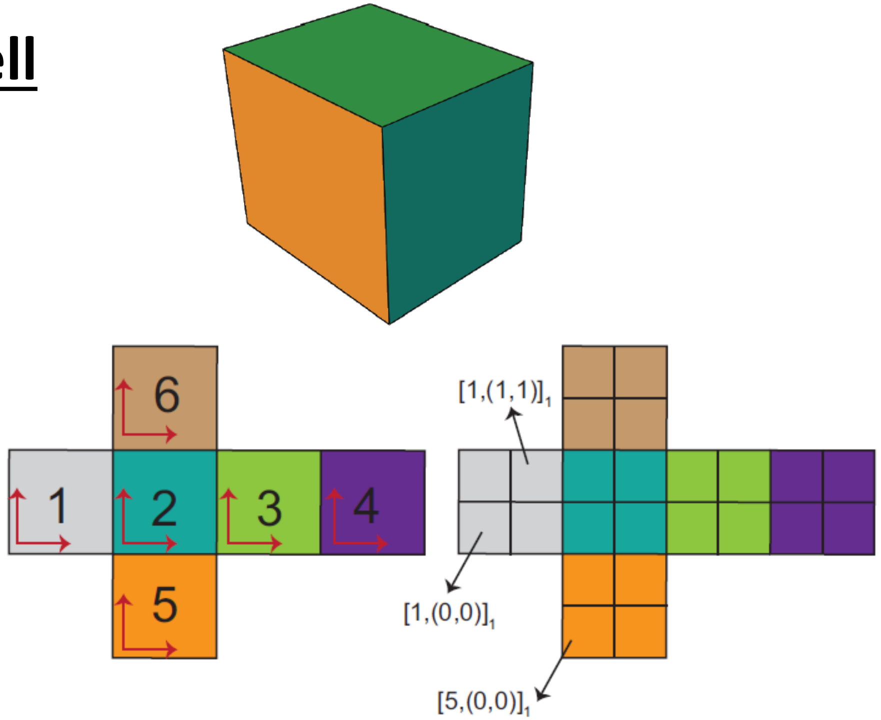
- *https://docs.ogc.org/as/15-104r5/15-104r5.html*

Other considerations of implementation

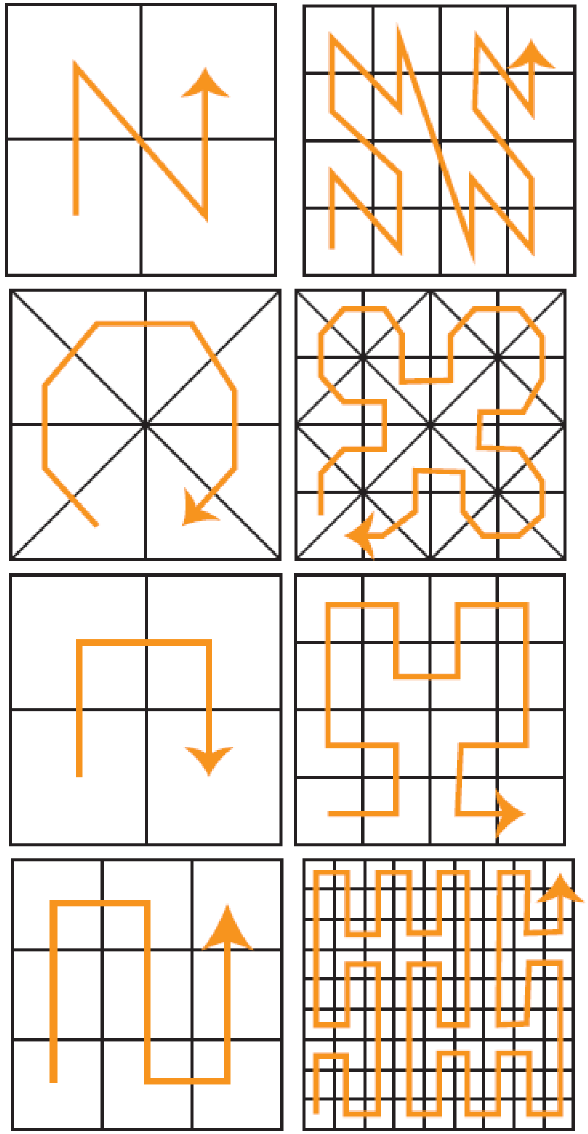
Unique index for each cell



Hierarchy-based



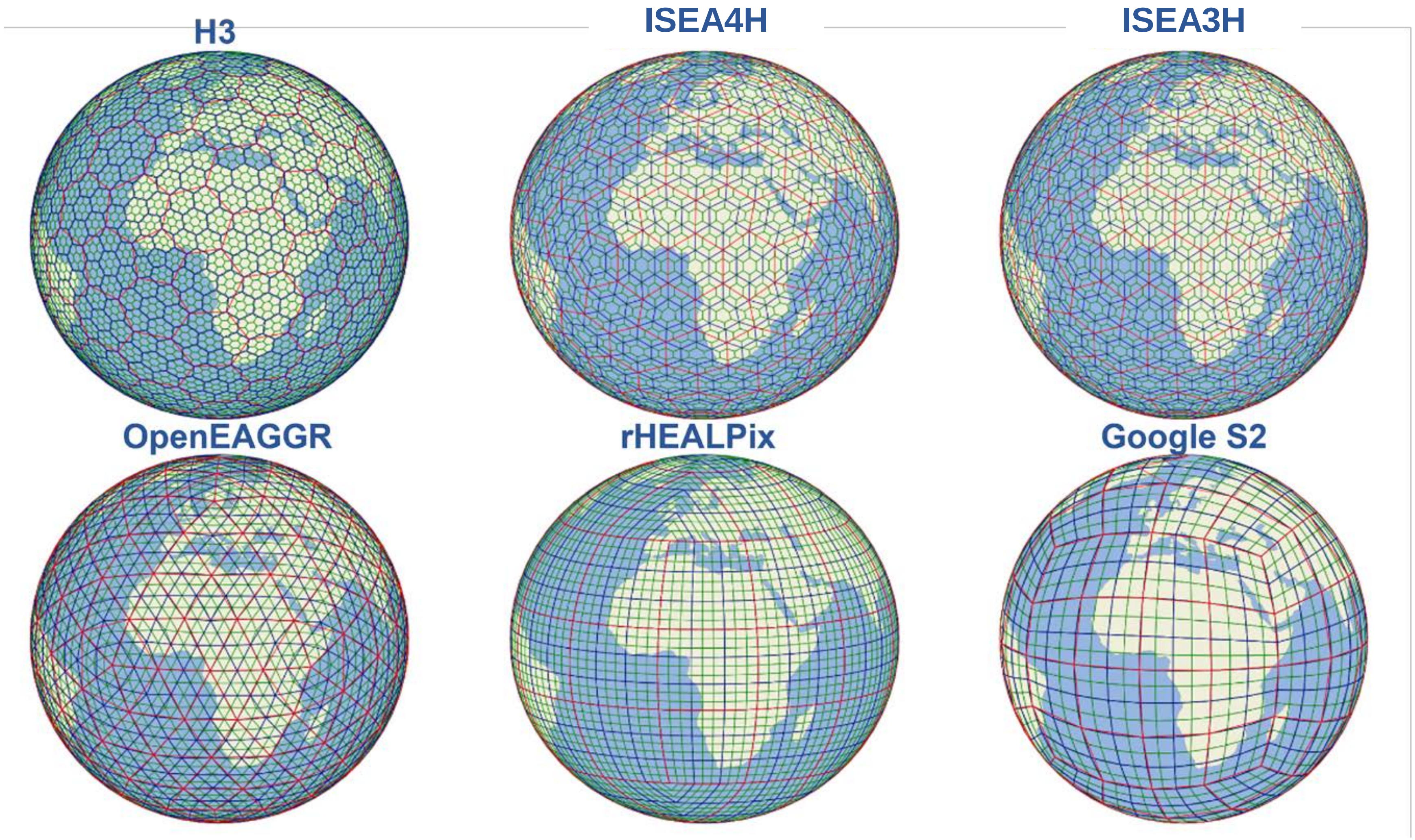
Coordinate-based



Space-filling curve (SFC) based

❖ *Mahdavi-Amiri et al., 2015*

DGGS Alternatives



DGGS Alternatives

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Name (Abbreviation)	Polyhedron	Cell Shape	Aperture	Direct Surface/Projected Polyhedron Tessellation	Ref.
Quaternary Triangular Mesh (QTM)	Octahedron	Triangle	4	Direct spherical subdivision	Dutton (1989)
Icosahedral Snyder Equal Area Aperture 3 Hexagon (ISEA3H)	Icosahedron	Hexagon	3	Icosahedral Snyder equal area projection	Sahr and White (1998)
Song's Small Circle Subdivision	Icosahedron	Triangle	4 or 9	Equal area small circle subdivision	Song et al. (2002)
Hierarchical Equal Area isoLatitude PIXelation (HEALPix)	Rhombic dodecahedron	Quadrilateral	4	Lambert cylindrical equal area projection and Collignon equal area projection	Gorski et al. (2005)
Octahedral Aperture 3 Hexagonal Discrete Global Grids (OA3HDGG)	Octahedron	Hexagon	3	Snyder's equal area projection	Vince (2006)
Octahedral Aperture 4 Hexagonal Discrete Global Grids (OA4HDGG)	Octahedron	Hexagon	4	Snyder's equal area projection	Ben et al. (2010)
Crusta	30-sided Polyhedron	Quadrilateral	4	Direct subdivision on the geoid	Bernardin et al. (2010)
Ellipsoidal Cube Map (ECM)	Circumscribing Cube	Quadrilateral	4	Quadrilateralized spherical cube projection	Lambers and Kolb (2012)
Hexagonal Quaternary Balanced Structure (HQBS)	Icosahedron	Hexagon	4	Icosahedral Snyder equal area projection	Tong et al. (2012)
One-to-Two Digital Earth	Cube	Quadrilateral	2	Roşca and Plonka's equal-area projection	Mahdavi-Amiri et al. (2013)
PlanetRisk Discrete Global Grid System	Icosahedron	Hexagon	3, 4, and 7	Icosahedral Snyder equal area projection	Sahr et al. (2015)
Rearranged hierarchical equal area isolatitude pixelization (rHEALPix)	Cube	Circle, triangle, and quadrilateral	9	Lambert cylindrical equal area projection and Collignon equal area projection	Gibb (2016)
Disdyakis Triacontahedron (DT) DGGS	Disdyakis Triacontahedron	Triangle	4	Modified Slice and Dice projection	Hall et al. (2020)

State-of-the-art DGGS implementations

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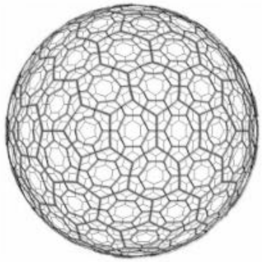
- https://github.com/sahrk/DGGRID
- https://healpix.sourceforge.io/
- https://github.com/cds-astro/cds-healpix-rust/
- https://github.com/JuliaAstro/Healpix.jl
- https://h3geo.org/
- https://s2geometry.io/
- https://github.com/ecere/dggal and https://dggal.org/
- https://a5geo.org/
- https://github.com/GeoPlegma/GeoPlegma
- https://github.com/manaakiwhenua/rhealpixdggs-py
- https://github.com/riskaware-ltd/open-eaggr
- https://github.com/mocnik-science/geogrid

OpenEAGGR

STCL



DGGRID version 7.0

H3

HEALPix

"GIS slices the world into layers of information; DGGS brings that information together again."

- *https://www.linkedin.com/pulse/gis-slices-world-layers-information-perry-r-peterson/*

Key benefits of DGGS in real-world applications

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Integration of Multi-Source Data

- A DGGS provides a shared spatial framework so heterogeneous sources can be integrated consistently, especially when they have different resolutions, footprints, coordinate systems, temporal frequency, and data formats.
- **Example:** integrating multi-source greenhouse gas inventories, monitoring data, and field observations in one analysis grid.

A Standard 'Data Bucket' – Congruent Geography (Dr. Goodchild, 2018)

- DGGS cells act like standardized geographic containers with persistent IDs that make it easier to attach observations, metadata, or assets to a stable spatial unit over time.
- **Example**: standardizing environmental variables like temperature, wind speed, humidity, forest cover, elevation, and treatment history into DGGS cells, creating a ready-to-analyze dataset for predicting forest insect population dynamics.

Comparisons Across Space and Time

- Because DGGS cells are equal area, comparisons across regions become much more meaningful since each unit represents the same amount of surface area. This supports fair intensity mapping across large extents.
- **Example**: comparing deforestation rate, flood exposure, or species occurrence density across latitude bands without spatial bias.

Key benefits of DGGS in real-world applications

Quantitative Spatial Resolution

- Each cell represents a precisely defined unit of area, which allows consistent reporting of metrics per area and supports reproducibility. DGGS has inherently defined resolutions that can be associated with cell index.
- **Example**: for methane emissions, instead of using vague reporting scales like basin level, urban level, or regional level, DGGS enables numeric spatial resolution reporting based on a known cell area.

Multiple Granularities for Analysis and Reporting

- The multi-resolution structure supports switching between detailed analysis and broader overviews without rebuilding the dataset. DGGS makes it easy to aggregate information from fine units into larger ones while preserving spatial meaning.
- **Example**: using fine cells for landslide susceptibility near roads, medium cells for municipal planning, and coarse cells for national-level hazard screening.

Key benefits of DGGS in real-world applications

Precise Hotspot Tracking and Trend Monitoring

- Because DGGS cells are fixed in location, repeated measurements line up cleanly through time. This supports trend analysis, change detection, and long-term monitoring programs without the shifting boundaries that can occur with some ad hoc gridding approaches.
- **Example:** tracking urban heat island hotspots year over year, monitoring invasive species spread, etc.

Global Vision, Especially for High Latitude Regions

- DGGS provides consistent global coverage and minimizes the spatial distortion that becomes severe near the poles, which makes it especially valuable for monitoring Arctic and other high-latitude environments.
- **Example**: supporting long-term tracking of permafrost dynamics and permafrost-related methane emissions across remote regions with sparse ground observations.

Application of DGGS in previous literature

UNIVERSITY OF CALGARY

I. Spherical cell bins to aggregate geospatial data without spatial bias

PLOS | BIOLOGY

ESSAY

Biodiversity data integration—the significance of data resolution and domain

Christian König[1]*, Patrick Weigelt[1], Julian Schrader[1], Amanda Taylor[1], Jens Kattge[2,3], Holger Kreft[1,4]

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Abstract

Articles

A Global Assessment of Amphibian Taxonomic Effort and Expertise

ANA S. L. RODRIGUES, CLAUDIA L. GRAY, BEN J. CROWTER, ROBERT M. EWERS, SIMON N. STUART, TONY WHITTEN, AND ANDREA MANICA

A Virtual Globe Using a Discrete Global Grid System to Illustrate the Modifiable Areal Unit Problem

Paulo Raposo, Anthony C. Robinson, Randall Brown

Cartographica: The International Journal for Geographic Information and Geovisualization, Volume 54, Number 1, Spring 2019, pp. 51-62 (Article)

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Mapping Global Diversity Patterns for Migratory Birds

Marius Somveille[1,2]*, Andrea Manica[1], Stuart H. M. Butchart[3], Ana S. L. Rodrigues[2]

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Application of DGGS in previous literature

UNIVERSITY OF CALGARY

II. A data fabric for heterogeneous data integration and multi-scale data queries

BIG EARTH DATA
https://doi.org/10.1080/20964471.2021.1965370
Taylor & Francis
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Intelligent Geospatial Maritime Risk Analytics Using The Discrete Global Grid System

Andrew Rawson[a], Zoheir Sabeur[b] and Mario Brito[c]

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CARTOGRAPHY AND GEOGRAPHIC INFORMATION SCIENCE
https://doi.org/10.1080/15230406.2021.1966648
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Integration of heterogeneous terrain data into Discrete Global Grid Systems

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DATA DESCRIPTOR

Eco-ISEA3H, a machine learning ready spatial database for ecometric and species distribution modeling

Michael F. Mechenich[1]✉ & Indrė Žliobaitė[1,2]

isprs International Journal of *Geo-Information*
MDPI

Article

Multi-Scale Flood Mapping under Climate Change Scenarios in Hexagonal Discrete Global Grids

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Application of DGGS in previous literature

UNIVERSITY OF CALGARY

III. Bottom-up predictive models

1 of 23

AGILE Association of Geographic Information Laboratories in Europe

Integrating cellular automata and discrete global grid systems: a case study into wildfire modelling

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Planar and spherical hierarchical, multi-resolution cellular automata

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A video demo
OGC Federated Marine Spatial Data Infrastructure (FMSDI) Pilot - D121 Data Fusion Server

❖ *https://www.youtube.com/watch?v=GMd3SyIu_7M*

D121 Data Fusion Server 2

Using Discrete Global Grid System

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