RÉPUBLIQUE FRANÇAISE
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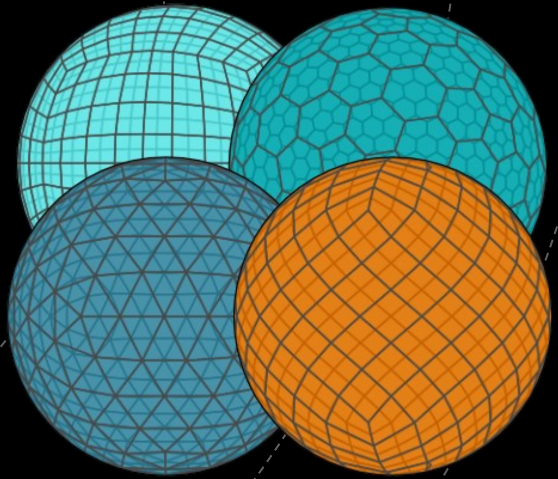
CENTRE NATIONAL D'ÉTUDES SPATIALES

Webinaire DGGS

Introduction COMET



comet
La communauté d'experts SIL
Architecture des Systèmes Informatiques et Génie Logiciel

CREALAB

26/06/2026

COMET

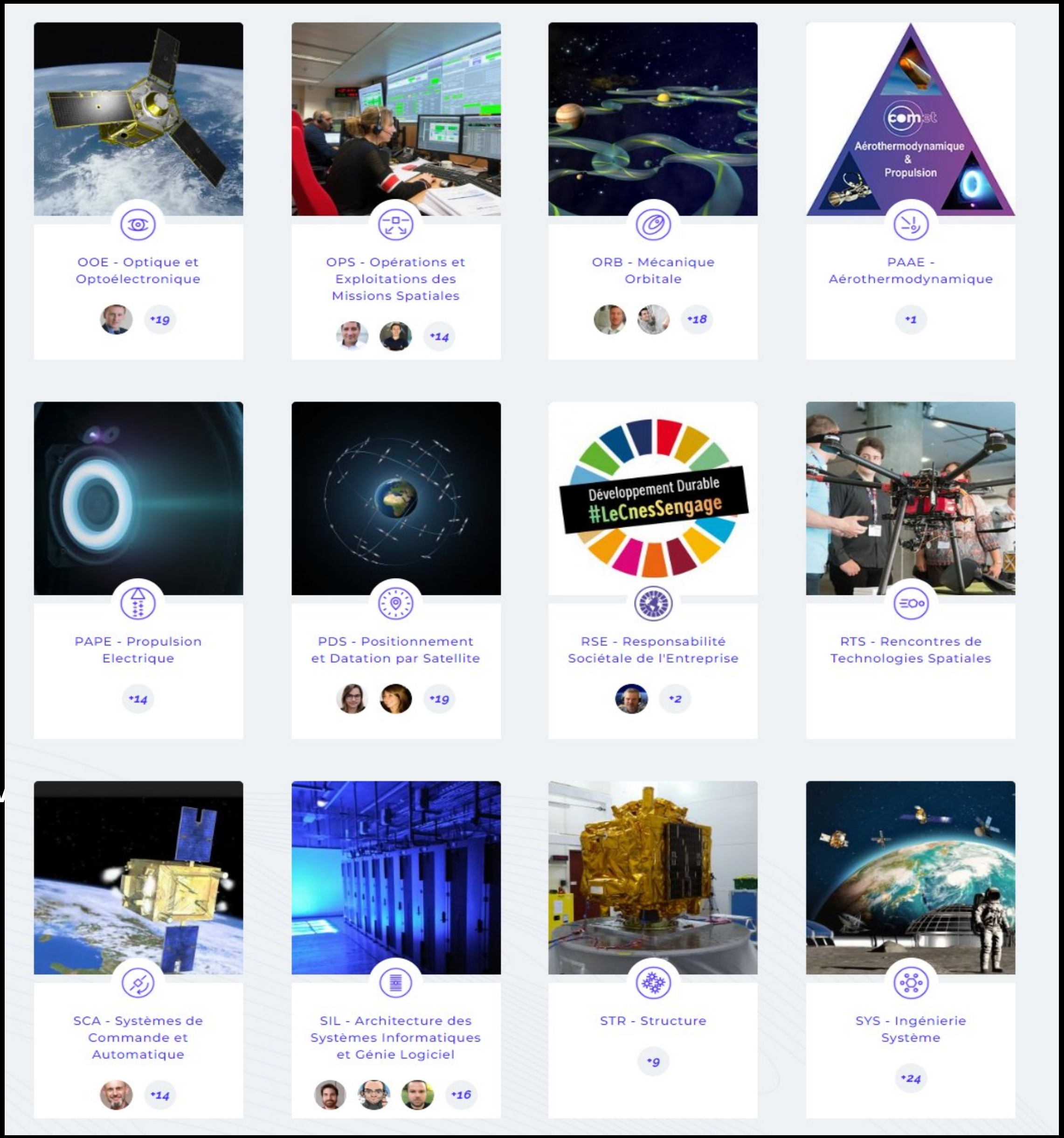
COMmunauté d'ExperTs

Quelques chiffres :

- Création en **1998** à l'initiative du CNES
- **23** Communautés
- **3000** Experts (dont env. 2000 externes)
- Organisation de 60 évènements/an

Les missions/objectifs :

- Favoriser **l'ouverture** du spatial aux autres secteurs d'activ
- Contribuer à l'**expertise** et l'**innovation**
- Favoriser la **collaboration**
- Produire, **partager** les connaissances



COMET

Structuration d'une COMET

une EQUIPE

ANIMATEUR et CO-ANIMATEURS
WEBMASTER

Un BUREAU

CNES,
industrie et recherche,
agences

Une COMMUNAUTE

Membres actifs, abonnés, visiteurs

Organise les évènements, les bureaux, gére la communauté.

Se regroupe, porte des sujets & évènements

Suit l'actualité COMET, reçoit les newsletters COMET, participe aux évènements.

COMET SIL

Poncet Maurice
Petiton Julien

11 membres

~450 adhérents
~170 abonnés

COMET

Comment participer aux COMET

Que vous soyez simple visiteur, participant occasionnel ou membre actif, n'hésitez pas à vous inscrire aux évènements sur le site : **https://www.comet-cnes.fr/**

Je suis une participante occasionnelle

Consultez régulièrement le CALENDRIER de tous les EVENEMENTS sur le site COMET, sélectionnez votre événement et inscrivez-vous.
Pas besoin d'autres formalités !

Ouvert à tous!

Je souhaite être informé des activités sur mes centres d'intérêt, je suis une ou plusieurs communautés

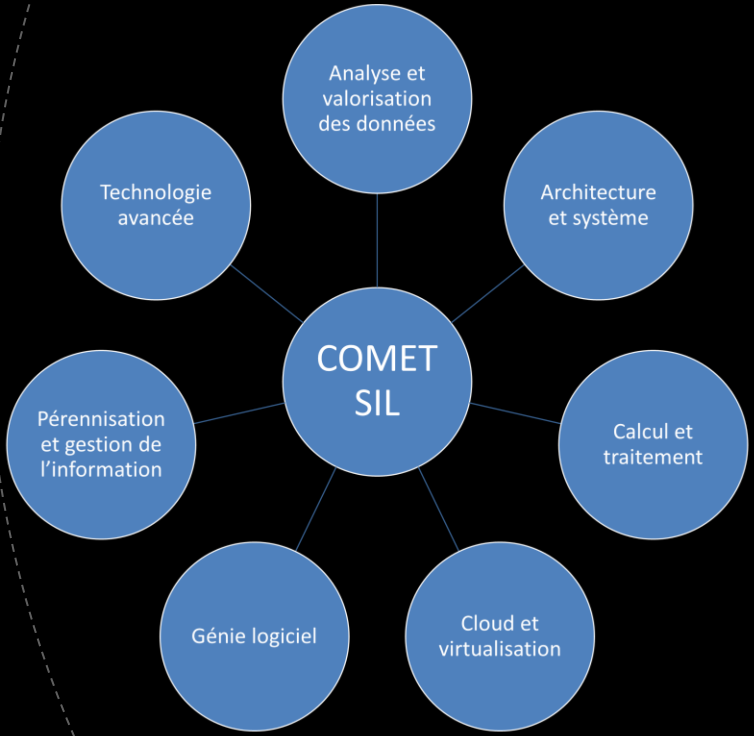
Allez sur la page des COMET qui vous intéresse et **renseignez votre email**.
Vous serez informés des futurs événements organisés par vos COMET d'intérêt, pensez à activez cette **alerte email** dans chacune de vos communautés d'intêret

Je suis expert d'un des domaines organisés en communauté et je veux devenir Membre Adhérent d'une communauté

Allez sur la page de la COMET couvrant vos expertises et sélectionnez Adhérer à la Communauté

SIL – ARCHITECTURE DES SYSTÈMES INFORMATIQUES ET GÉNIE LOGICIEL

https://www.comet-cnes.fr/sil



17 juin 2025
de 09H00 à 17H00
EN SAVOIR +

2eme journée de la communauté d'Architecture d'Entreprise du Sud-Ouest

SIL - Architecture des Systèmes Informatiques et Génie Logiciel

Nous avons le plaisir de vous inviter à une deuxième journée de la Communauté d'Architecture d'Entreprise du Sud-Ouest le 17 Juin. Cette journée portera le thème de : « Les activités de l'architecte, la gestion de la connaissance et l'outillage » L'évènement se déroulera dans les locaux de la FFT à Balma. Plan d'accès : https://maps.app.goo.gl/kRvEDxW9mioXfrzR9 Au cours de cette journée, nous avons prévu une succession de présentations de nos retours d'expérience entrecoupées de moments libres ...

25 - 27 février 2025
de 09H00 à 17H00
EN SAVOIR +

CNES ONERA Workshop on Earth-space radiowave Propagation

SIL - Architecture des Systèmes Informatiques et Génie Logiciel

The objective of this workshop is to present research activities concerning Earth-space radiowave propagation. It will address the following applications: NTN (Non Terrestrial Networks including mega-constellations), mobile communications for 5G and 6G, GNSS (Global Navigation Satellite Systems), remote sensing and radio-occultation. The targeted frequency bands range from HF to EHF, that is from 3 MHz to 300 GHz. Issues related to standardization, e.g. for ITU-R (International Telecommunications Union – Radiocommunications sector) and new frequency ...

15 septembre 2025
de 08H30 à 18H00
EN SAVOIR +

KOSMOS DAY 2025

SIL - Architecture des Systèmes Informatiques et Génie Logiciel

KOSMOS DAY 2025KOSMOS (Kit for Onboard Software in Modular Oriented Systems / Kit pour Logiciels de Vol embarqués dans des Systèmes Modulaires), anciennement appelé LVCUGEN, est une infrastructure logicielle générique permettant de ne pas redémarrer de zéro à chaque nouveau développement d'un Logiciel de Vol pour une nouvelle mission spatiale.{"preview_thumbnail":"/sites/default/files/styles/video_embed_wysiwyg_preview/public/video_thumbnails/4TdfrHzAN5Q.jpg?itok=7HgGAq12","video_url":"https://www.youtube.com/watch?v=4TdfrHzAN5Q","settings":{"responsive":true,"width":"854","height":"480","autoplay":true,"title_format":"@provider | @title","title_fallback":true},"settings_summary":["Embedded Video (Adaptatif, autoplaying)."]}https://www.youtube.com/watch?v=4TdfrHzAN5QAu fil des ans, les utilisateurs de KOSMOS se sont multipliés dans l'écosystème spatial français et ...

2 octobre 2025
de 09H00 à 18H00
EN SAVOIR +

Forum Usine Logicielle 2025

SIL - Architecture des Systèmes Informatiques et Génie Logiciel

Nous avons le plaisir de vous inviter au Forum annuel de l'Usine Logicielle du CNES. Ce rendez-vous est conçu pour créer des liens plus étroits pour mieux collaborer, capter vos besoins et vous communiquer les dernières actualités ! Au programme : Accueil et présentation des services Bilan et perspectives Démonstration des fonctionnalités et cas d'usage Les components GitlabCI Git+LFS dans Gitlab Runners GitlabCI dynamiques Etc... Sessions interactives de questions-réponses Pourquoi participer ? Echanges directs : créez un lien avec nos équipes et découvrez comment améliorer ...

20 novembre 2025
de 08H30 à 17H00
EN SAVOIR +

Agilité & DevSecOps - Où en sommes-nous ?

SIL - Architecture des Systèmes Informatiques et Génie Logiciel

Agilité & DevSecOps - Où en sommes-nous ?Au travers de divers témoignages et moments d'échanges, faisons le bilan de la mise en oeuvre de l'agilité et du Dev(Sec)Ops dans les organismes publics et privés. Objectifs de l'ÉvénementExplorer les avancées récentes en matière d'Agilité et de Dev(Sec)Ops.Discuter des défis et des opportunités liées à la transformation Agile dans les établissements publics et privés.Partager des retours d'expérience sur l'agilité à l'échelle.Identifier les bonnes ...

26 novembre 2025
de 08H30 à 17H00
EN SAVOIR +

Cap sur l'IA : l'ingénierie système en orbite !

SYS - Ingénierie Système

Cap sur l'IA : l'ingénierie système en orbite avec Evènement COMET SYS X AFIS – Étape toulousaine de la Journée Thématique itinéranteLes COMET SYS et SIL en collaboration avec L'AFIS vous invitent à une journée d'échanges, de présentations et de débats. Experts industriels, académiques et institutionnels partageront leur vision d'une ingénierie système "augmentée" par l'IA, au service des grands projets technologiques d'aujourd'hui et de demain.Le mercredi 26 novembre, à la Ligue Occitanie ...

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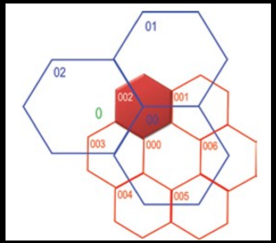
DGGS INTRODUCTION WEBINAIRE

DGGS OU DGGRS ?

« Les systèmes de grilles globales discrètes (DGGS, Discrete Global Grid System) proposent une nouvelle manière d'organiser, de stocker et d'analyser des données spatio-temporelles.
Un système de référence (RS, Reference System) a été incorporé au cœur du DGGS. » *iso.org*

ISO



« Un DGGS est un système de référence spatiale qui utilise une tessellation hiérarchique de cellules pour partitionner et adresser le globe. » *OGC definition*

Open Geospatial Consortium

POURQUOI LA COMMUNAUTÉ OT S'INTÉRESSE AU DGGS?

Croissance exponentielle des données dans le domaine de l'observation de la Terre,

Les coûts de stockage et de calcul de plus en plus onéreux (achat de matérielle),

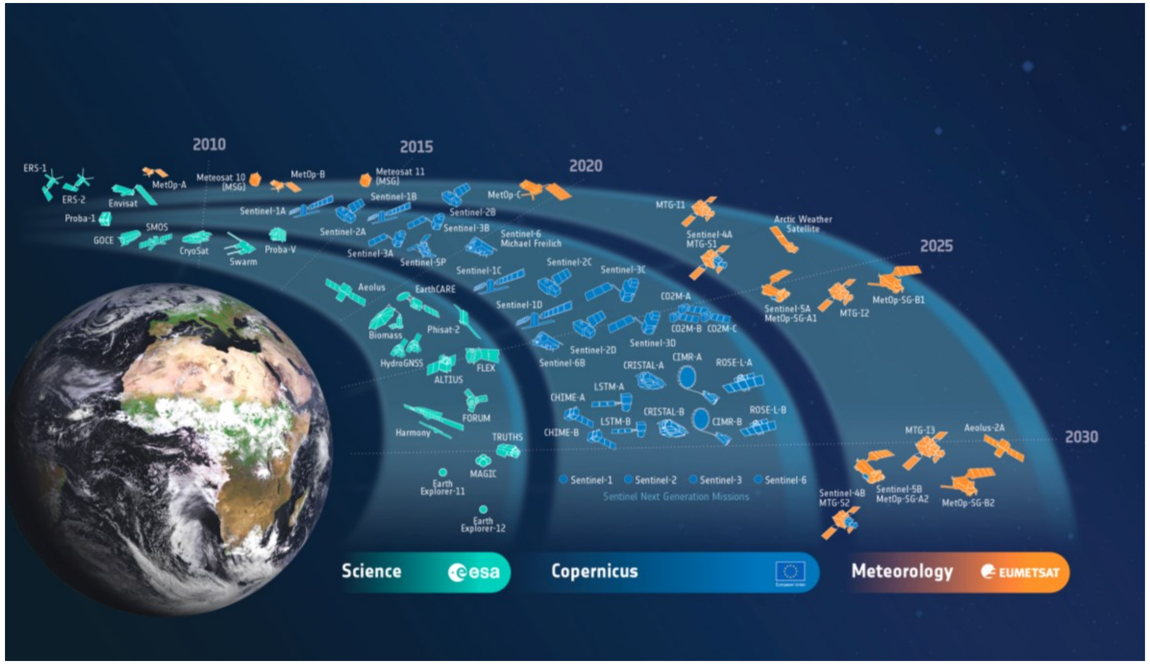
La mise à disposition de plus de ressources va à l'encontre des nouveaux enjeux environnementaux,

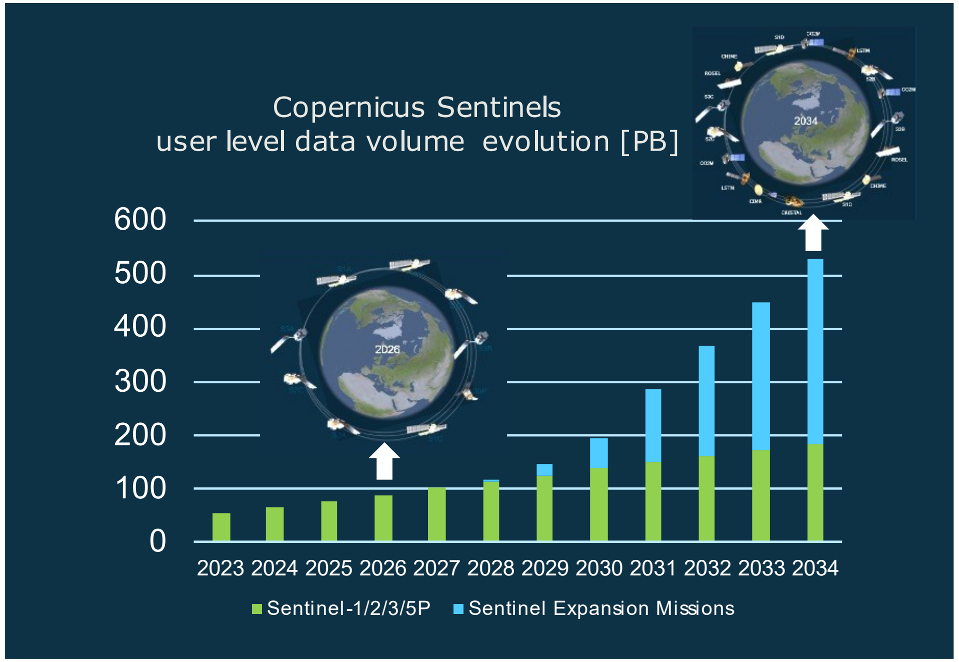
Démocratisation de l'IA nécessite l'ingestion & agrégation massive de données afin d'optimiser les modèles.

Les DGGS sont potentiellement identifiés comme outil/format pouvant répondre à ces dernières.

Pour cela, le CNES a initié des études avec l'Ifremer, Geomatys & CS Group.

Why DGGS ?





Exponential number of missions (each with its grid)

Exponential Volume of Data

=> Provide common indexing scheme and a homogenic framework for earth analysis

Enhancing Earth Observation with DGGS

Grid4Earth Consortium

Introduction to DGGS

- Historical context and Motivation: Current challenges
- Definition: Discrete Global Grid Systems (DGGS)
- Purpose: Uniform spatial representation for geospatial data
- Different types of DGGS (hexagonal, triangular, square grids)

DGGS: Historical context and development

- Early developments
- Emergence of DGGS
- Standardization and uptake
- Emergence of new use cases
- Future directions

1960s-1980s: Initial concepts of global grid systems arise, motivated by geospatial challenges.

1990s-2000s: Advancements in global spatial data systems lead to the concept of hierarchical grids. HEALPix introduced for astrophysics, marking a significant milestone for DGGS-like approaches.

2010s: OGC begins formalizing DGGS standards to ensure interoperability.

2020s: DGGS applications expand into Earth observation, environmental monitoring, and beyond.

> 2021: Increasing adoption in SAR and optical satellite processing. Exploring hybrid approaches with data formats like Zarr for efficiency and scalability.

Motivation – Challenges in data representation with Data cubes

xarray.Dataset

▸ Dimensions: (**time**: 39, **latitude**: 2041, **longitude**: 4320, **elevation**: 50)

▾ Coordinates:

elevation	(elevation)	float32	-5.728e+03 -5.275e+...
latitude	(latitude)	float32	-80.0 -79.92 -79.83 ......
longitude	(longitude)	float32	-180.0 -179.9 ... 179....
time	(time)	datetime64[ns]	2021-07-01 ... 2024-...

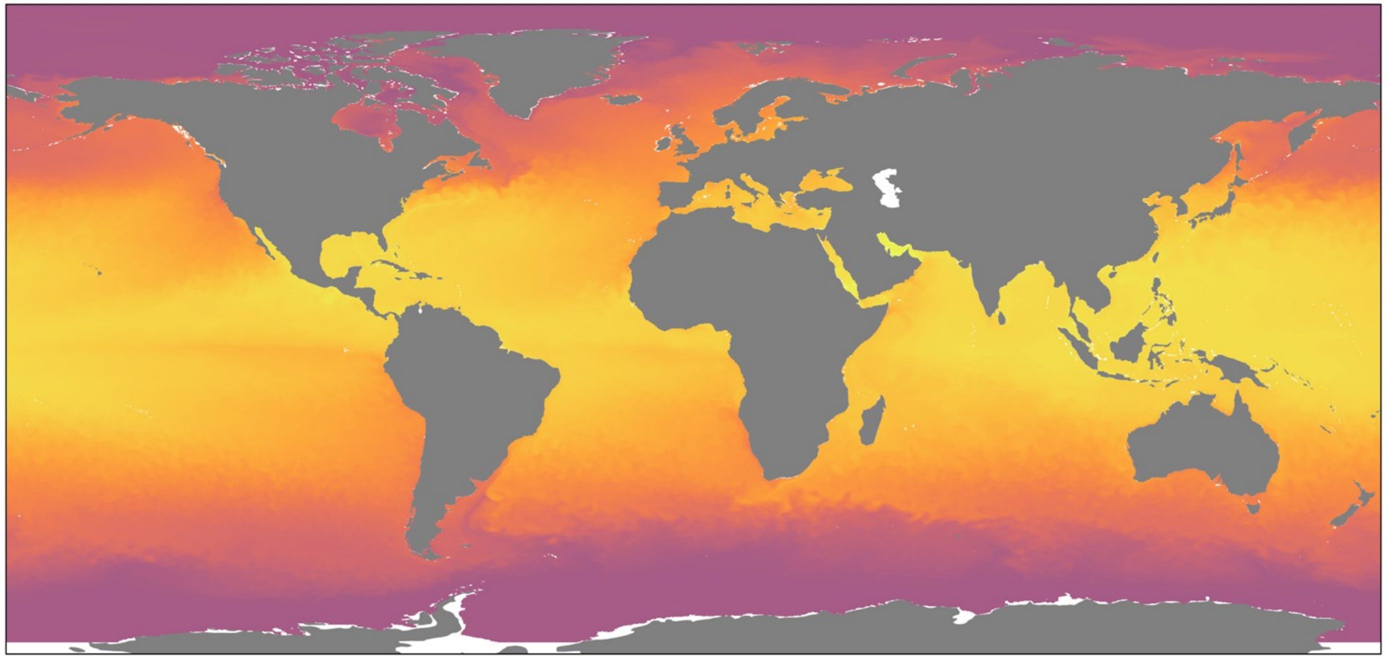
▾ Data variables:

bottomT	(time, latitude, longitude)	float64	dask.array<chunksiz...
mlotst	(time, latitude, longitude)	float64	dask.array<chunksiz...
siconc	(time, latitude, longitude)	float64	dask.array<chunksiz...
sithick	(time, latitude, longitude)	float64	dask.array<chunksiz...
so	(time, elevation, latitude, longitude)	float64	dask.array<chunksiz...
thetao	(time, elevation, latitude, longitude)	float64	dask.array<chunksiz...
uo	(time, elevation, latitude, longitude)	float64	dask.array<chunksiz...
usi	(time, latitude, longitude)	float64	dask.array<chunksiz...
vo	(time, elevation, latitude, longitude)	float64	dask.array<chunksiz...
vsi	(time, latitude, longitude)	float64	dask.array<chunksiz...
zos	(time, latitude, longitude)	float64	dask.array<chunksiz...

▸ Indexes: (4)

▸ Attributes: (14)

CMEMS GLORYS12V1 ocean surface water temperature, 0.083° × 0.083°



Model: https://doi.org/10.48670/moi-00021

Motivation – Limitations of traditional Map Projections

⇒ **Planar**: shape and area distortion increase away from the center.

⇒ **Conical**: distortion along the lines of latitude, with minimal distortion along the standard parallels. The cone can be adjusted to focus on various latitudes. Seam lines at the edges of the cone create discontinuities where the map does not cover the entire globe.

⇒ **Cylindrical**: Severe distortion at the poles leads to unrealistic representations and significant breaks in spatial continuity.

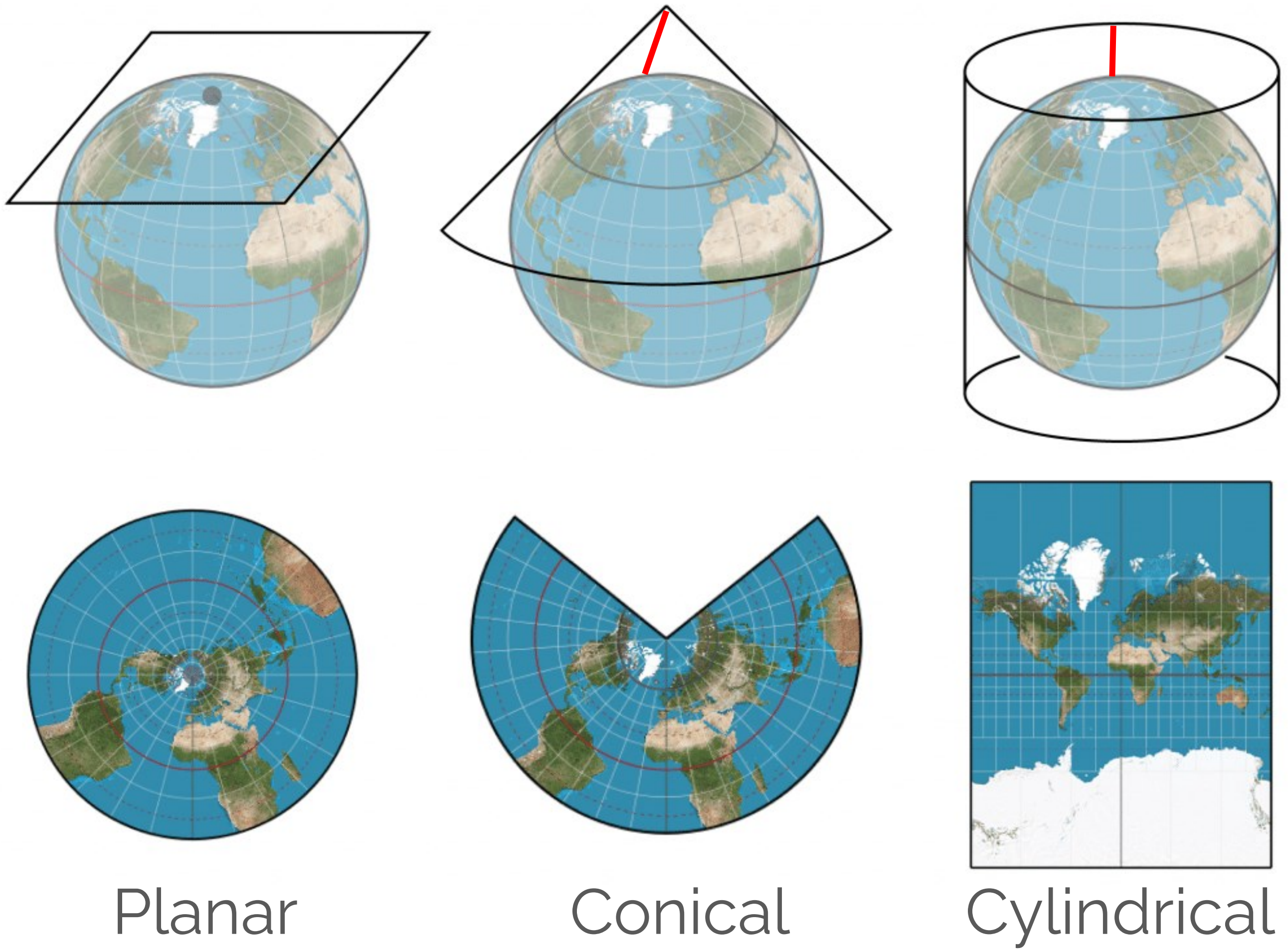


Image from gistbok.ucgis.org

Discrete Global Grid Systems

“*A Discrete Global Grid System is a spatial reference system that uses a hierarchical tessellation of cells to partition and address the globe.*”
(OGC Abstract Specification, 2017).

General principle: recursively subdivide the spheroid

1. Choose a base solid / subdivide the surface into faces
2. Choose an orientation of the base solid
3. Define a hierarchical spatial partitioning method
4. Choose a method to transform the partitions to the spheroid’s surface
5. Choose a method to index the grid cells

Initial subdivision: Base solids

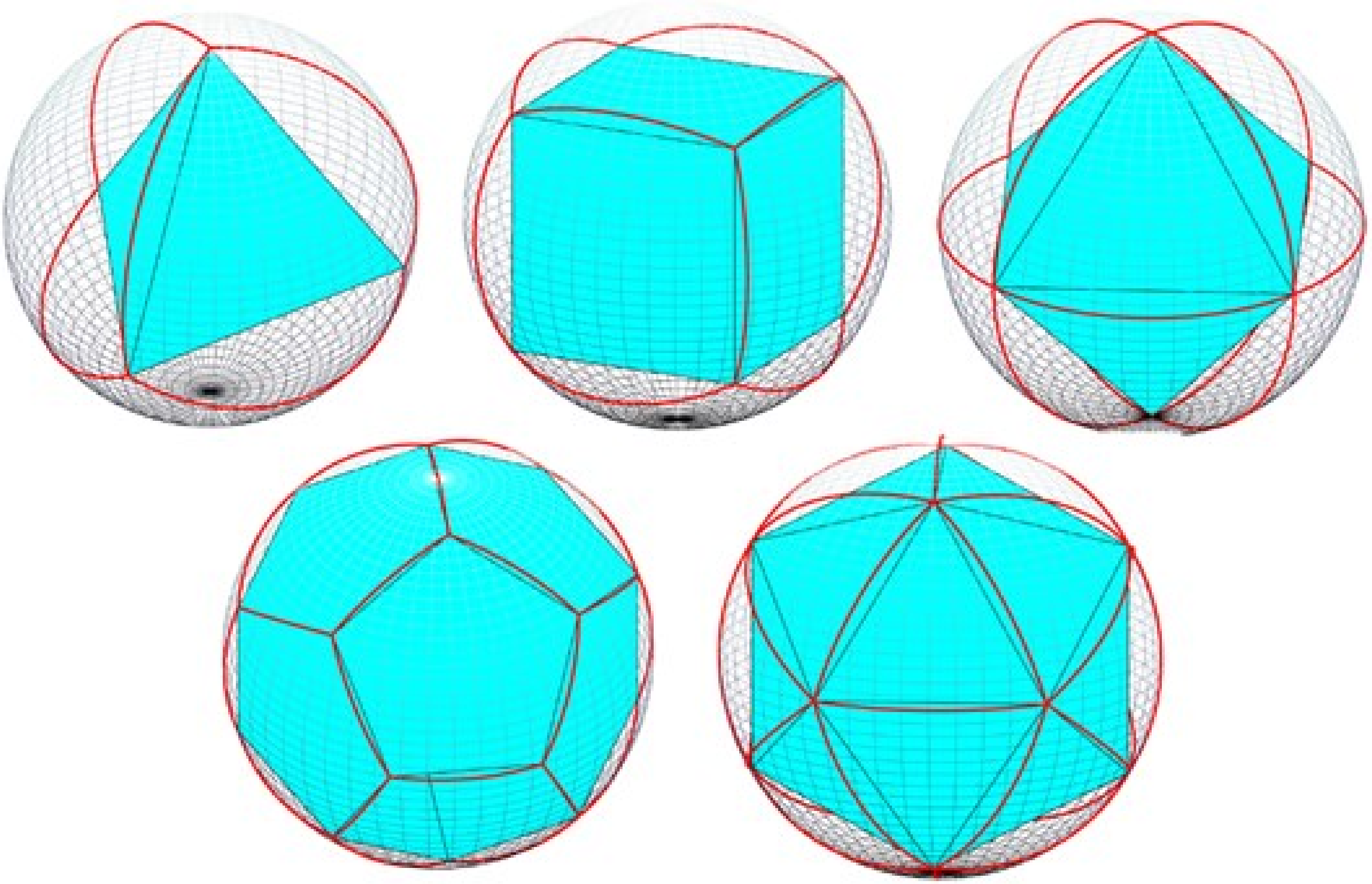


Image from: Lei, Qi, & Tian, 2020

- Common base solids:
    1. Tetrahedron
    2. Cube
    3. Octahedron
    4. Dodecahedron
    5. Icosahedron
- The smaller the face, the less it is distorted
- Choice limits the cell shape
- Can also use spherical geometry instead

Orientation

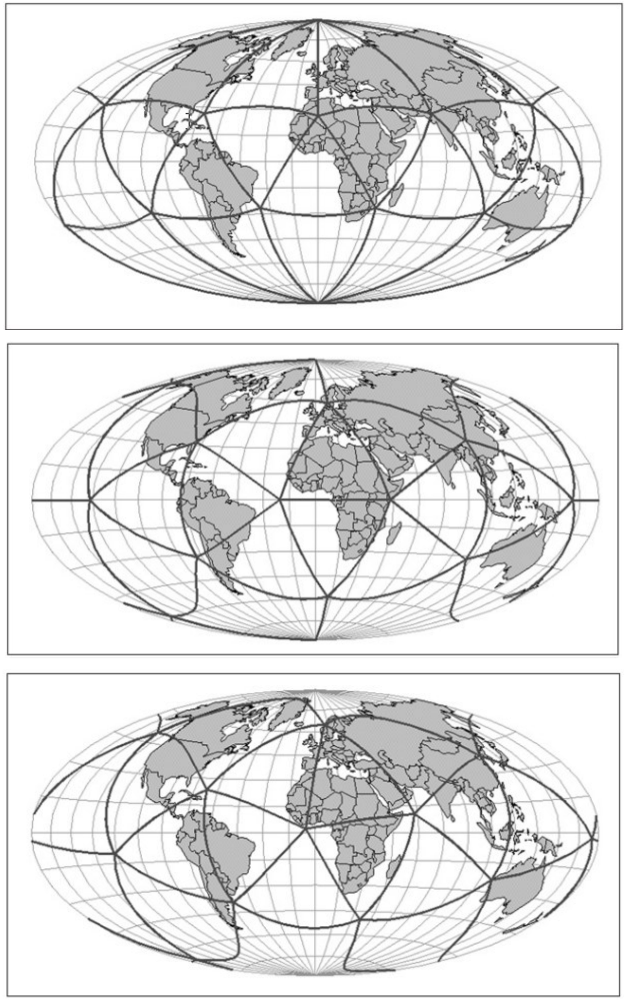


Image from Sahr et al., 2004

- The choice depends on the application
- Aim: keep areas of high distortion away from areas of interest
- examples for the orientation
    1. vertices at the poles
    2. symmetrical to the equator
    3. all vertices in the ocean

Partitioning methods

DGGS methods recursively subdivide the faces of polyhedra to cover the spherical surface, creating cells with different geometric shapes.

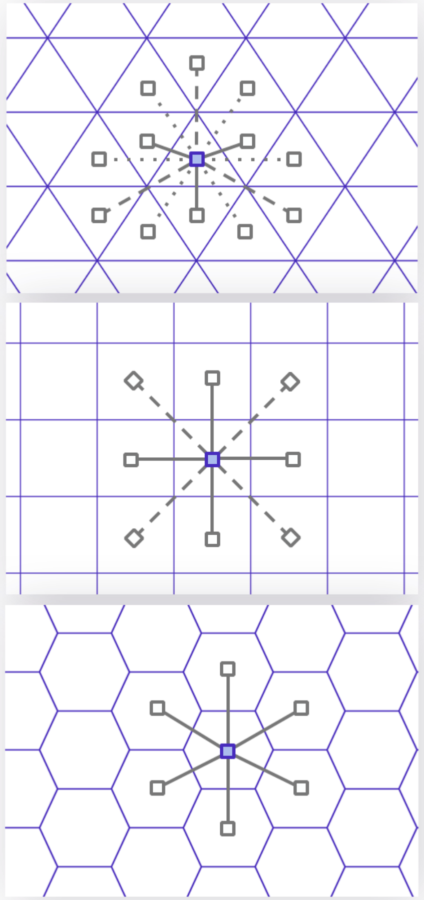


Image from h3geo.org

Cell shapes:

- Affects how the spherical surface is covered and the grid's efficiency
- possible choices: Triangle, Square, Diamond, Hexagon

Key Properties:

- **Congruence**: Seamless subdivision without gaps.
- **Aperture**: Number of subdivisions (higher = more parts).
- **Adjacency**: Relation to neighboring cells (sharing edges/corners).
- **Compactness**: Area-to-perimeter ratio (higher = better efficiency).

Transformation to the spheroid's surface

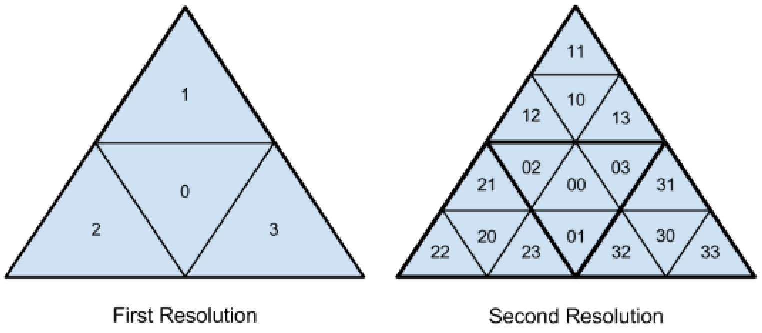
Transforming spherical data to 2D involves methods that balance area, shape, and structure, each with trade-offs.

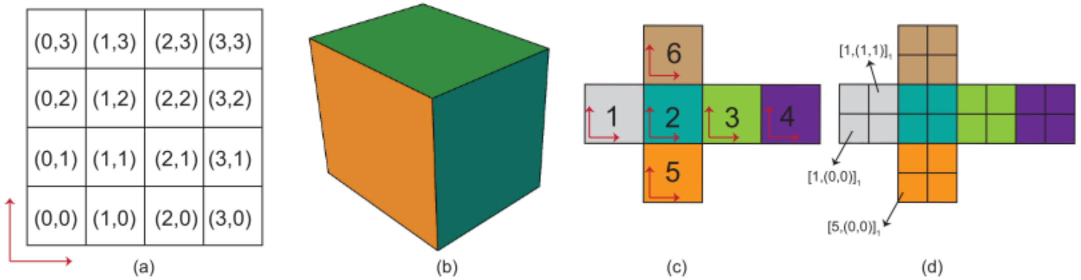
Most common: inverse map projection

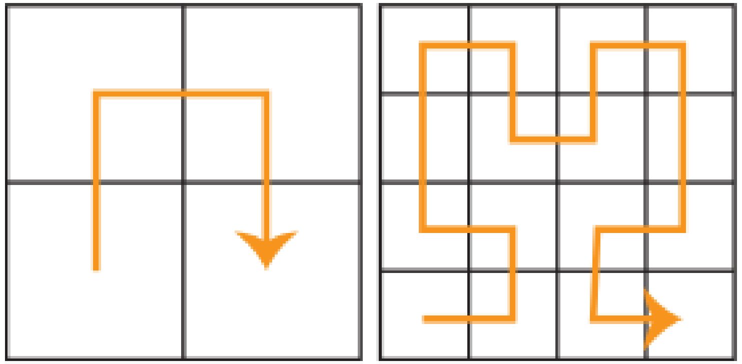
- Transforms 3D spherical coordinates to 2D map coordinates.
- Common in mapping applications, useful for visualizing spherical data on a flat plane.
- Trade-off in distortion between area and shape preservation:
  - *Area preservation:* Snyder equal area projection
  - *Shape preservation*: Gnomonic projection
  - *Compromises*: Fuller - Gray projection

Indexing scheme

- Allows assigning a unique numerical index to each cell
- Different choices (top to bottom):
  - Hierarchical indexing
  - Axis-based indexing (“Coordinates”)
  - Space-filling curve
- Position on the grid: a single 64-bit integer
- Allows for lots of operations:
  - Hierarchical access (parents, children, siblings)
  - Neighbours search
  - Alignment

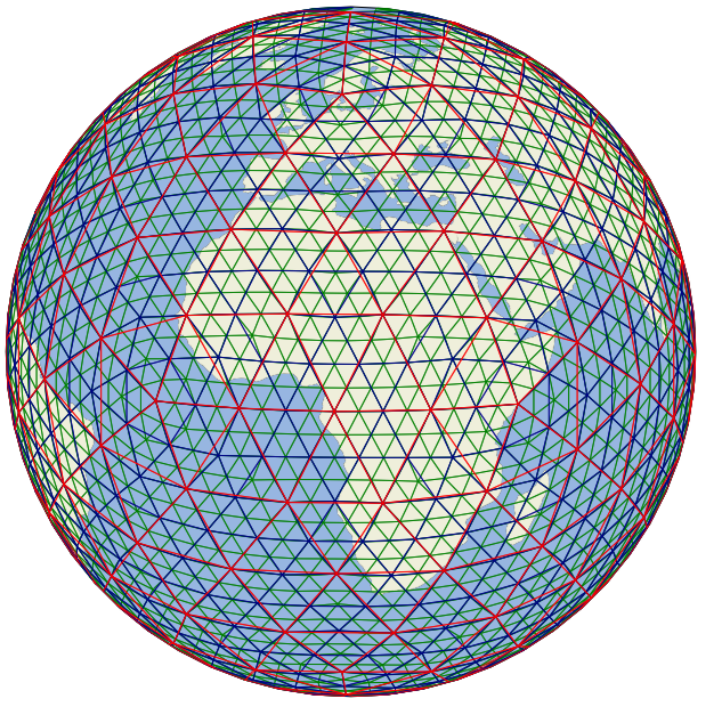




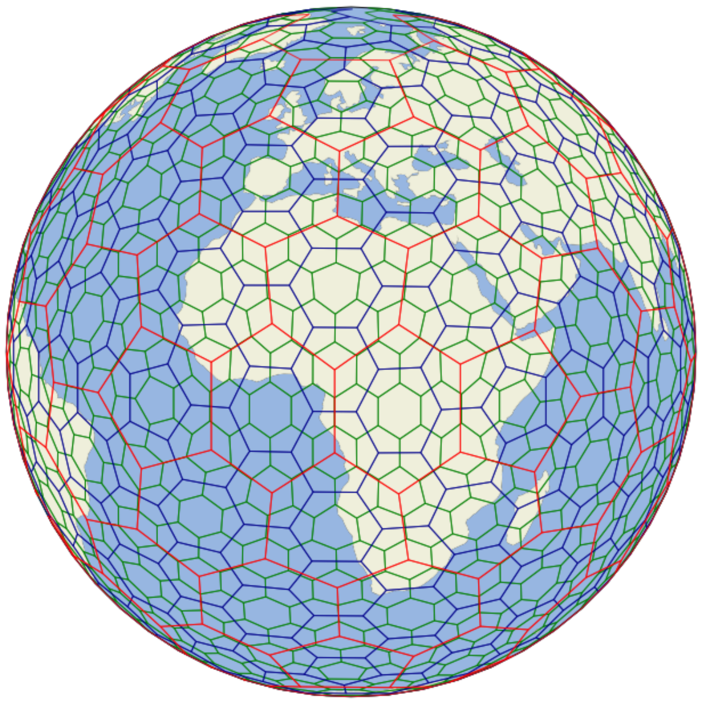


Images from Mahdavi-Amiri et al., 2015 and Bush, 2017

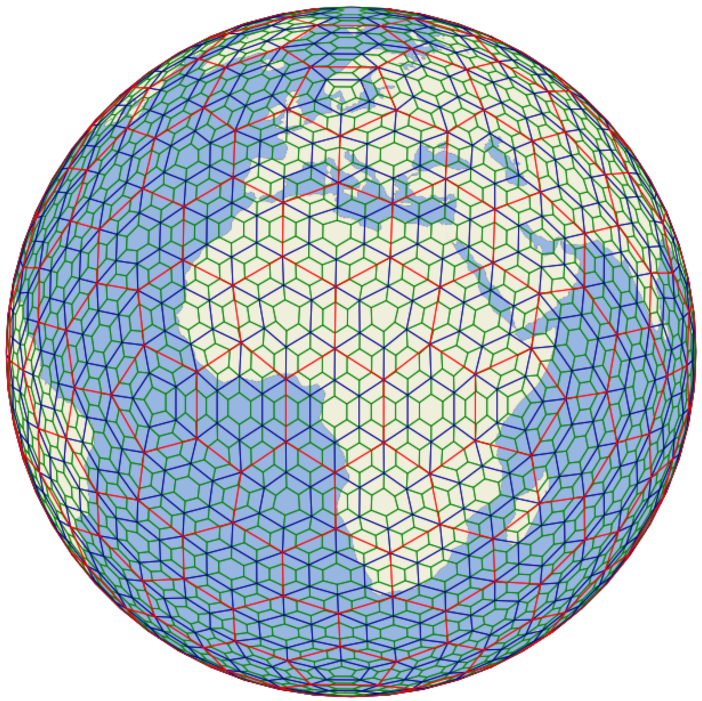
Different types of DGGS



ISEA4T



ISEA3H

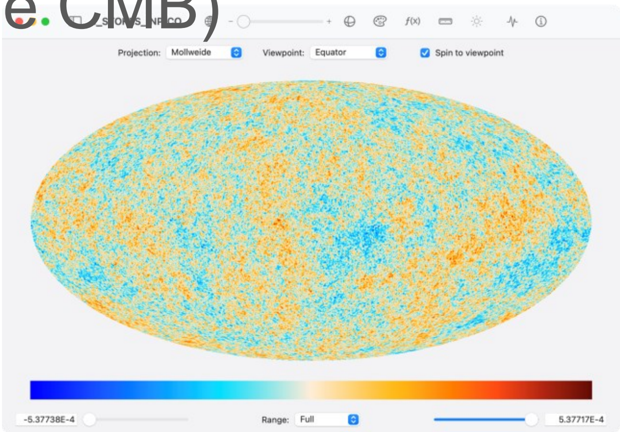


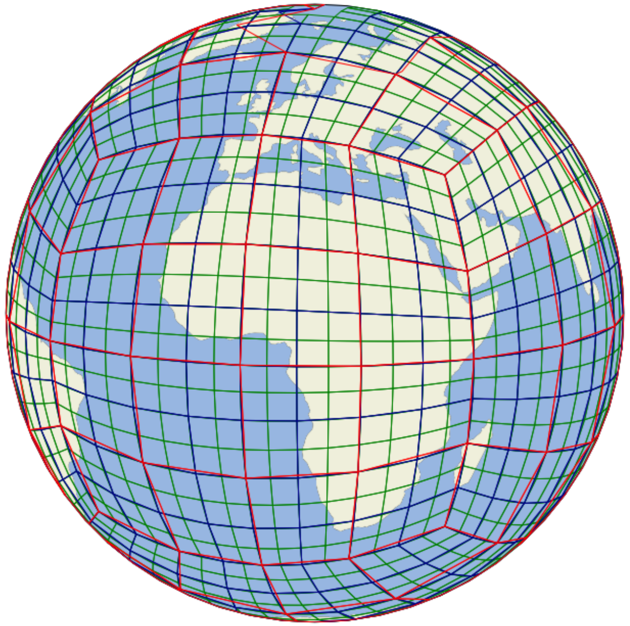
ISEA4H

Images from Kmoch et al. 2022 10.5194/agile-giss-3-41-2022

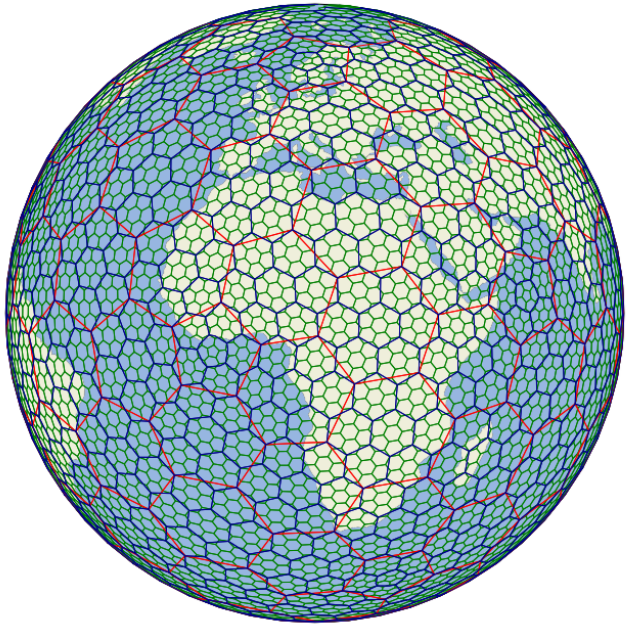
Different types of DGGS

HEALPix from cosmology (example CMB)

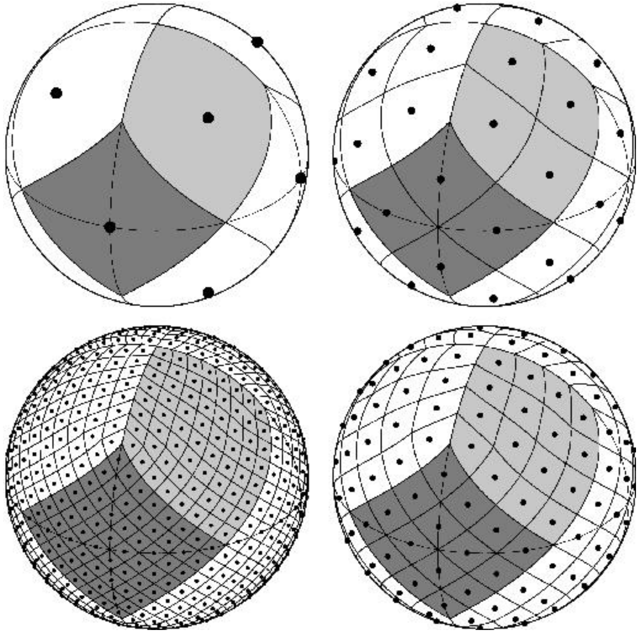




Google S2



Uber H3



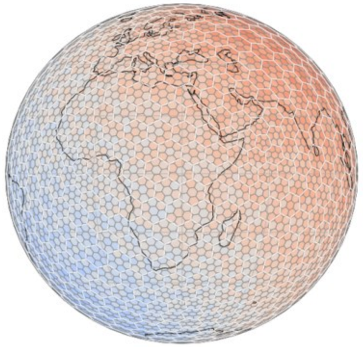
HEALPix

Images from Kmoch et al. 2022 and healpix.sourceforge.io

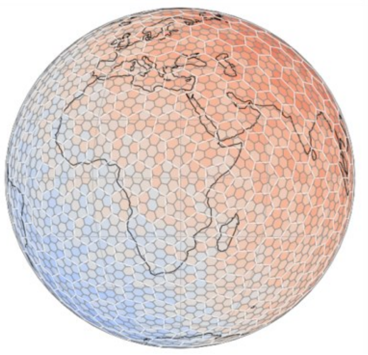
DGGS: Summary of Key Features

- **Consistent Grid**: Provides a uniform system for geospatial data across resolutions.
- **Improved Integration**: Aligns diverse datasets globally for comprehensive analysis.
- **Multi-Resolution Analysis**: Supports detailed local and broad global assessments.
- **Interoperability**: Promotes seamless exchange between geospatial datasets.
- **Scalability**: Adapts to varying levels of detail and geographic extents.
- **Reduced Distortion**: Minimizes Earth's surface distortion for accurate representation.
- **Efficient Storage/Retrieval**: Optimizes handling of large geospatial datasets.
- **Advanced Analysis**: Supports spatial statistics and machine learning with a uniform structure.

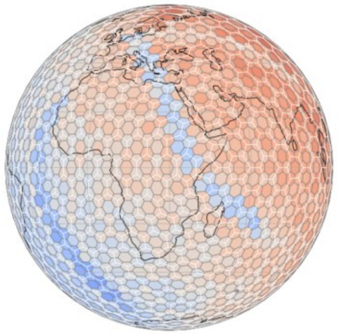
HEALPix : the best for the equal area.



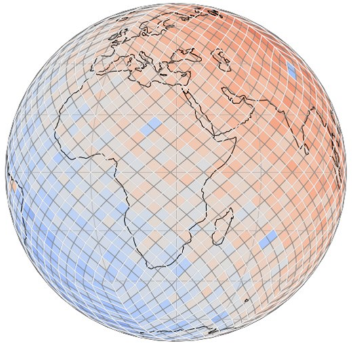
H3 (res. 1,2)



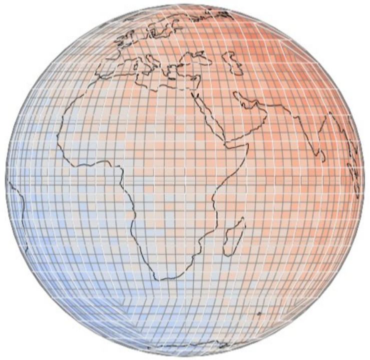
DGGRID ISEA7H (res. 2,3)



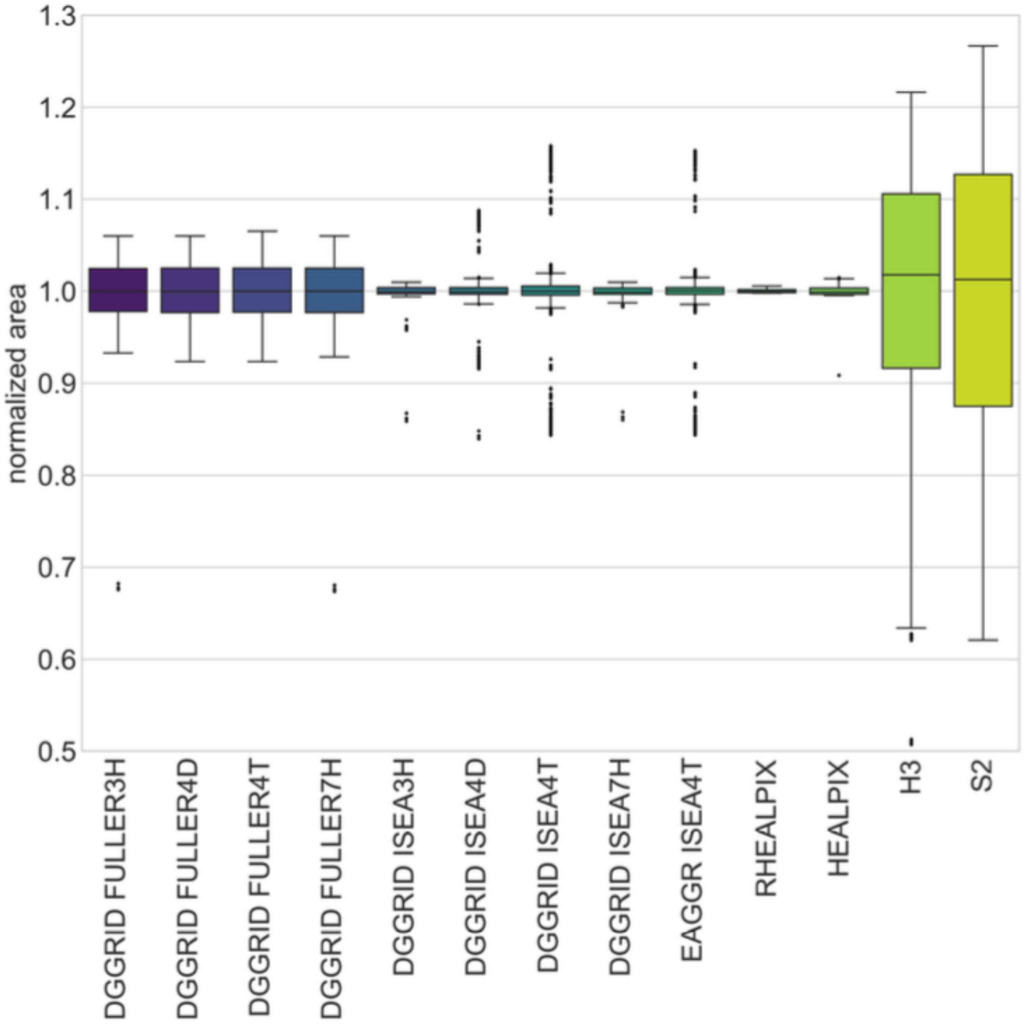
DGGRID ISEA3H (res. 4,5)



HEALPIX (res. 3,4)



rHEALPix (res. 2,3)



Images from Kmoch et al. 2024 10.5194/isprs-archives-XLVIII-4-W12-2024-75-2024

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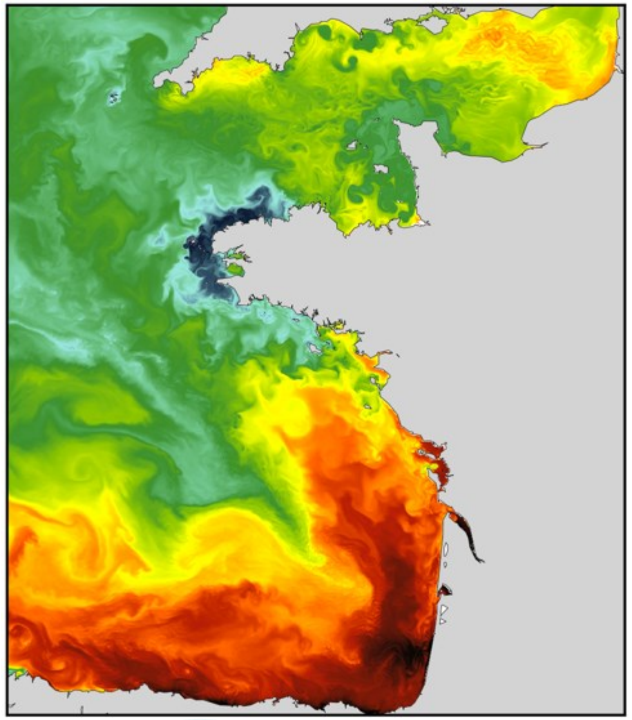
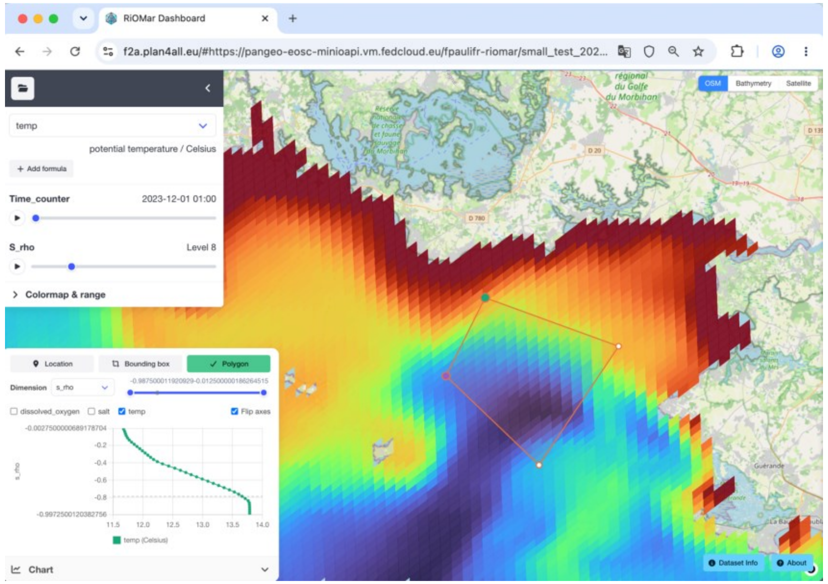
Example of HEALPix used in Climate change adaptation





RiOMar
Interface fleuve-mer horizon 2100

eosc | FAIR2Adapt

https://f2a.plan4all.eu/#https://pangeo-eosc-minioapi.vm.fedcloud.eu/fpaulifr-riomar/small_test_2026m06d12_001_hp.zarr::varname=temp::dimIndices_time_counter=0::dimIndices_s_rho=8::boundlow=11.219304525844814::boundhigh=14.425458908081055

Destination Earth and DGGS (HEALPix)

Global Fish Tracking System Destination Earth use case and pangeo-fish

development SEED
Ifremer
decod de la source à l'océan
LOPS
simula
LifeWatch ERIC

DestinE Platform

GFTS - Global Fish Tracking Service

Bridging Marine Biologging Science with Conservation Policy

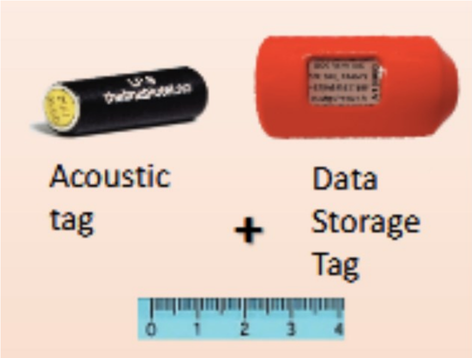
Destination Earth Funded by the European Union Implemented by ECMWF esa EUMETSAT

What is Biologging

Fish capture

Stabulation, then anesthetize the fish

Implant the acoustic tag + Data Storage Tag (DST)



Fish release

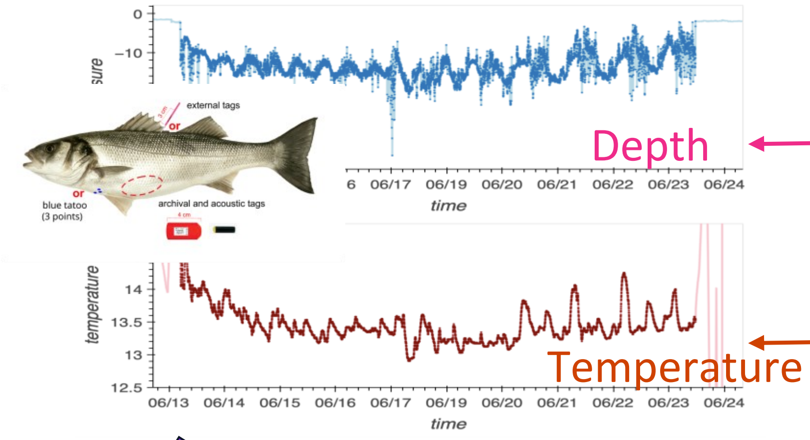
Waking and housing fish

Data Storage Tag: Store time series of observed temperature, depth in a tag.
Acoustic Tag: tag emits signal, detect tagged fish using acoustic telemetry network
Combine both approaches together with earth science data: *Infer fish trajectory from individual environmental data histories using geolocation models*

Pangeo-fish: Fish Tracking Modeling

Destination Earth
Core Service Platform Use Cases

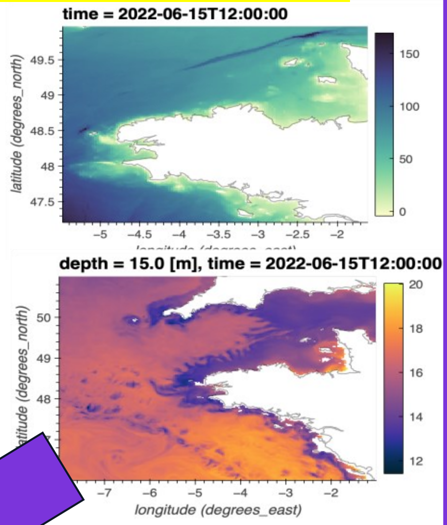
Bio-Logging data



Bathymetry

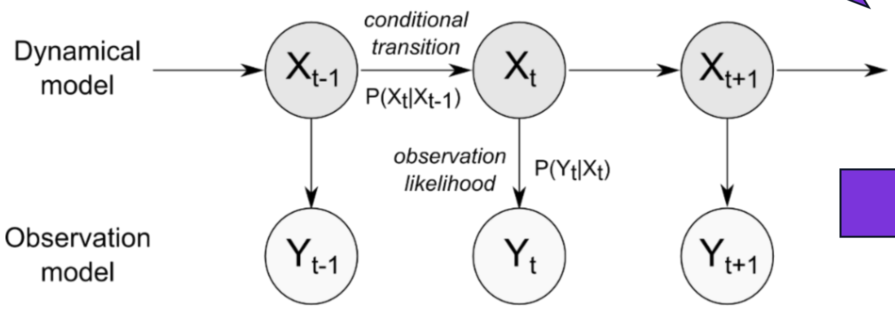
Temperature at depth

Earth science data

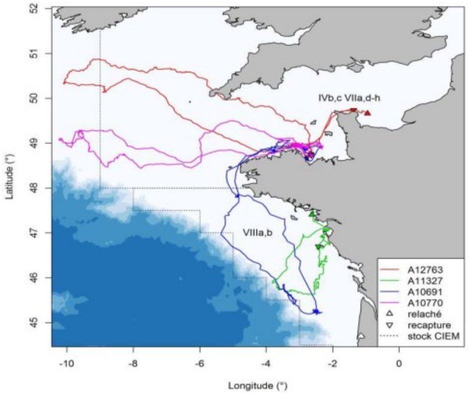


Hidden Markov Method

Hidden states sequence (here the daily fish positions)



Observations sequence (here the temperature and depth conditions)



Model: ***Hidden Markov Method***

Geolocation model developed by Woillez et al. (2016), temperature and bathymetry as reference fields, adapted from Pedersen et al. (2008)

Constrains:

- ***acoustic detection,***
- ***bathymetry***
- ***release location***
- ***recapture location***

Likelihood of Observed Temperature at depth by fish from earth science data

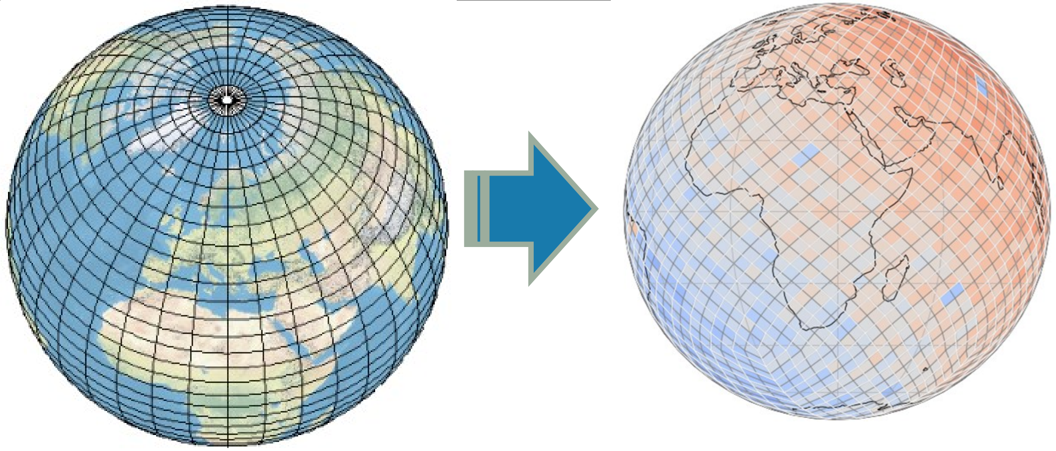
Copernicus Marine Service

Quality and resolution (both spatial and temporal) **of Earth science data, such as** sea temperature, **are crucial for accurate track reconstruction.**

→ **PANGEO and HEALPix for computing fish-track = Pangeo-fish**

Zarr dask xarray

Why **HEALPix** for **pangeo-fish**?



HEALPix is a type of DGGS

"A Discrete Global Grid System (DGGS) is a spatial reference system that uses a **hierarchical** tessellation of cells to partition and address the globe." OGC Abstract Specification, 2017

Equal Area, Seamless Global Coverage, and Multi-Scale.

Expand possible fish tracking system to globa application!!!

xdggs : easily access, process, and visualise ClimateDT/ pangeo-fish HEALPix data

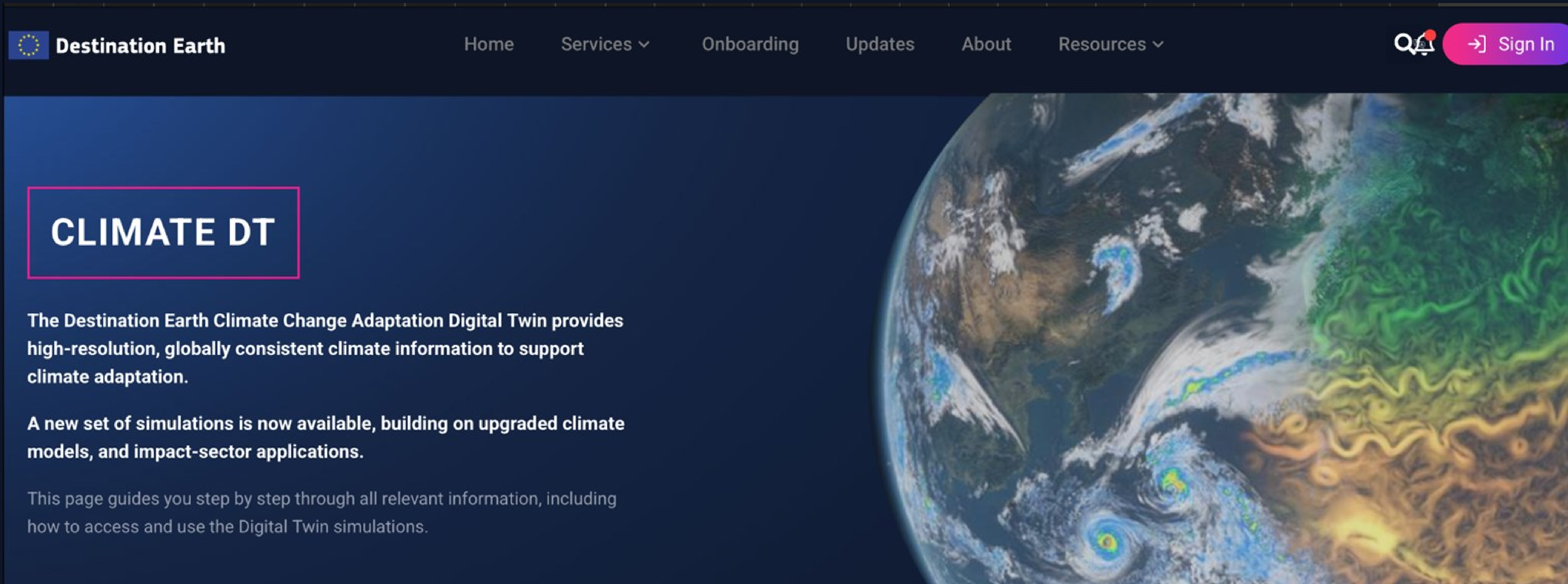
xdggs

Serco
Business

Destination Earth Climate DT

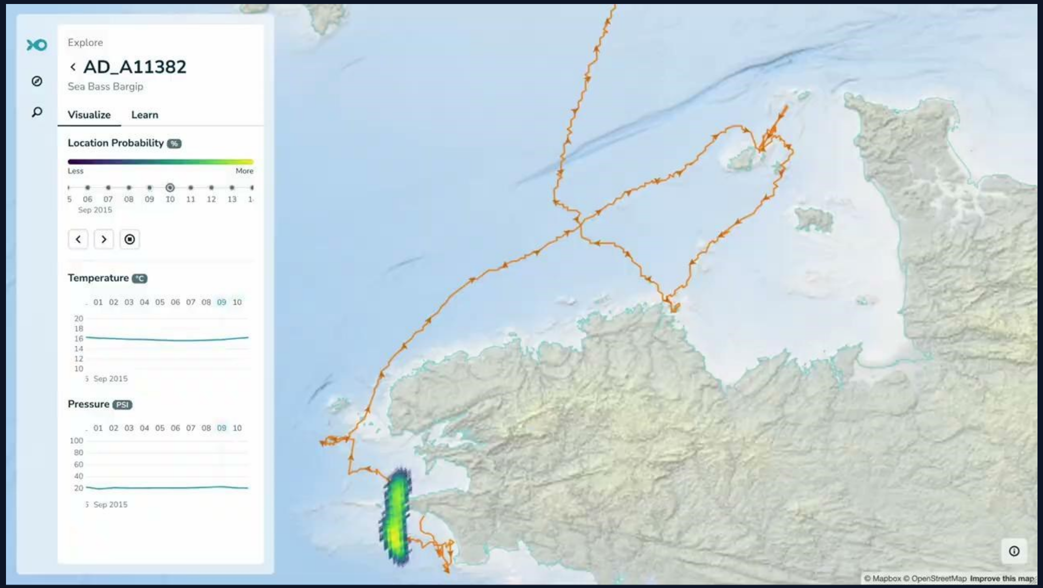
Destination Earth

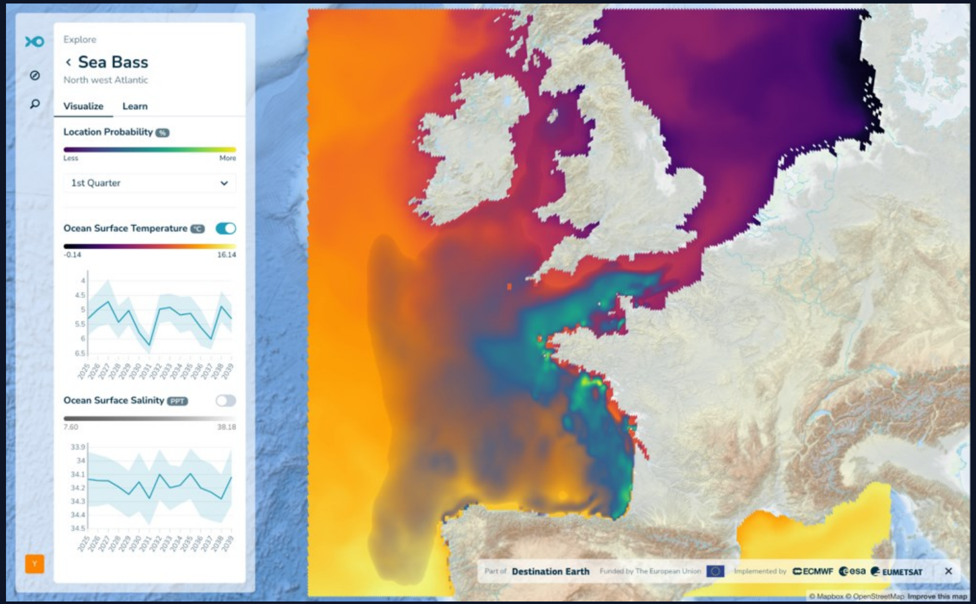
All model is accessible in HEALPix



View Individual Fish Tracks

Inspect model results in detail





GRID4EARTH : Toward an Ellipsoidal HEALPix* Grid

for Analysis-Ready Earth Observation and Climate Data

A common DGGS for Copernicus & Destination Earth

on Behalf of the ***GRID4EARTH*** project with the financial support of ESA

Jean-Marc Delouis[1], B. Bovy[2], A. Fouilloux[3], A. Kmoch[4], J. Magin[1], P. Richard[5], V. Dumoulin[6], T. Odaka[1]

[1]IFREMER/CNRS/LOPS [2]Bovy EI [3]LifeWatch ERIC [4]Univ. Tartu [5]Richard EI [6]ESA/ESRIN

THE PROBLEM

A Fragmented Landscape of Spatial Grids

Copernicus & DestinE produce massive global datasets on heterogeneous grids:

- Regular lat/lon (Sentinel, ERA5)
- Reduced Gaussian (ECMWF models)
- Swath / orbit geometries (L1/L2)
- Unstructured meshes (ICON, FESOM)

Costly regridding

Ad-hoc interpolations repeated by every user

Error-prone

Information loss, aliasing, area biases

Not reproducible

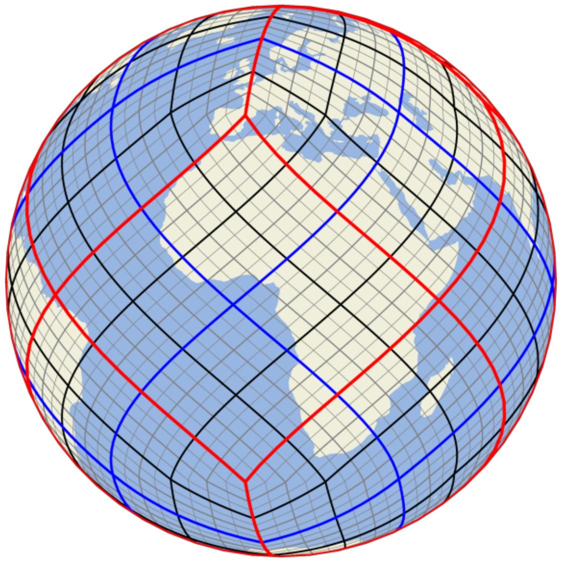
No standard → different results per workflow

→ **We need a common Discrete Global Grid System (DGGS)**

THE CANDIDATE

HEALPix Nested = A Native Quadtree

Each pixel subdivides into 4 children → built-in multi-resolution hierarchy



3 depths on the sphere

Equal Area at Every Depth

Same surface area per pixel at any resolution → unbiased statistics

Down / Upscaling

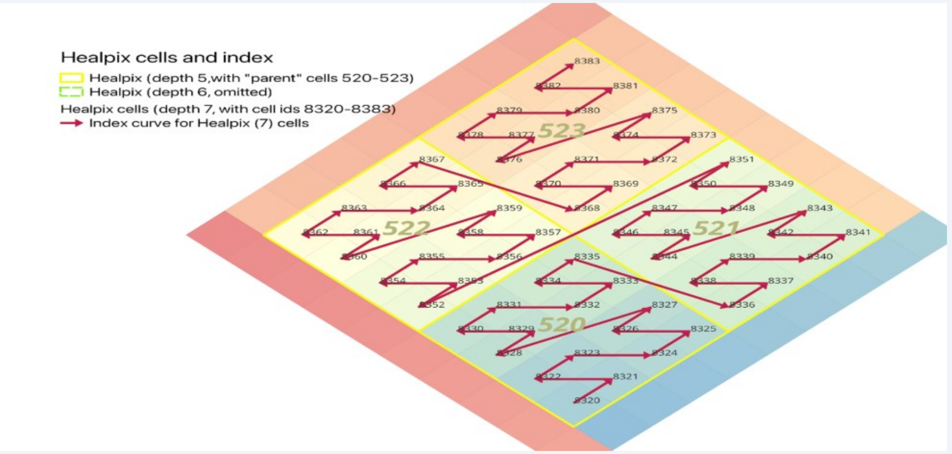
Parent = mean of 4 children — trivial aggregation, no interpolation needed

AI-Ready Indexing

Space-filling curve preserves locality → GPU batching, ML-friendly tiles

Cloud-Native Chunks

Zarr / COG tiling aligned with quadtree nodes, scalable on object stores



Already adopted: ESA DestinE Climate DT, ECMWF, Planck, WMAP, Euclid...

Why diadic scaling is important for earth observation

- Many observed process are driven by advection (atmosphere, Ocean,etc.) that is by nature diadic (thank to Navier-Stokes equation),
- Thus, multiscale, AI and other statistical analysis are built on top of diadic statistics,
- Multiscale computation on a dyadic grid is very efficient (small kernel ~5x5, or even 3x3) is sufficient for the smallest scale (see the next slide for more explanations),

Why diadic scaling is not a problem

Resolution adjustment between the detector and the HEALPix grid is not necessary.

The next finer grid scale can be used instead; for example, level 20, corresponding to approximately 6 m, for data with a 10 m resolution:

- The increased **storage cost** can be **compensated** by informed **compression**, since there is no additional information between 10 m and 6 m.

- A **forward resampling** model ensures information consistency between the two grids.

THE GAP

Sphere ≠ WGS84 Ellipsoid

HEALPix is formally defined on a perfect sphere — but Earth is an oblate ellipsoid

What happens when you ignore it?

At coarse resolution (≥ 50 km):

Negligible — flattening ~ 0.3%

At Copernicus resolution (10–100 m):

Non-negligible position shift (~km)

Latitude-dependent pixel area bias

Zonal & regional statistics become unreliable

Key numbers

~0.3%
Earth flattening (f)

~0.67%
Max area distortion

The spherical assumption breaks the equal-area guarantee that makes HEALPix valuable.

→ **The equal-area property must hold on the ellipsoid, not just the sphere**

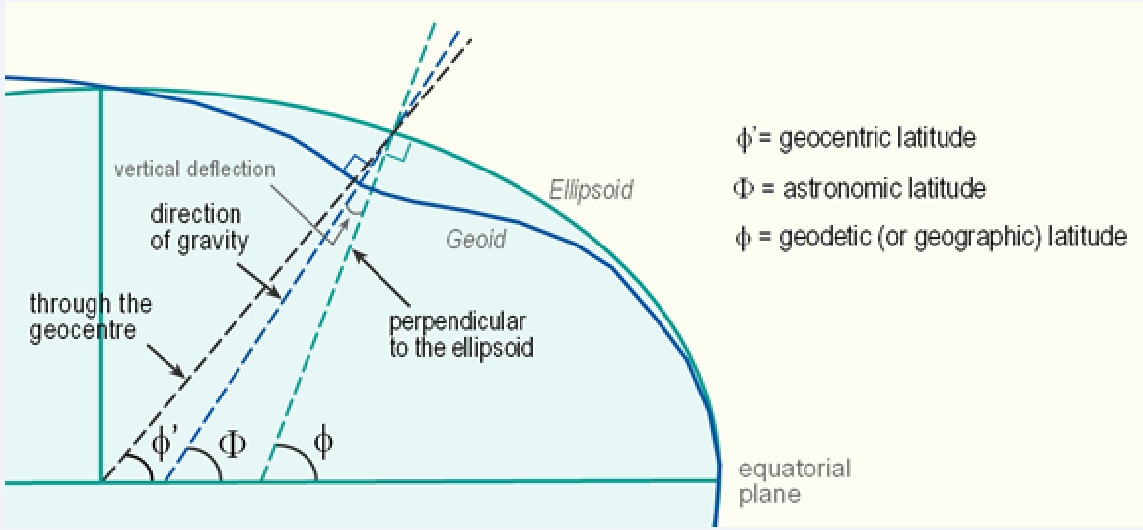
Sphere and Ellipsoid

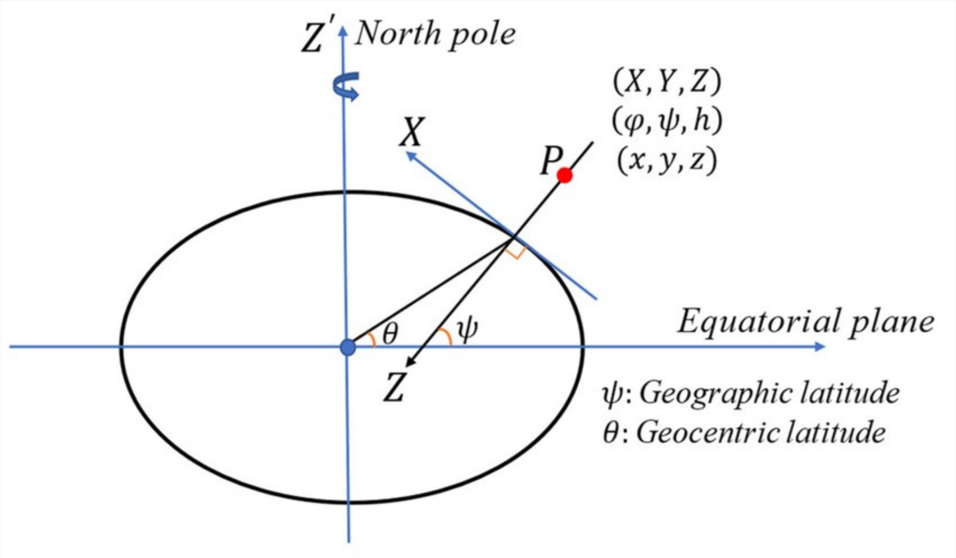
Both models can introduce displacement due to simplifications.

WGS84 (the widely used ellipsoid) is typically 2 meters off in terms of positional accuracy.

Coordinate Systems:

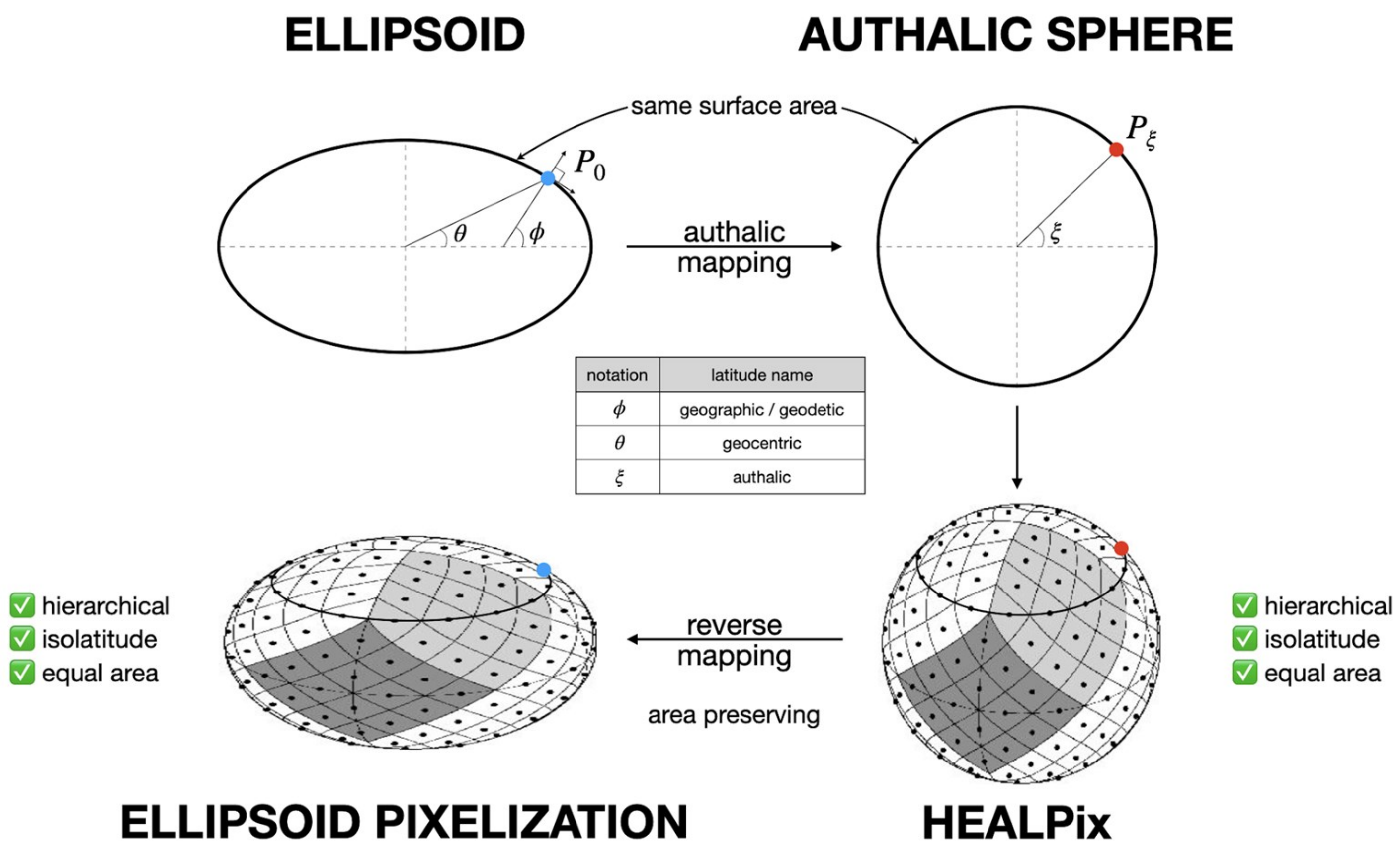
- **Geocentric Latitude:** Measured from the Earth's center, considering the ellipsoid's shape.
- **Authalic Latitude:** Latitude on a perfect sphere that has the same surface area as the ellipsoid.
- **Geographic Latitude:** The common latitude along the Earth's surface





THE SOLUTION

Ellipsoidal HEALPix via the Authalic Sphere



Key Properties

✓ **Equal area on WGS84**

Same ellipsoidal surface area per pixel

✓ **Backward compatible**

Reduces to standard HEALPix on sphere

✓ **No new tooling**

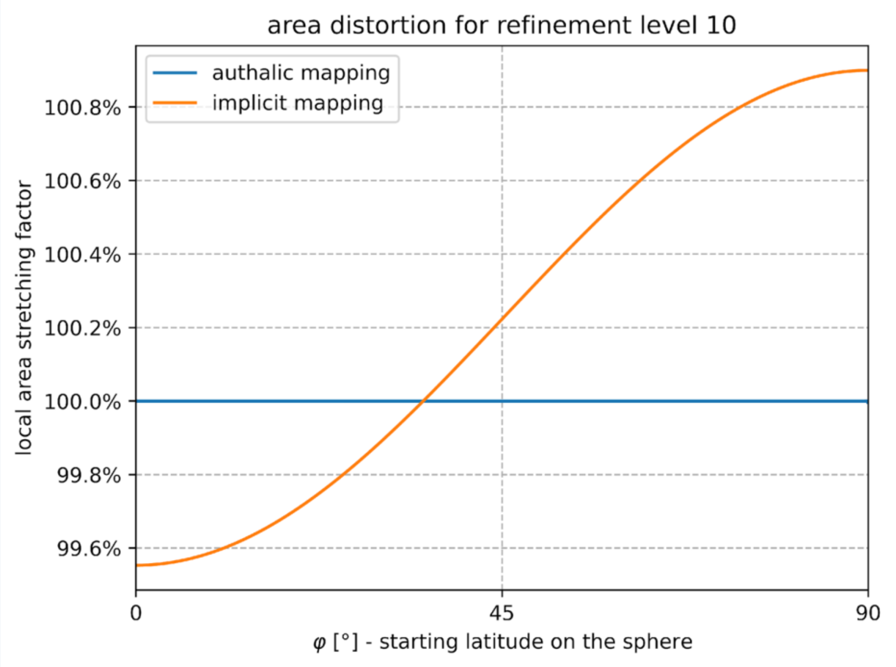
Only the coordinate mapping changes

✓ **Exact & invertible**

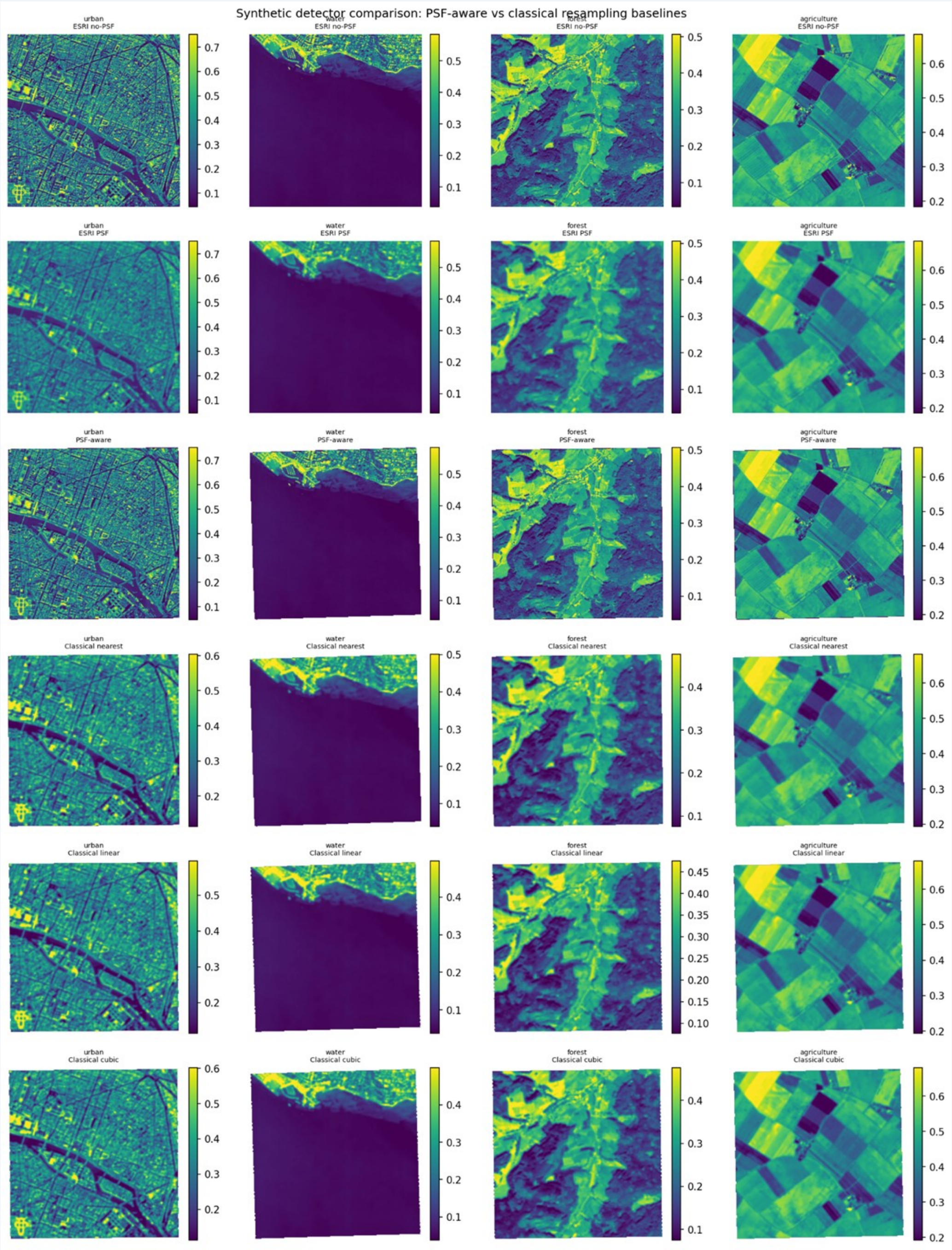
Analytical transform, ~1 nm precision

RESULTS

Area Distortion: Sphere vs. Ellipsoid

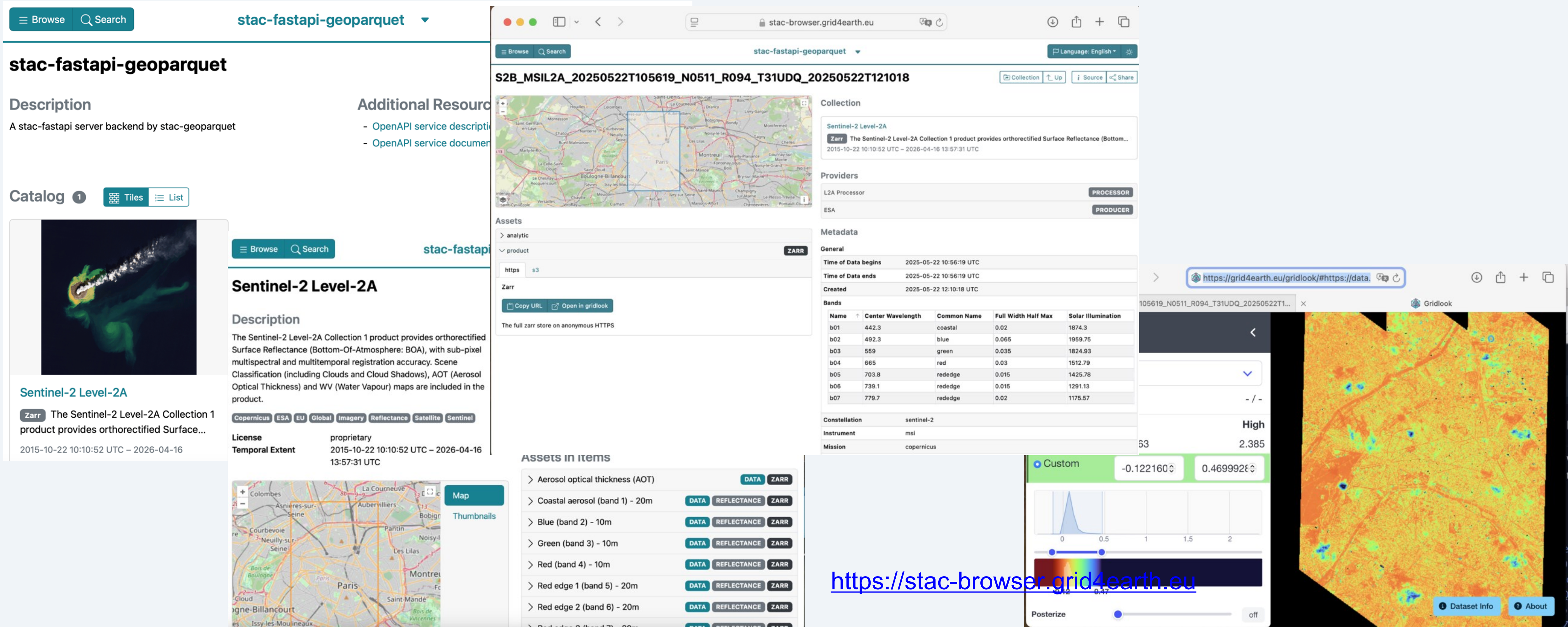


Area distortion vs. latitude (refinement level 10)



RESULTS

Conventions: dggs-zarr, CF_convetions, STAC compatible



https://stac-browser.grid4earth.eu

UNIFICATION

One Grid to Bridge Models & Observations

Climate Models (Sphere)

- DestinE Climate DT
- ECMWF IFS / ICON
- CMIP / reanalysis

Defined on the sphere

→ Standard HEALPix

Ellipsoidal HEALPix

=

Earth Observation (Ellipsoid)

- Sentinel-1 / 2 / 3
- Copernicus services
- In-situ networks

Referenced to WGS84

→ Ellipsoidal HEALPix

→ Analysis-ready data: no regridding, consistent statistics, interoperable workflows

Takeaways & Next Steps

Ellipsoidal HEALPix works

The authalic sphere approach preserves equal-area on WGS84 with minimal complexity

Compatible & practical

No new libraries needed — same HEALPix tools, just a coordinate transform layer

A foundation for FAIR data

One DGGS for models + EO = analysis-ready, reproducible, cloud-native

Next Steps

1. Validate at full Copernicus/Destination E resolution
2. Community adoption & feedback

GRID4EARTH : Open source packages

healpix-geo:
HEALPix geospatial algorithms library

healpix-analyse:
HEALPix EO analysis toolkit

healpix-resample:
Geospatial data to HEALPix grid

healpix-plot:
Fast HEALPix plots for Earth observation

Thank you! Any question?

https://grid4earth.eu for more information

GEOMATYS

CNES
CENTRE NATIONAL D'ÉTUDES SPATIALES

&

CS
a Sopra Steria company

R&T – Etude et conception d'un index DGGS Spatio-Temporel (4D) dans un cadre de standardisation OGC

Réunion de clôture - 26/06/2026

JOHANN SOREL

Master en Géomatique
License en programmation
↳ *il y a 20 ans déjà*

Open Geospatial Consortium

APACHE S.I.S

- GeoAPI
- Apache SIS
- GeotoolKit
- Examind SDK
- Examind Server

MVT OGCAPI Anarisdk COG S-57 Shapefile OSM VPF HDF VTS HGT Khronos S-52 WCS CSW HIPS WMTS KML KTX IHO MLT ISO DTED Geotiff SVG DGGRS OGC 3dtiles W3c Grib SLD WPS S-100 GML STANAG netcdf GLTF DAFIF PLY S-63 Geojson opengl WMS Collada WFS ARINC424 ZARR

OGCAPI - DGGRS

Le modèle OGC-API

OGC-WXS
(WMS, WMTS, WFS, WCS, ...)

- XML
- statique (une seule API)
- extensible (propriétaire)
- REST

OGC-API
(Features, Coverages, Map, ...)

- JSON
- dynamique (multi-API)
- extensible (OpenAPI)
- REST (resource oriented)

Approuvée : 2025-05-04
Publication : 2025-10-03

OGC API - DGGRS

Découverte

/

↳ page d'accueil du service

/conformance

↳ liste des standards auxquelles le service se conforme

/dggs

↳ liste des DGGRS du service

/dggs/{dggsId}

↳ description d'un DGGRS en particulier

/dggs/{dggsId}/definition

↳ définition plus complète et statistique d'un DGGRS

/dggs/{dggsId}/zones

↳ liste ou recherche de zones

/dggs/{dggsId}/zones/{zoneId}

↳ description d'une zone en particulier

OGC API - DGGRS

Téléchargement

/collections

↳ liste des données disponibles sur le serveur

/collections/{collectionId}

↳ description d'une donnée

/collections/{collectionId}/schema

↳ description de la structure de la donnée

/collections/{collectionId}/queryables

↳ liste des propriétés requêtable

/collections/{collectionId}/dggs

↳ liste des DGGRS disponibles pour une donnée

/collections/{collectionId}/dggs/{dggrsId}/zones/{zoneId}/data

↳ téléchargement d'une tuile DGGRS

OGC API - DGGRS

GetZoneList

(/collections/{collectionId})/dggs/{dggrsId}/zones/

- collection ids ⇨ une ou plusieurs collections
- bbox ⇨ emprise voulue
- zoneLevel ⇨ niveau de profondeur des zones dggrs
- compactZones ⇨ retourne une liste compacte
- offset + limit ⇨ pagination
- parentZone ⇨ limiter à une zone parente pour la recherche
- subset + subsetCrs + datetime ⇨ filtrer les dimensions supplémentaires
- geometry ⇨ type de retour (zone-centroid,zone-region,vectorized,none)
- crs ⇨ CRS des données en sortie
- filter + filterLang ⇨ filtre CQL ou autre
- format + profile ⇨ format de sortie

OGC API - DGGRS

GetZoneData

(/collections/{collectionId})/dggs/{dggrsId}/zones/{zoneId}/data

- collection ids ⇨ une ou plusieurs collections
- properties + excludeProperties ⇨ sélection des propriétés retournées
- subset + datetime ⇨ filtrer les dimensions supplémentaires
- filter + filterLang ⇨ filtre CQL ou autre
- crs ⇨ CRS des données en sortie
- geometry ⇨ type de retour (zone-centroid,zone-region,vectorized,none)
- format + profile ⇨ format de sortie
- zone-depth ⇨ sous-niveau de profondeur des zones dggrs
- valuesOffset + valuesScale ⇨ ajustement des valeurs

OGC API-DGGRS : amélioration

Un nouveau end-point ?

L'API actuelle permet de récupérer les données par zone:
/collections/{collectionId}/dggs/{dggrsId}/zones/{zoneId}/data

Le problème vient des clients qui veulent télécharger une emprise spécifique à une résolution.

Avec l'API actuelle le client doit :

- trouver les zones parent intersectant les zones de données
- s'assurer que c'est compatible avec les capacités du serveur (subzone depth maximum)
- faire plusieurs requêtes de téléchargement
- supprimer les zones dupliquées et celles en dehors de l'emprise voulue.

Bien sûr ces opérations peuvent être simplifiées avec un client DGGRS complet.

Proposition

Le nouveau end-point est identique à l'existant à l'exception qu'il accepte les paramètres sous forme de géométrie.

/collections/{collectionId}/dggs/{dggrsId}/zones with additional parameters :

domain : une géométrie WKT
domainCrs : le CRS de la géométrie
zone-depth : devient absolue et non relatif
zone-accuracy : alternative à zone-depth (example : 500 m)

Les futurs standards : ISO 19170

- Part 1: Core Reference System and Operations, and Equal Area Earth Reference System
  ↳ Spécification de 2021, en cours de première révision, tout les 5 ans

Publiée
en révision ✓

- Part 2 - 3D Equal Volume Zones
  ↳ 3D Equal Volume Earth Reference System
  ↳ Voxel 3D, tessellation sur l'ellipsoid
  ↳ Classes de conformance

A venir
ébauche

- Part 3 - Temporal Zones
  ↳ Equal Area Earth Spatio-Temporal Reference system
  ↳ 3D Equal Area Volume Spatio-Temporal Reference system
  ↳ Axis Aligned Spatio-Temporal Reference system
  ↳ Classes de conformance

A venir
ébauche

- Part 4 Axis-Aligned Zones
  ↳ Describes a way to define DGGS from coordinate reference system
  ↳ Classes de conformance

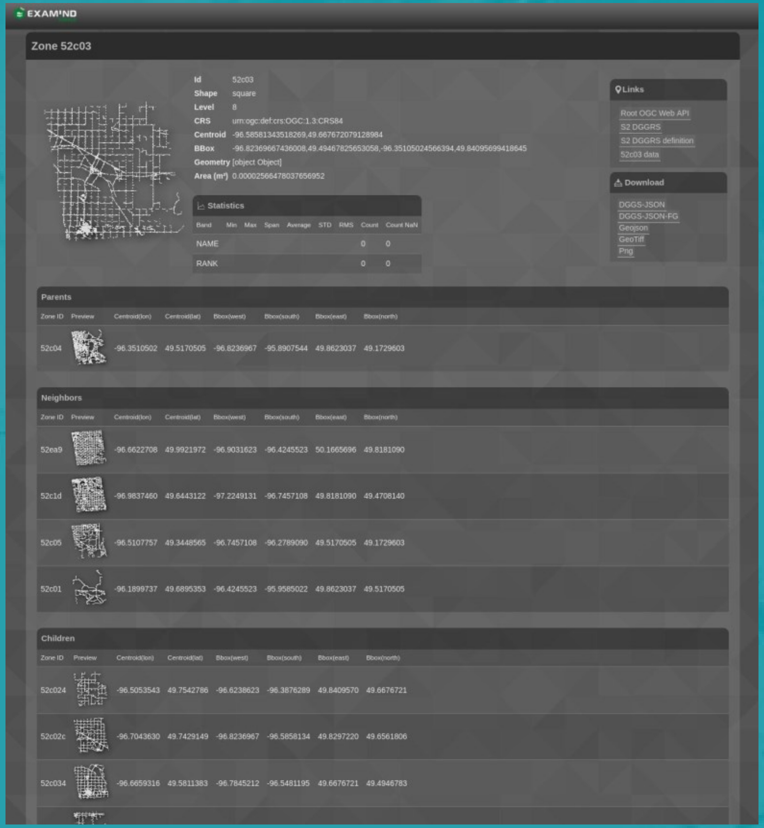
En cours
de finalisation

DÉMONSTRATEUR

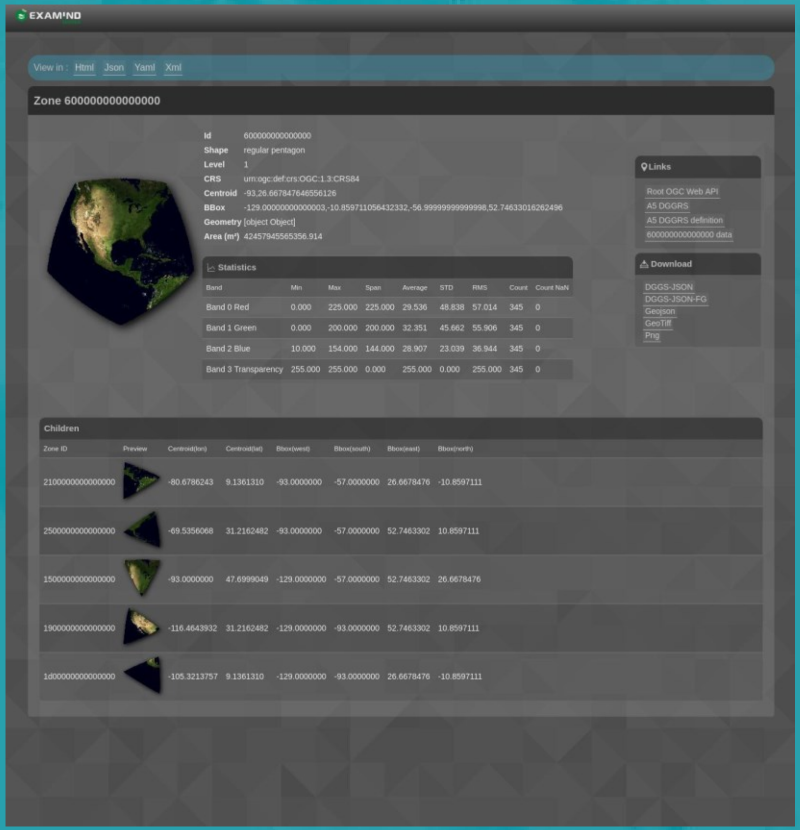
Démonstrateur : Examind Server

Serveur de démonstration

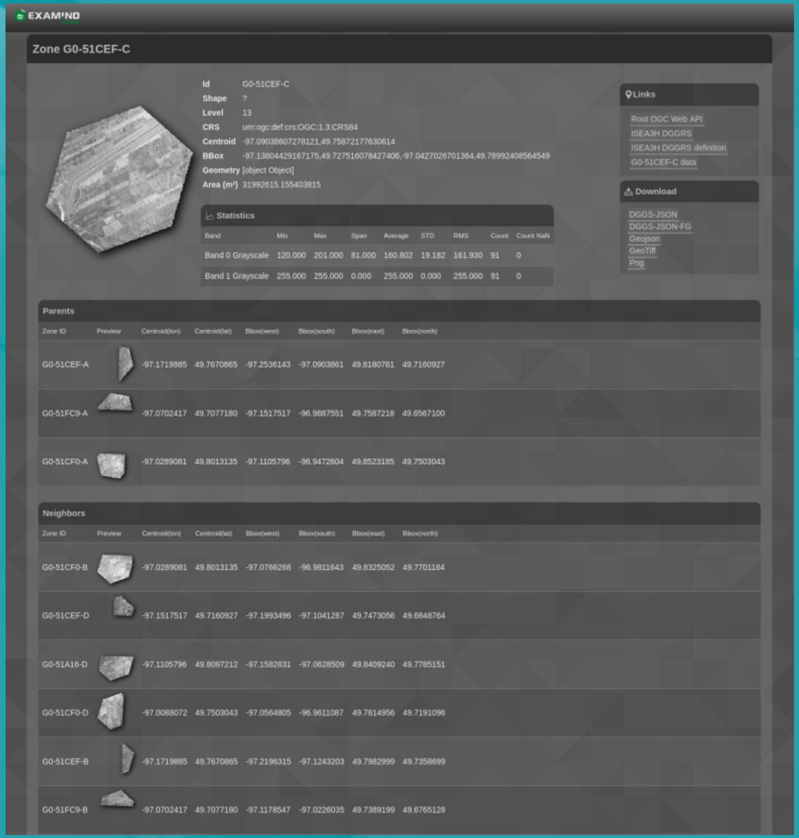
S2 zone : Roads



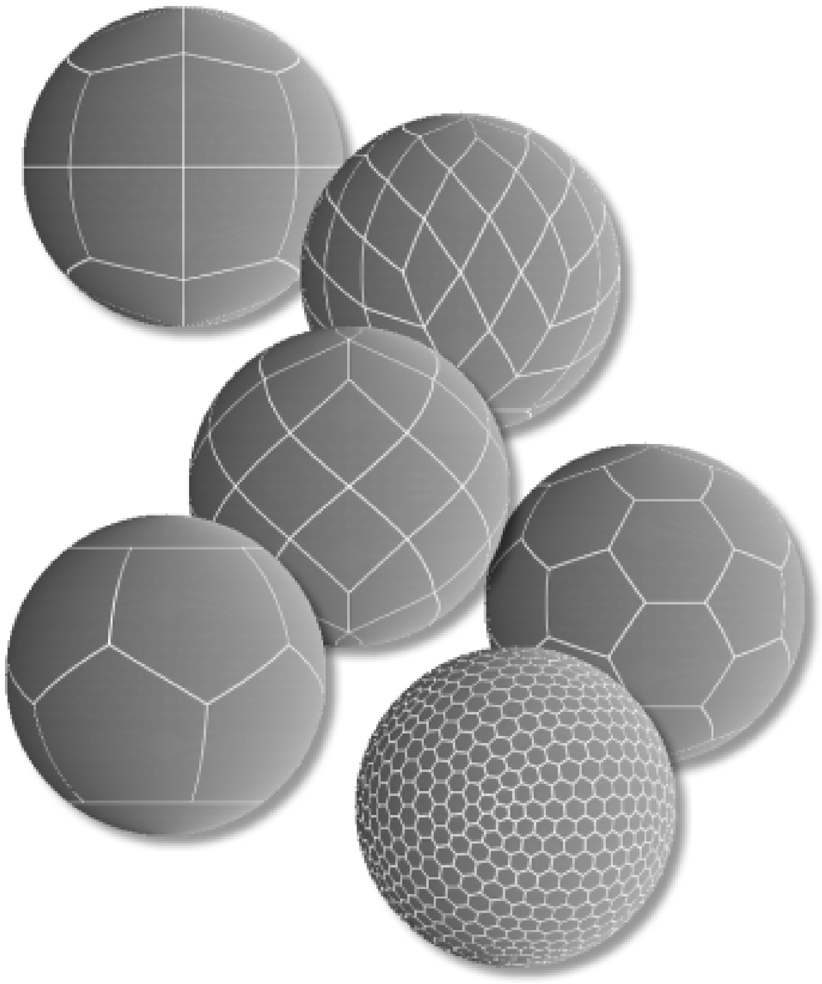
A5 zone : Truemarble



H3 zone : NAPL



Architecture : Open-Source



21

A5, H3, Healpix, rHealpix, S2,GNOSISGlobalGrid, ISEA3H, ISEA4R, ISEA7H, ISEA7H_Z7, ISEA9R, IVEA3H, IVEA4R, IVEA7H, IVEA7H_Z7, IVEA9R, RTEA3H, RTEA4R, RTEA7H, RTEA7H_Z7, RTEA9R

20 / 25

20 out of 25 conformance classes supported.

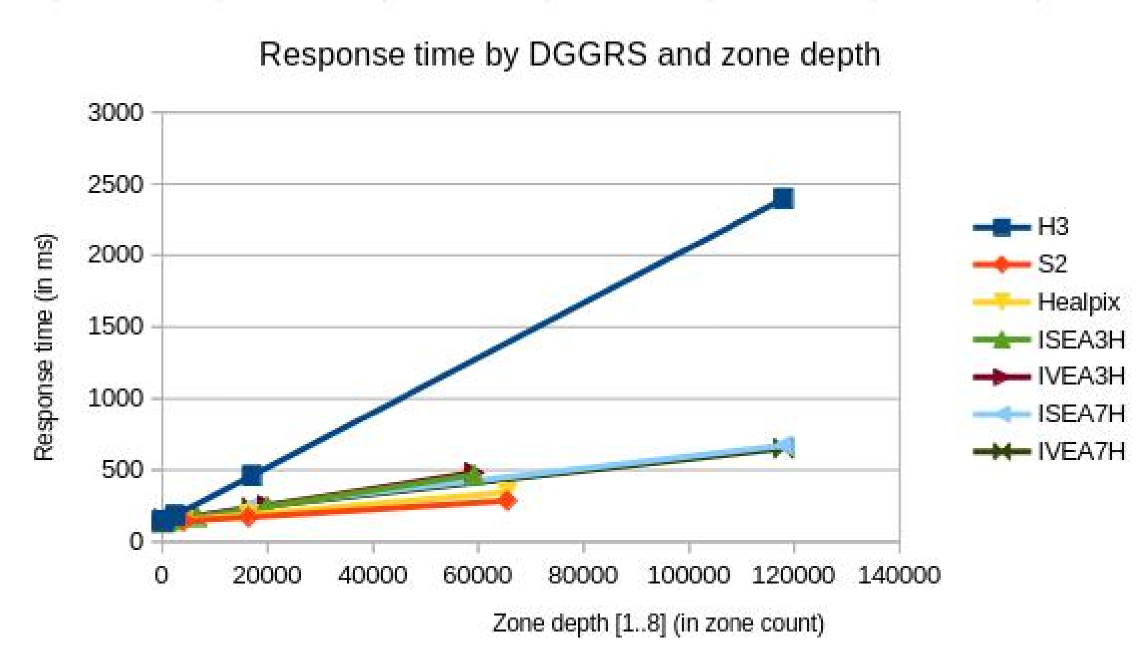
All the mandatory ones + some optional

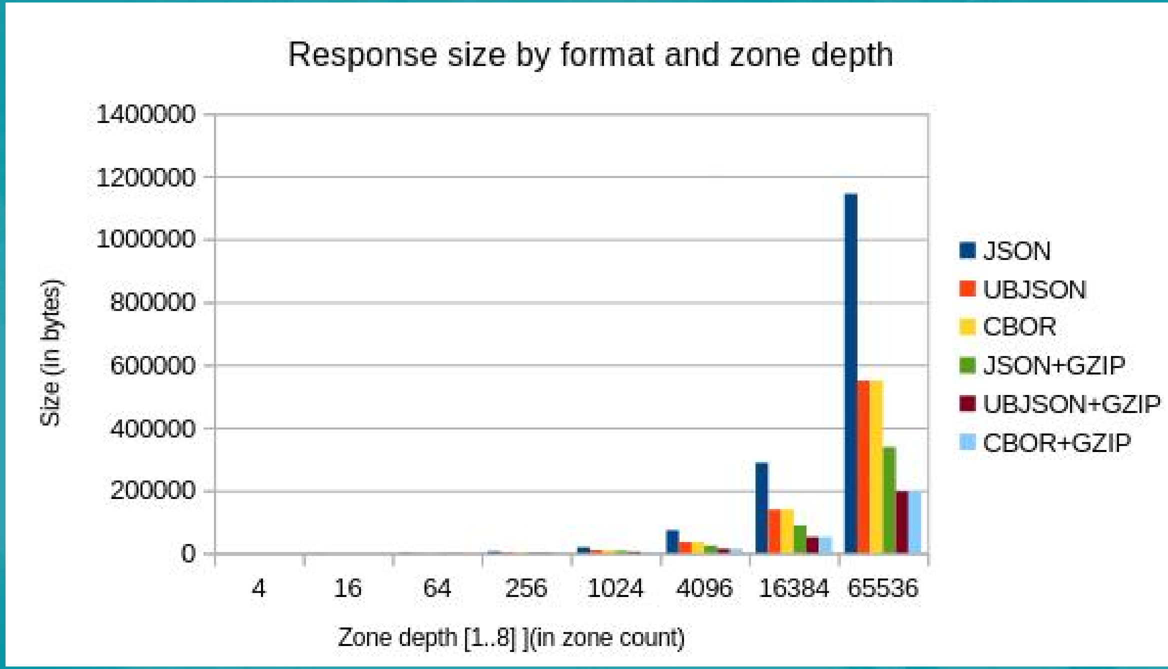
7

JSON, UBJSON, GeoJSON, Geotiff, NetCDF, Zarr, PNG output formats available.

Add many more possible on request.

Performance DGGRS





Tous : les performances sont toujours meilleurs en temps par zone avec un niveau de sous-zone important.
H3 : est le DGGRS le plus lent lors de ce test
S2 : est le DGGRS le plus rapide, suivi de pret par Healpix
ISEA7H or **IVEA7H** : sont des remplacants matures à utiliser à la place de H3.
A l'exception de H3 : tous peuvent fournir l'équivalent d’une tuile de 256×256 (65000 zones) en moins de 500ms.
CBOR : le format le plus efficace, suivi de UBJSON
GZIP : devrait être toujours activé si possible, améliorant la compression à un coût null.

Merci à tous

PROGRAMME OF THE EUROPEAN UNION

co-funded with

Discrete Global Grid System (DGGS)
Sentinel-2 feasibility study

Georgia Doxani I Serco for ESA
Nicolas Vila I CS Group

On behalf of the ESA S2 and S2 MPC teams

How ?

DGGS availability

Study and analysis of the current DGGSs, pros and cons

Suitability for EO data

Analysis in terms of **area distortion, compactness, indexing, raster storing size, resolution, radiometry preservation**, etc.

Tools availability

Investigation of **the maturity level of libraries/software/tools available** for DGGS implementation

Development of a DGGS demonstrator software

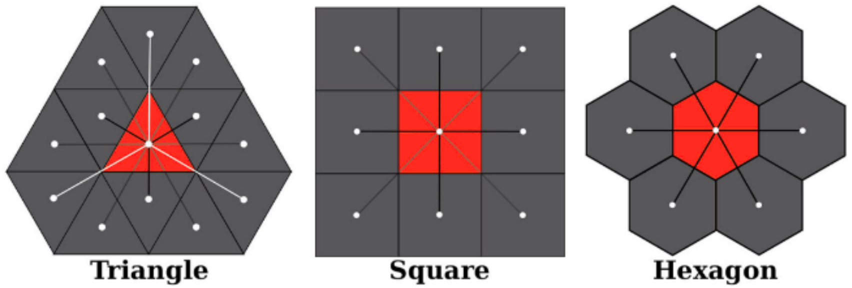
Selection of a DGGS with tools availability. Relatively few libraries dealing with DGGS, and these libraries do not have a large user community/ development inactivity during the last years

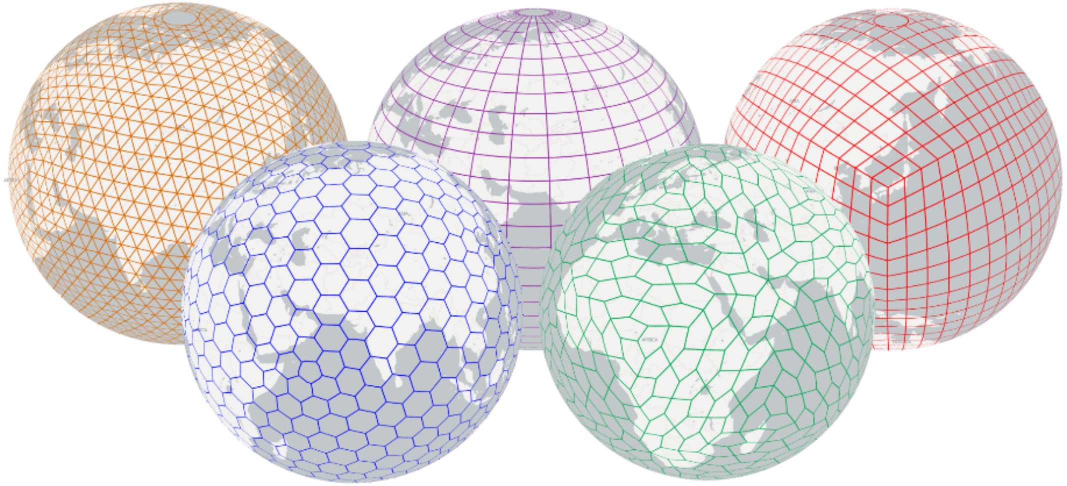
How ?

Phases 1 & 2 (2023): **study** and **select** an appropriate **DGGS Framework**, addressing:

- Heterogeneity of the sensors, resolution, georeferencing and data format, ...
- Increasing number of open remote sensing data,
- Use case: ARD products storage (Datacube)
- **rHEALPix** & **H3** DGGRS have been tested during the study (study's toolbox available on Github)

Phases 3 & 4 (2025): **development of a simple DGGS demonstrator** platform handling Sentinel-2 ARD products.





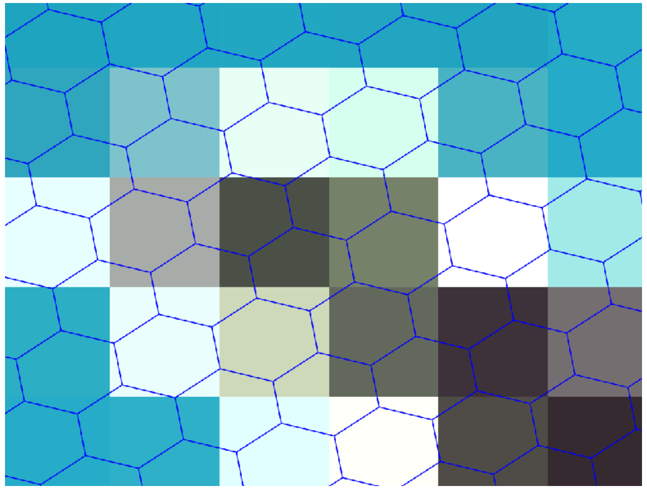
Different DGGS implementations

From S2 imagery pixels to DGGS cells

DGGS refinement levels and native products resolutions are not aligned.

Independently of the DGGS implementation choice, two strategies were possible for the storage of pixels data:

- “**Sparse**” DGGS cells storage for imagery data on DGGS grid: in this case each pixel is projected into the corresponding DGGS cell, with the highest refinement level. This leads to have cells with no-data when native resolution is lower than the grid refinement level.
- **Interpolated data** on DGGS grid. In this case, an interpolation is made on the data so that all DGGS cells contains interpolated values:
  - nearest-neighbor interpolation (fast)
  - **bicubic** interpolation (accurate)



DGGS refinement level finer than original S2 image resolution

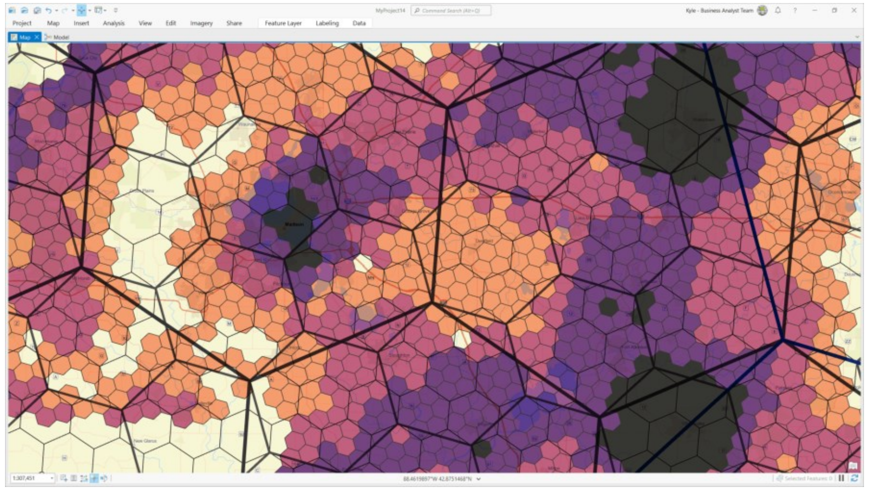
Res	Average Hexagon Area (m^2)	Pentagon Area* (m^2)
8	737,327.598	372,048.038
9	105,332.513	53,147.195
10	15,047.502	7,592.318
11	2,149.643	1,084.609
12	307.092	154.944
13	43.870	22.135

DGGS (H3) cells area, according to the Refinement Level

Analysis-Ready Data Processing & Interpolation

Radiometry preservation in DGGS datacube can be quite a challenging step

- **Regridding** imagery products on a discrete global grid, depends on the DGGS implementation : (r)HEALPix, IGO7, H3, etc.)
- DGGS cells are **oversampled** regarding the native resolution, to avoid the loss of information, producing an “antialiasing” effects.
- At first simple **interpolation** was used: we assigned DGGS cells values from of the raster pixel which center is the closest to the cell centroid.
- Then we evaluated **bicubic** & nearest neighbor impact on image quality




```
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```


Sample S2 data on H3 DGGS

Schema of the IQ evaluation

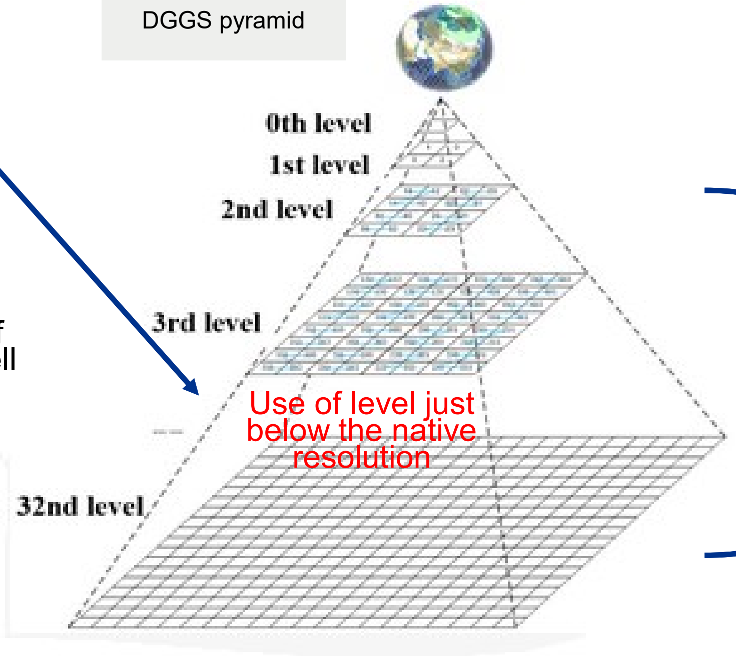
- Begin from L1C directly, although from L1B would be more operational (and with better quality).
- Different resampling solutions from input to DGGS (Bicubic resampling preferred)
- Different resampling solutions from DGGS to output (own method preferred, bad results from off the shelf solutions)

Image Quality
- Dense correlation : geometric shifts
- Comparison of PSF (possible blurring)
- Radiometric shift (in uniform sites)

S2 L1C tile (ortho UTM square pixel 10:20:60m)

S2 output in same geometry of the tile

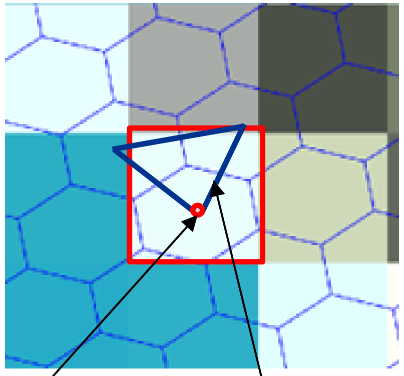
DGGS pyramid



Use of level just below the native resolution

Load in DGGS
resampling with NN, and BICUBIC
considering lat,lon of centroid of DGGS cell

Rasterizing from DGGS on the same output geometry
- With off the shelf solutions
- With our own algorithm : linear interpolation inside triangle, at the center of the output pixel.



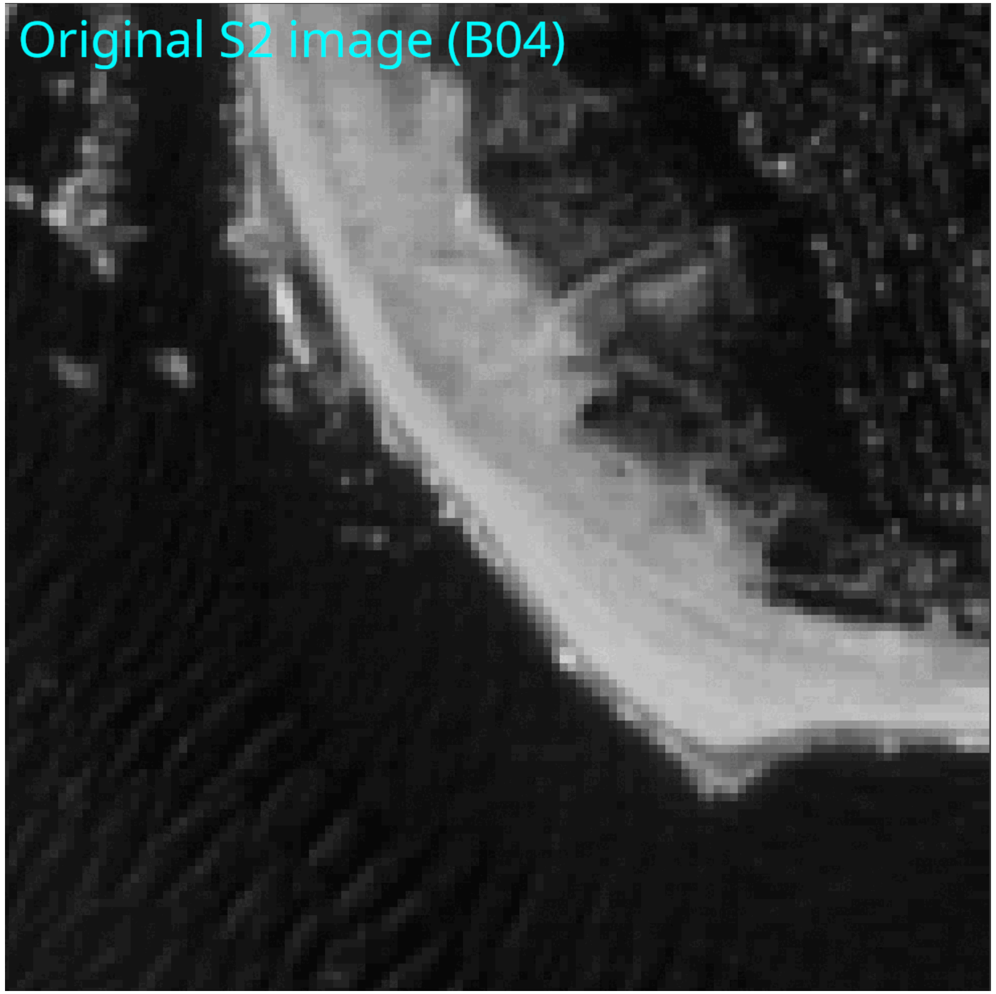
Center of output pixel

Triangle with the DGGS centroids the closest to the output pixel center

Evaluation of Image Quality when using DGGS

Simple image comparison (S2 band 04, 10m resolution)

Simple image comparison (S2 band 04, 10m resolution)

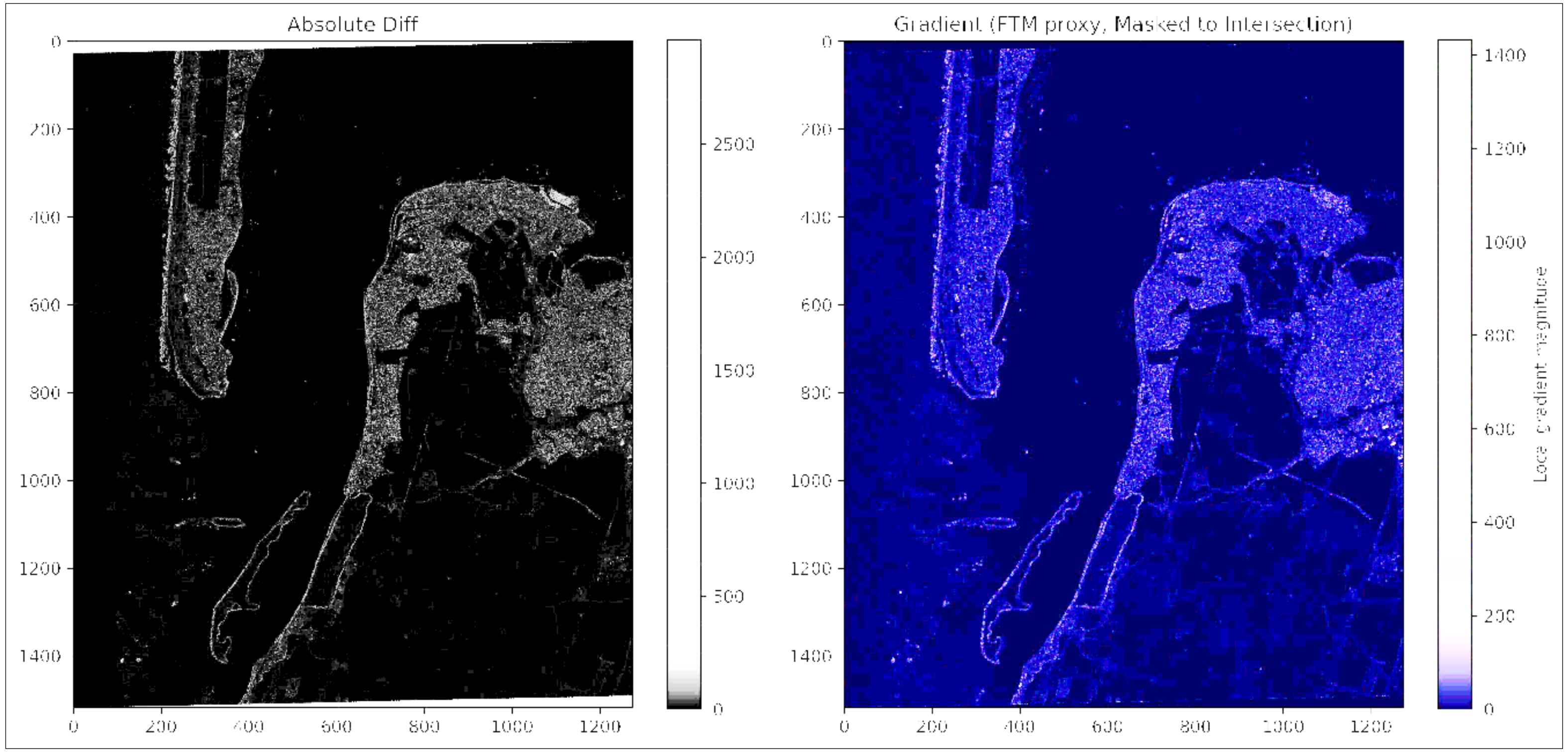


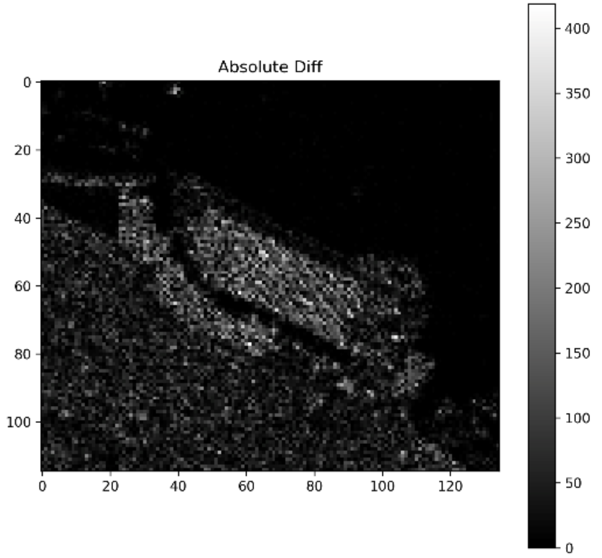
Evaluation of Image Quality when using DGGS

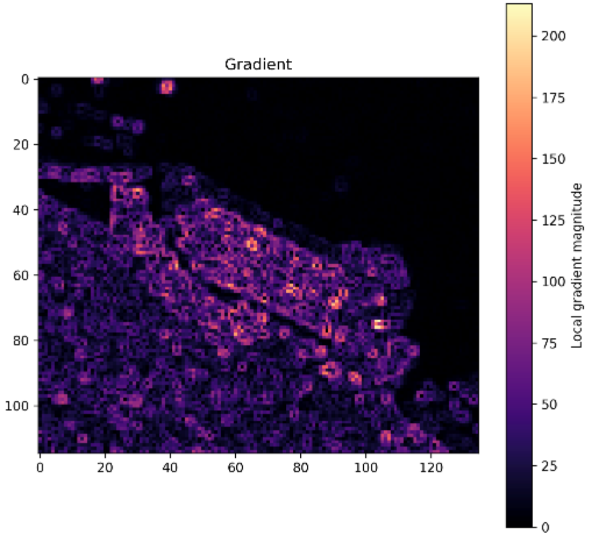
- Study of images of differences (input / output), comparison with gradient global image of test, harbor zone.

⇒ No radiometric shift in uniform zones.

⇒ Variations in high gradient zones due to small blurring



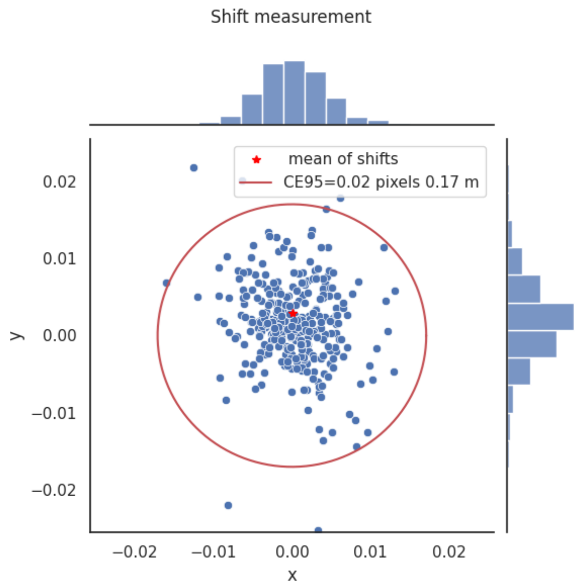


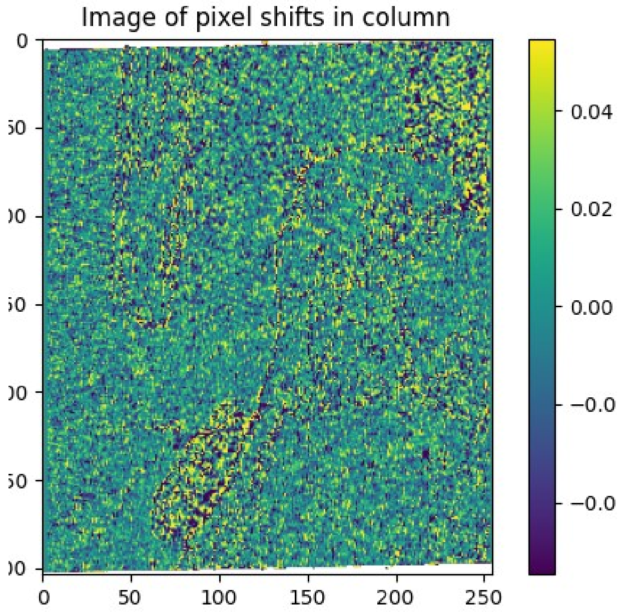


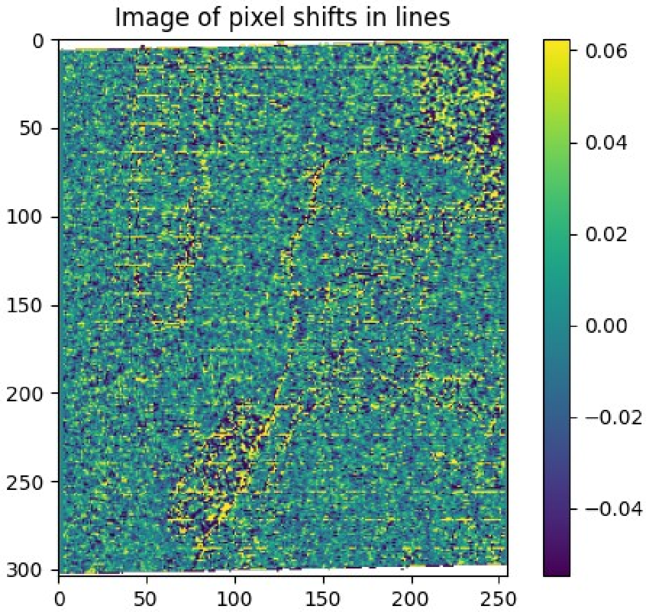
Evaluation of Image Quality when using DGGS

Geometric study using dense correlation.

- 0 shift measured,
- no trend inside the images,
- only correlation noise visible







Proposed Way forward :

- Begin checks from L1B directly (avoid 1 interpolation step, and potential loss of MTF)
- Test other interpolation methods from DGGS to User projection (bicubic like, surface intersection)
- Quantitatively assess the MTF loss on natural MTF target sites from MPC.

DGGS Demonstrator Architecture

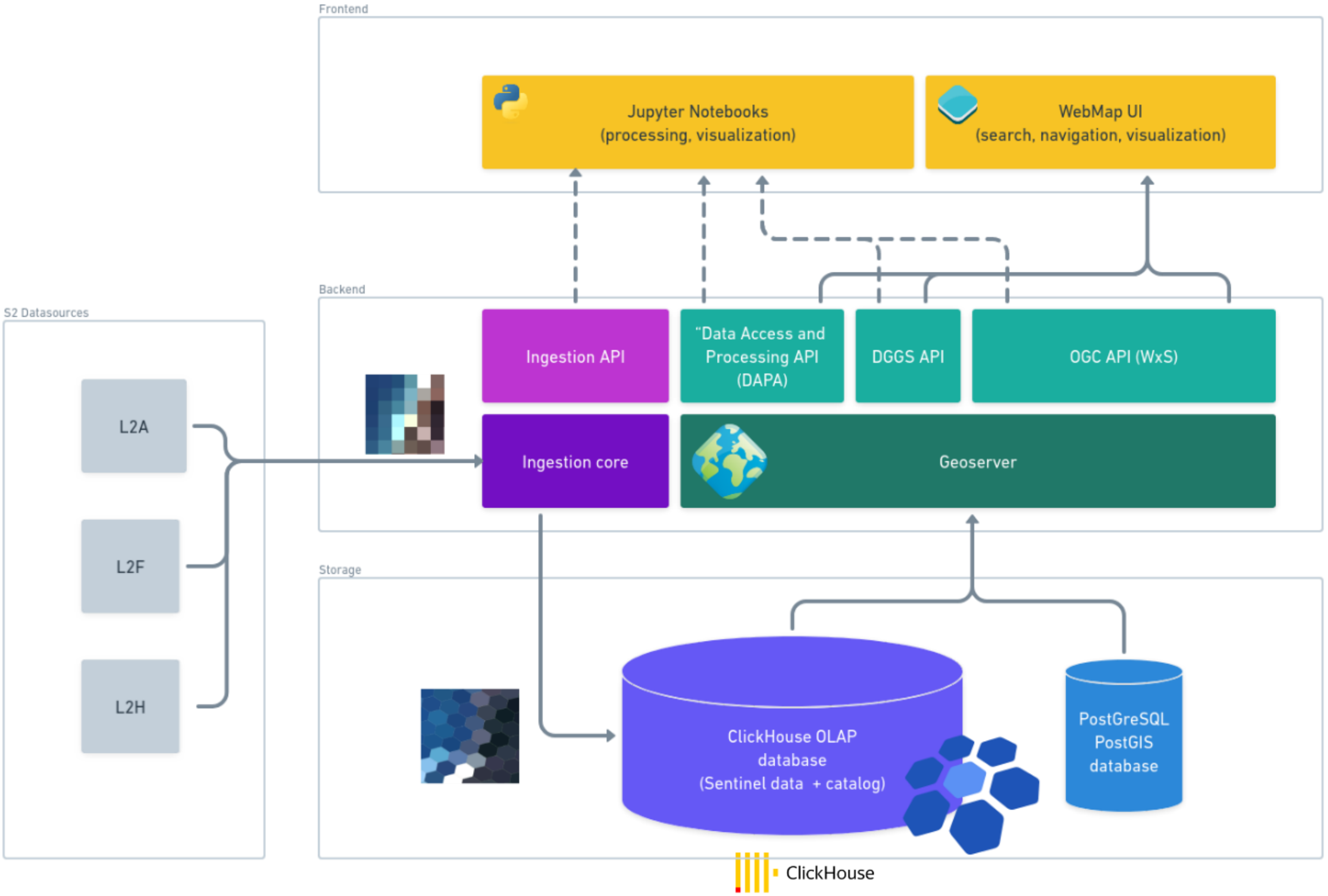
a Sopra Steria company

PROGRAMME OF THE EUROPEAN UNION

co-funded with

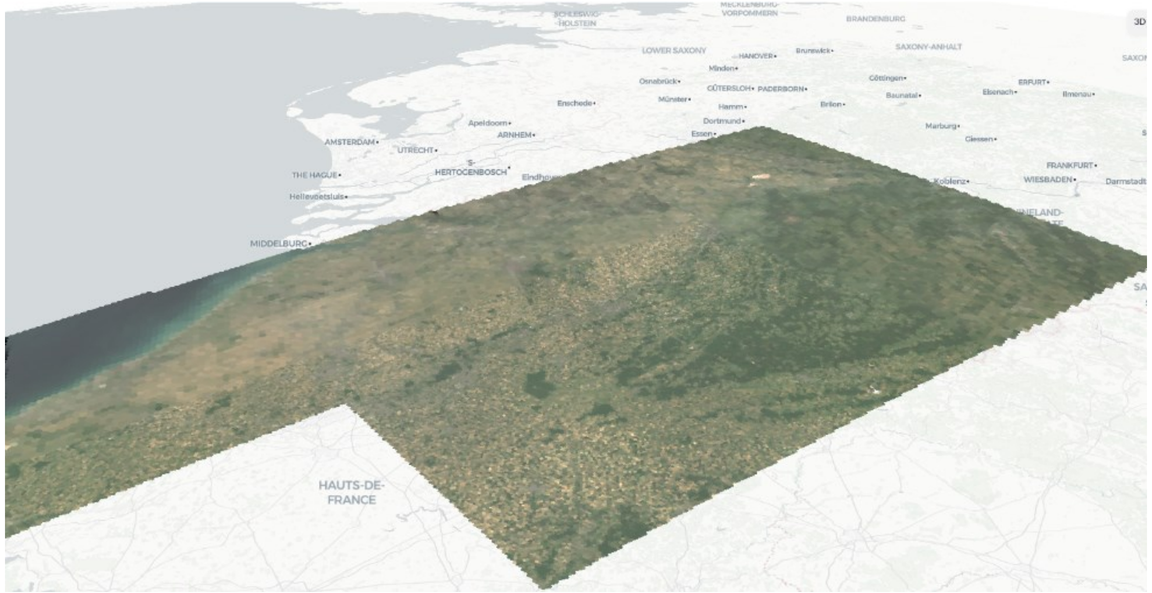
Demonstrator objectives:

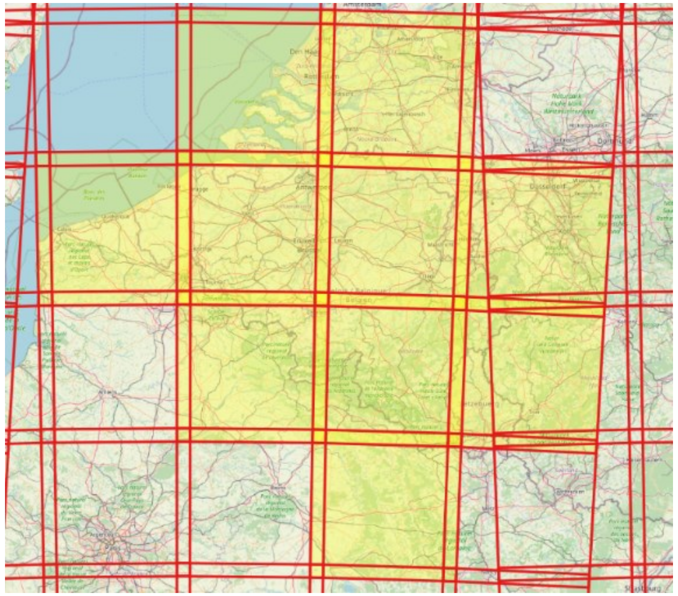
- Development of a pilot demonstrator at country scale : **Belgium** area
- Explore & demonstrate efficiency in terms of **ARD product storage**, search, visualization, and analysis
- Support of various products:
  - **Sentinel2** (L2A/L1C)
  - **Sen2Like** products (L2F, L2H),
  - **Landsat** 8/9 *(soon)*,
  - **Sentinel3** optical *(soon)*
- Extension with sample DEM dataset (Copernicus EU-DEM)
- OGC Standards support



DGGS Demonstrator Country-Level datacube

- The demonstrator **datacube** is currently & progressively populated with **one year** of Sentinel2 regridded data (ongoing work)
- For now, only 7 Sentinel 2 MGRS tiles are used (out of the 10 necessary to fully cover Belgium)
- A few sample **development datasets** have already been generated over Belgium country with L2A S2 tiles, and Toulouse area, and Latium/Roma region in Italy





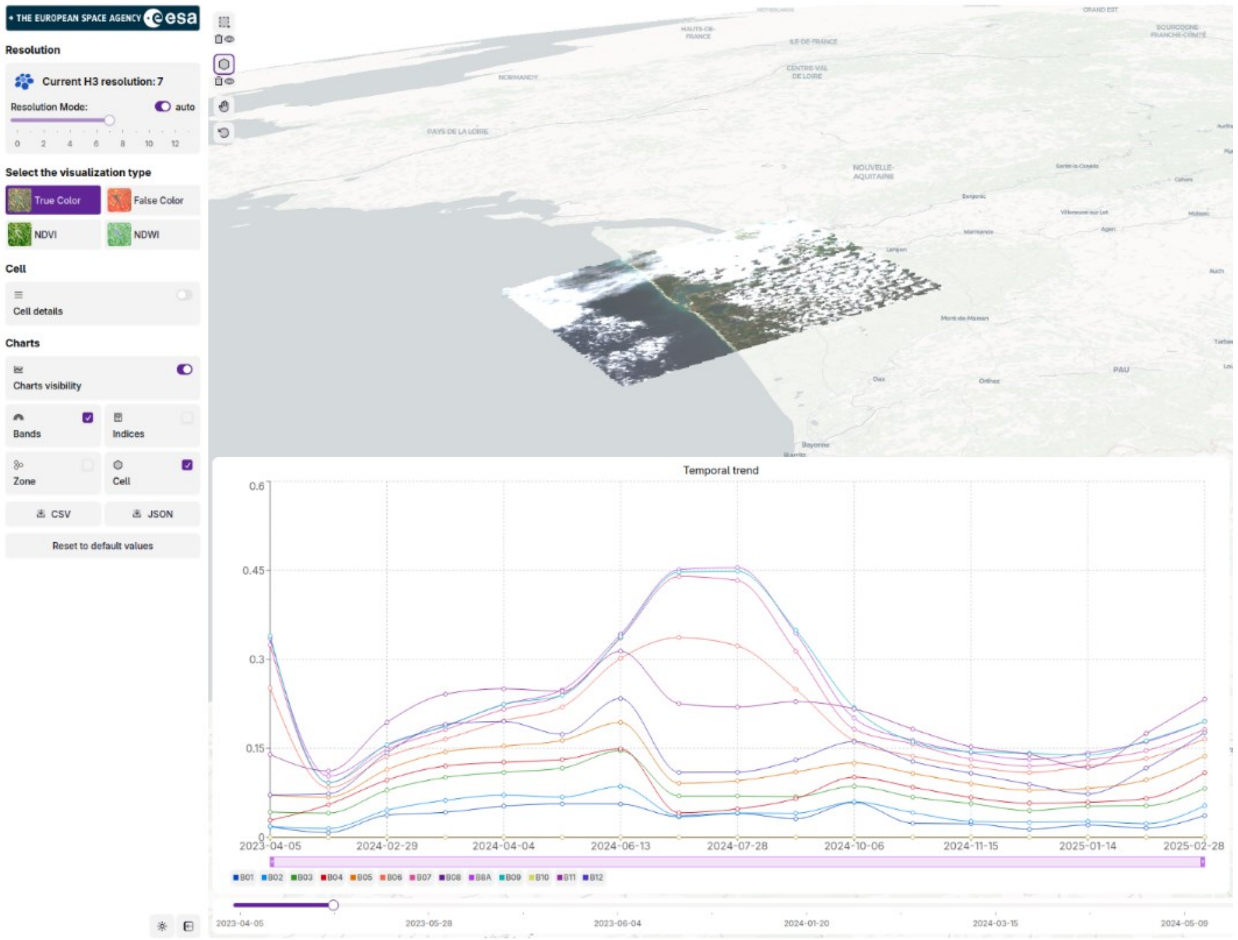
Belgium area coverage using 7 center MGRS Sentinel2 tiles

DGGS Demonstrator Web User Interface

The demonstrator proposes a user interface to navigate and dig through the **datasets** and **DGGS datacubes**. Many different combination of mapping frameworks were tested for this purpose to assess the best performance and user experience:

- OpenLayers, **MapLibreGL + DeckGL,** KeplerGL, Lonboard

- With DGGS data we are between vector and raster: “**vectorized / discretized” ARD data”**.

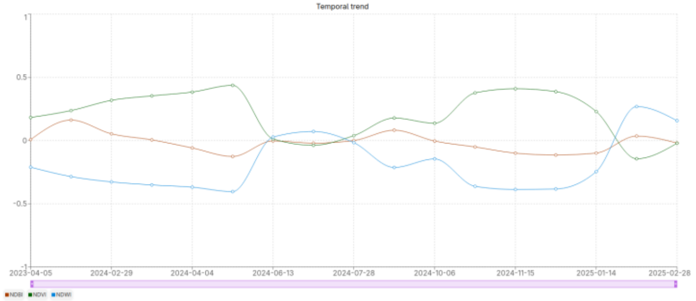


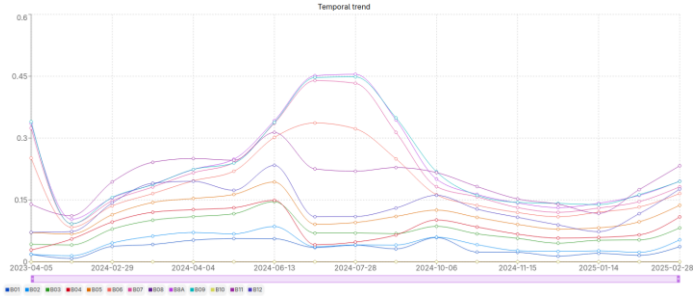
Web frontend and timeseries from datacube

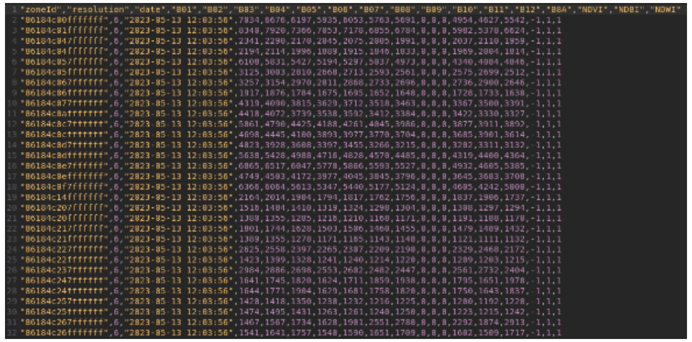
DGGS Datacube On-The-Fly Analysis

Making **DGGS Analysis-Ready-Data** available through **Web UI** and **APIs**:

- Extraction of **per-cell temporal timeseries/trends** at different DGGS **refinement level**
- **AOI selection** implemented on the map frontend
- The frontend allows to display basic graphs for **radiometric indices**, or **bands data timeseries**
- Standard and well-known APIs are used to extract time series data.
- Making the output accessible and downloadable in well-known format. (JSON and/or CSV formats will be used by default for exports)



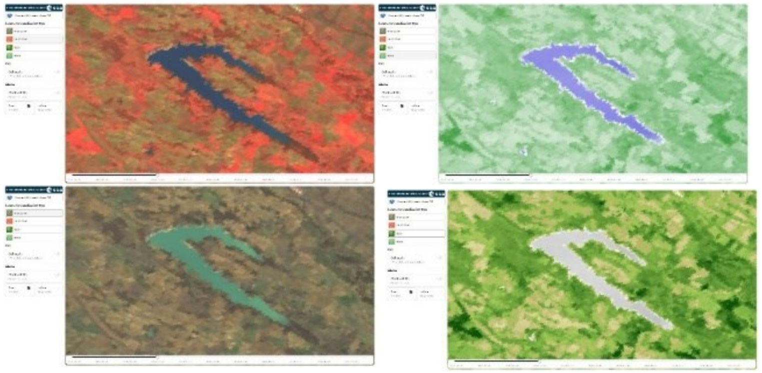




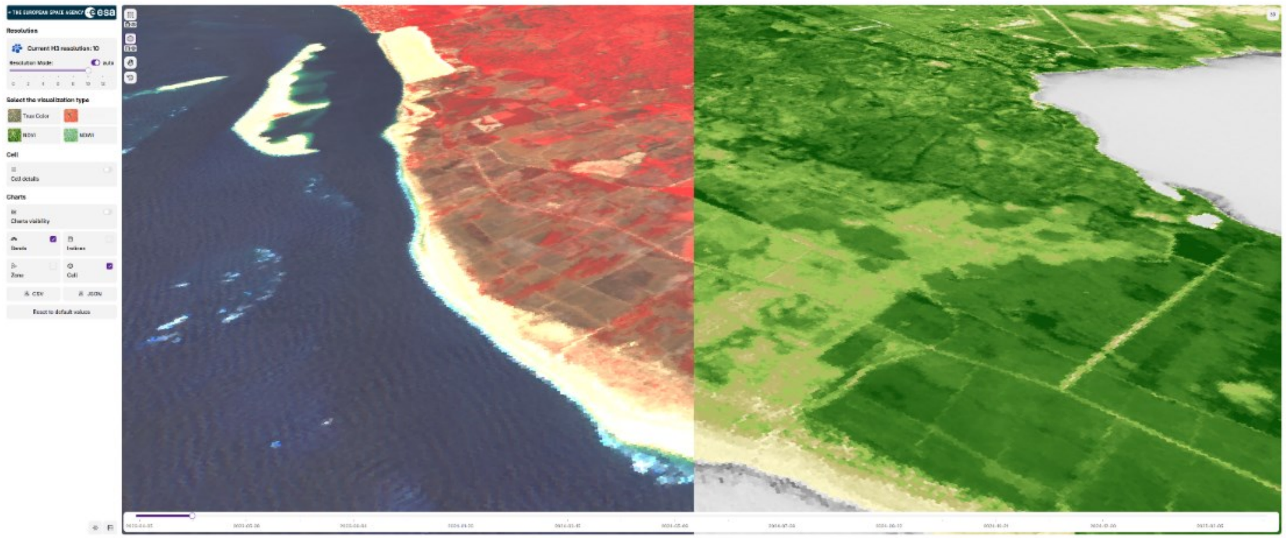
Sentinel2 DGGS data exported

DGGS Datacube On-The-Fly Analysis

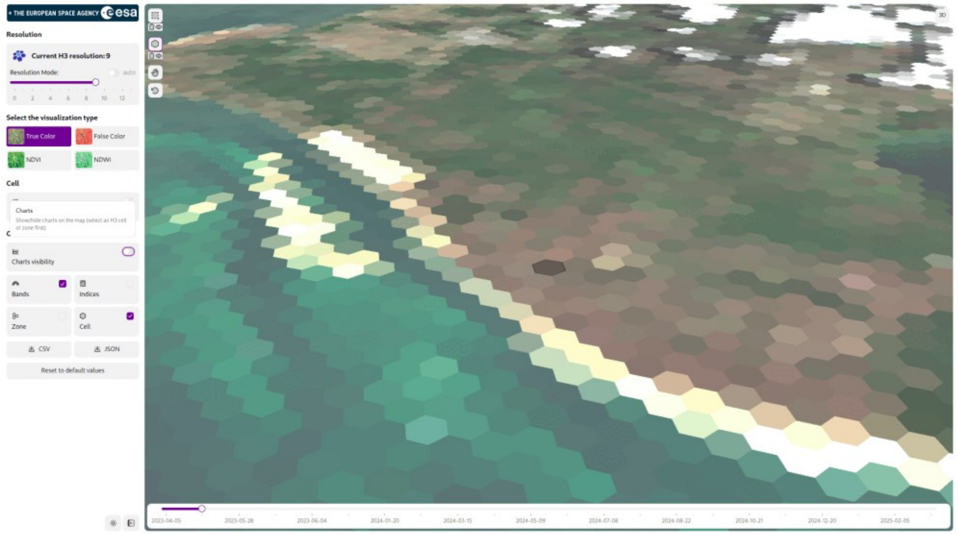
- The demonstrator proposes generation of **simple radiometric indices** (e.g. NDVI, NDWI, NDBI, LAI, etc.) combining data across different grid levels;
- Radiometric Indices can be implemented on **both client and server sides.** The demonstrator is processing data **on the client** (frontend) from the raw data.



Radiometric indices



False colors & NDVI rendering



Analysis at different scales

DGGS Demonstrator
Basic Analysis & Radiometric Indices

DGGS Demonstrator
Lessons learned & way forward.

- Some lessons learned during the development of the DGGS demonstrator
  - **The perfect DGGS does not exist**. The choice of a specific DGGS to handle different missions and sensor characteristics is always leaded by the use case.
  - **Cloud native formats** will be the key to build planetary scale and serverless DGGS datasets (Zarr, Parquet)
  - **Equal Area cells DGGS:** for a data cube implementation for managing environmental data and spatial statistics, having equal area cells is desired (**HEALPix** , **IGEO7**/ISEA7H_7Z, etc.)
  - DGGS "regridding process" can be improved and new **interpolation methods** could be tested to improve the result and reduce the radiometry loss in MFT even further.
  - Tests to be made on **L1B + S2VM** geolocation grids (then DGGS conversion and L1C comparison)
- Many challenges pave the way to a DGGS adoption: **multiple grids, different storage solutions,** standard **APIs,** and new ways to interact with imagery products : **software, pipelines, tools, frameworks, etc.**)
- **Standards** are being developed (OGC/ISO), tested in OGC pilots, and **best practices** will follow
- Global grids are still considered as experimental, but we can see today that there is **a growing community** around DGGS, and thanks to early initiatives lead by space agencies.

C.01.07 Discrete Global Grid Systems (DGGS)

Hexahedral Projections For Future Global Gridding Solutions

Peter Strobl [1] *(Presenter)*, Aleksandar Dimitrijevic [2]

AFFILIATIONS: 1. European Commission, Joint Research Centre (JRC) 2. University of Niš, Faculty of Electronic Engineering

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Introducing the OGC API – Discrete Global Grid Systems Standard for Enhanced Geospatial Data Interoperability

Matthew Brian John Purss [1] *(Presenter)*, Jérôme Jacovella-st-louis [2], Alexander Kmoch [3], Wai Tik Chan [3], Peter Strobl [4]

AFFILIATIONS: 1. Pangea Innovations Pty Ltd 2. Ecere Corporation 3. Landscape Geoinformatics Lab, Institute of Ecology and Earth Sciences, University of Tartu 4. European Commission Joint Research Centre

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Interoperable Global and Local Indexing of Earth Observation Data Referenced to ISEA Discrete Global Grid Systems for Efficient Storage, Processing and Transmission

Jérôme Jacovella-st-louis [1] *(Presenter)*, Marta Padilla Ruiz [2], Luís Moreira de Sousa [3], Perry Peterson [2]

AFFILIATIONS: 1. Ecere Corporation 2. University of Calgary 3. University of Lisbon

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Highly Scalable Discrete Global Grid Systems Based on Quaternary Triangular Mesh and Parallel Computing

Davide Consoli [1] *(Presenter)*, Daniel Loos [2], Luís Moreira de Sousa [3], Tomislav Hengl [1]

AFFILIATIONS: 1. OpenGeoHub Foundation 2. Max Planck Institute for Biogeochemistry 3. Instituto Superior Técnico

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A DGGS (Discrete Global Grid System) Datacube Demonstrator For Sentinel-2 Data

Nicolas Vila [1] *(Presenter)*, Georgia Doxani [2], Silvia Enache [1], Ferran Gascon [3], Rosalinda Morrone [4], Valentina Boccia [3]

AFFILIATIONS: 1. CS Group 2. Serco Italia SpA 3. European Space Agency (ESA, ESRIN) 4. Starion Group

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XDGGS: Integrating Xarray with Discrete Global Grid Systems for Scalable EO Data Analysis

Justus Magine [1] *(Presenter)*, Benoit Bovy [2], Jean-Marc Delouis [1], Anne Fouilloux [3], Lionel Zawadzki [4], Alejandro Coca-Castro6 [5], Ryan Abernathey [6], Peter Strobl [7], Daniel Loos [8], Wai Tik Chan [9], Alexander Kmoch [9], Tina Odaka [1]

AFFILIATIONS: 1. LOPS - Laboratoire d'Oceanographie Physique et Spatiale UMR 6523 CNRS-IFREMER-IRD-Univ.Brest-IUEM 2. Georode 3. Simula 4. CNES 5. The Alan Turing Institute 6. Earthmover PBC 7. European Commission Joint Research Centre 8. Max Planck Institute for Biogeochemistry 9. University of Tartu, Institute of Ecology and Earth Sciences, Landscape Geoinformatics Lab

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C.01.07 Discrete Global Grid Systems (DGGS)

Main Takeaways

DGGS are moving from research to operational reality through refined methods, standards, demonstrators, and tools.

They deliver efficiency, scalability, and interoperability for next-generation EO infrastructures.

Adoption will require continued tool development and community engagement.

DGGS will be a cornerstone for global-scale EO analysis and the Digital Twin Earth.

Thank you for your attention!

DGGS Demo

Any questions? Feel free to contact us:

DGGS Toolbox

georgia.doxani@ext.esa.int
nicolas.vila@cs-soprasteria.com