Copernicus Human Settlement layer for SORA

A joint presentation by EUSPA and JRC at EASA Population Density Workshop, Cologne 2023-10-06

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EUSPA
European Union Agency for the Space Programme

European Commission

EU Agency for the Space Programme
Copernicus EO system

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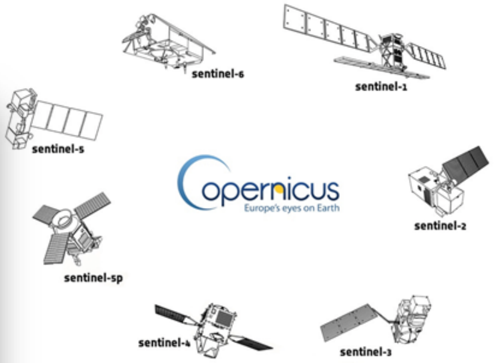
European Union's Earth observation programme, looking at our planet and its environment to benefit all European citizens
Copernicus provides **free** and **openly** accessible data to all users around the world



SPACE

In Situ

IN SITU

Atmosphere Monitoring
Copernicus Marine Service
Land Monitoring
Climate Change
Security
Emergency Management

SERVICES

Nr.1 world provider of space data and information

20TB/day

European Commission

Ground Risk Assessment usecase activity

EUSPA activity 2022-2023

Pilot project with Flying Basket drone operator, including SORA and flight demonstration in the Italy.
Using Copernicus Urban Atlas data.

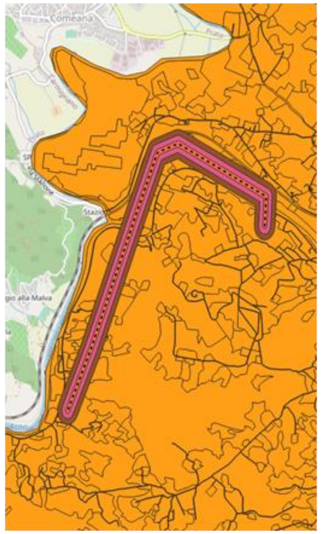
Set-up the core parameters → Flight plan information (with corresponding buffer zones) → Copernicus Urban Atlas data (LU/LC) → Calculate % of the flight track flown over each risk category → Assess UAS Ground Risk Class → Calculate proportional risk and final Risk score

Time of the day
- Peak
- Off-peak

Drone size
- 1
- 3
- 8
- 8+

OPS type
- VLOS
- BVLOS

Controlled areas*
- None
- Yes

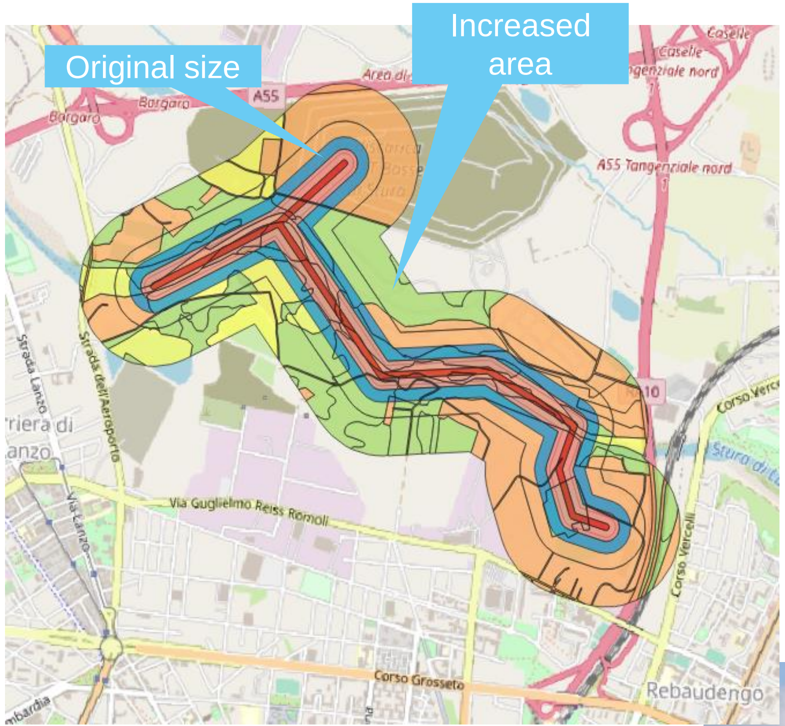


Legend	
Critical infrastructure	E
Populated areas that are less populated during off-peak hours	D
Sparsely populated areas that are most likely empty during off-peak hours	C
Empty areas that remain empty regardless of time of the day	B
Areas marked as Controlled by the operator	A

UAS dimensions		1	3	8	8+
Type of operation	Risk				
VLOS/BVLOS	A	1	2	3	4
VLOS	B	1.2	2.2	3.2	4.2
BVLOS	B	1.5	2.5	3.5	4.5
VLOS	C	2	3	4	5
BVLOS	C	3	4	5	6
VLOS	D	4	5	6	8
BVLOS	D	5	6	8	10
VLOS	E	9	N/A	N/A	N/A
BVLOS	E	10	N/A	N/A	N/A

Ground Risk Assessment usecase activity

Copernicus Urban Atlas



Pilot project in cooperation with

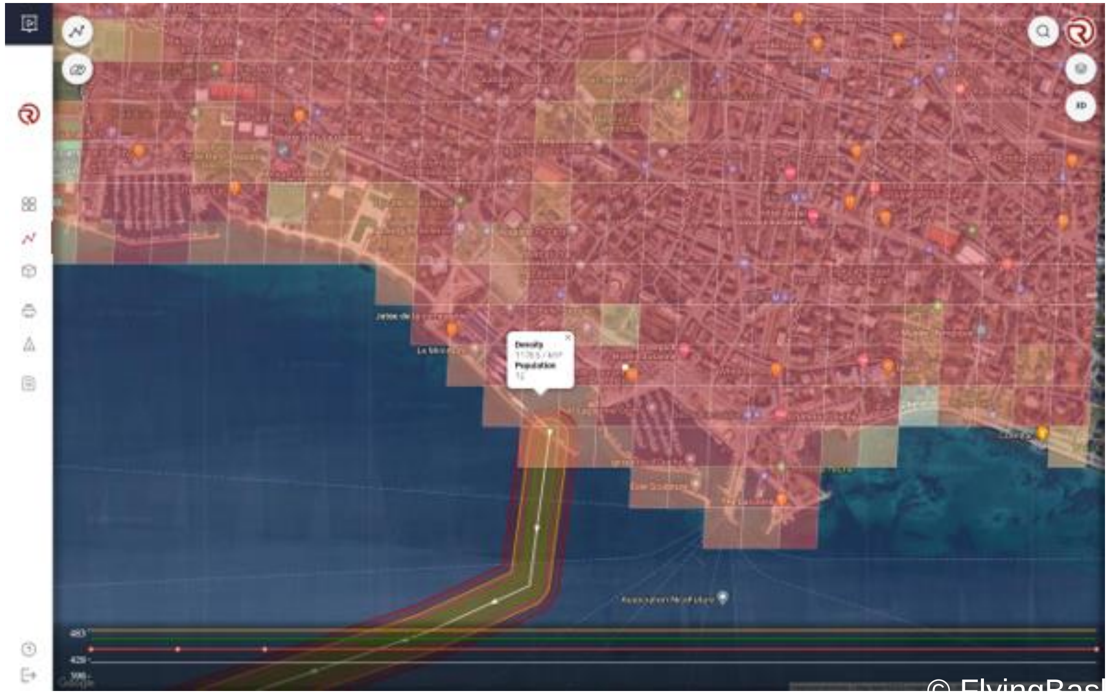
FlyingBasket

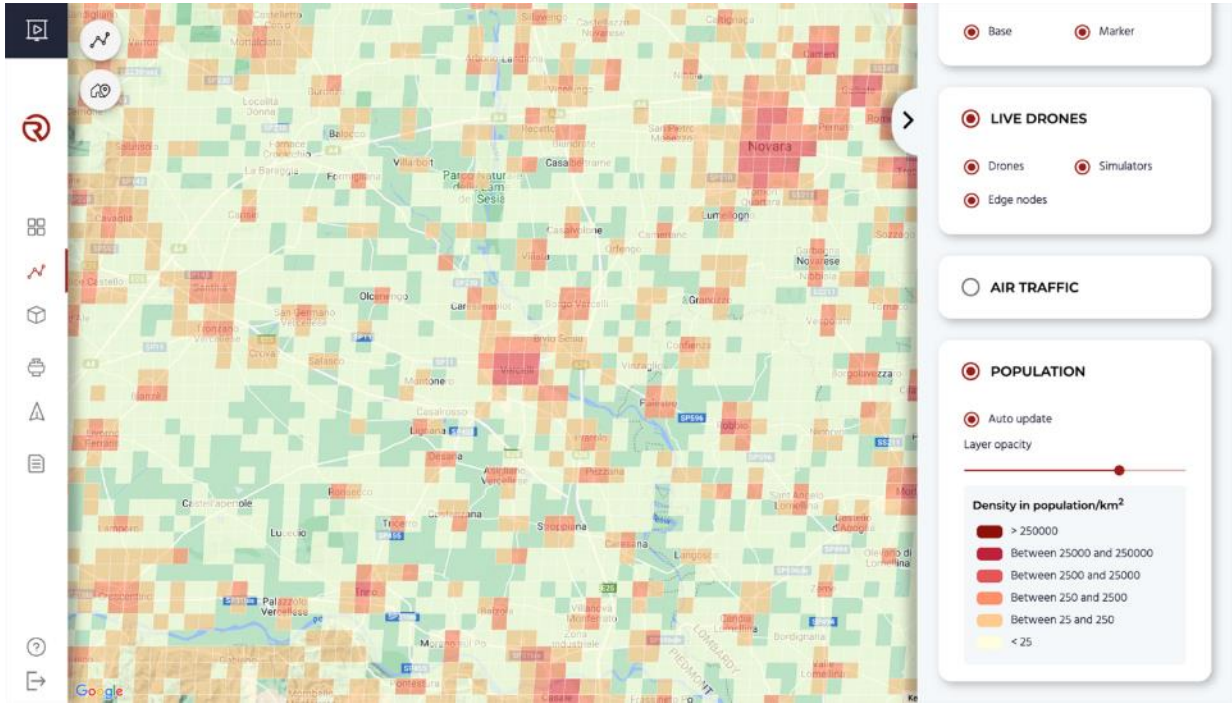
- **Pilot project** with Flying Basket drone operator, including SORA and flight demonstration in the Italy
- **Development of the Copernicus GHSL** between drone operators, NAA's
- **EUSPA** presented Copernicus GHSL in JARUS Plenary meeting in Rome (04/2023)
- **EUSPA** joined JARUS SRM group

Drone operator example - RigiTech

Copernicus GHSL implemented into their Flight planner, population density resolution according to SORA

Copernicus DEM implemented into their Flight planner - profile of the flight trajectory, 3D view





Credit: RigiTech

CAA, ANSP example - Poland

GHSL implemented into the e-SORA tool for ground risk map

PANSA

Urząd Lotnictwa Cywilnego

2. Ground risk map –high resolution

GHSL
Global Human Settlement Layer
100m x 100m, 2020

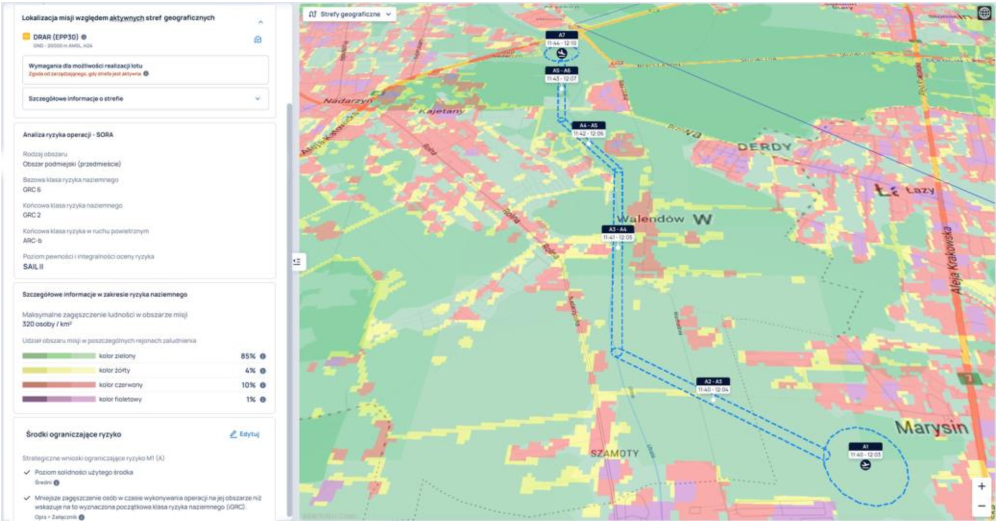
National Database of Topographic Objects,
Vector data, July 2023

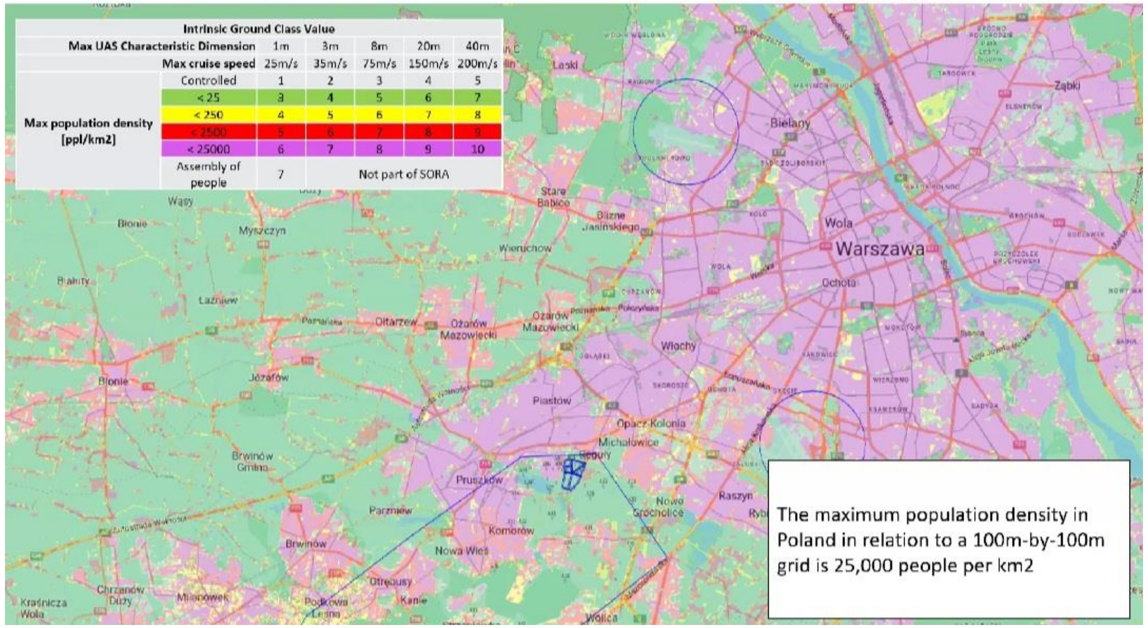
Information about the type of building, recreational areas, sports facilities, roads, sidewalks etc

GROUND RISK MAP
Resolution 20m by 20m

1. Maximum population density
2. Percentage limit of boxes of a given category

Ottawa | 20 September 2023 r.



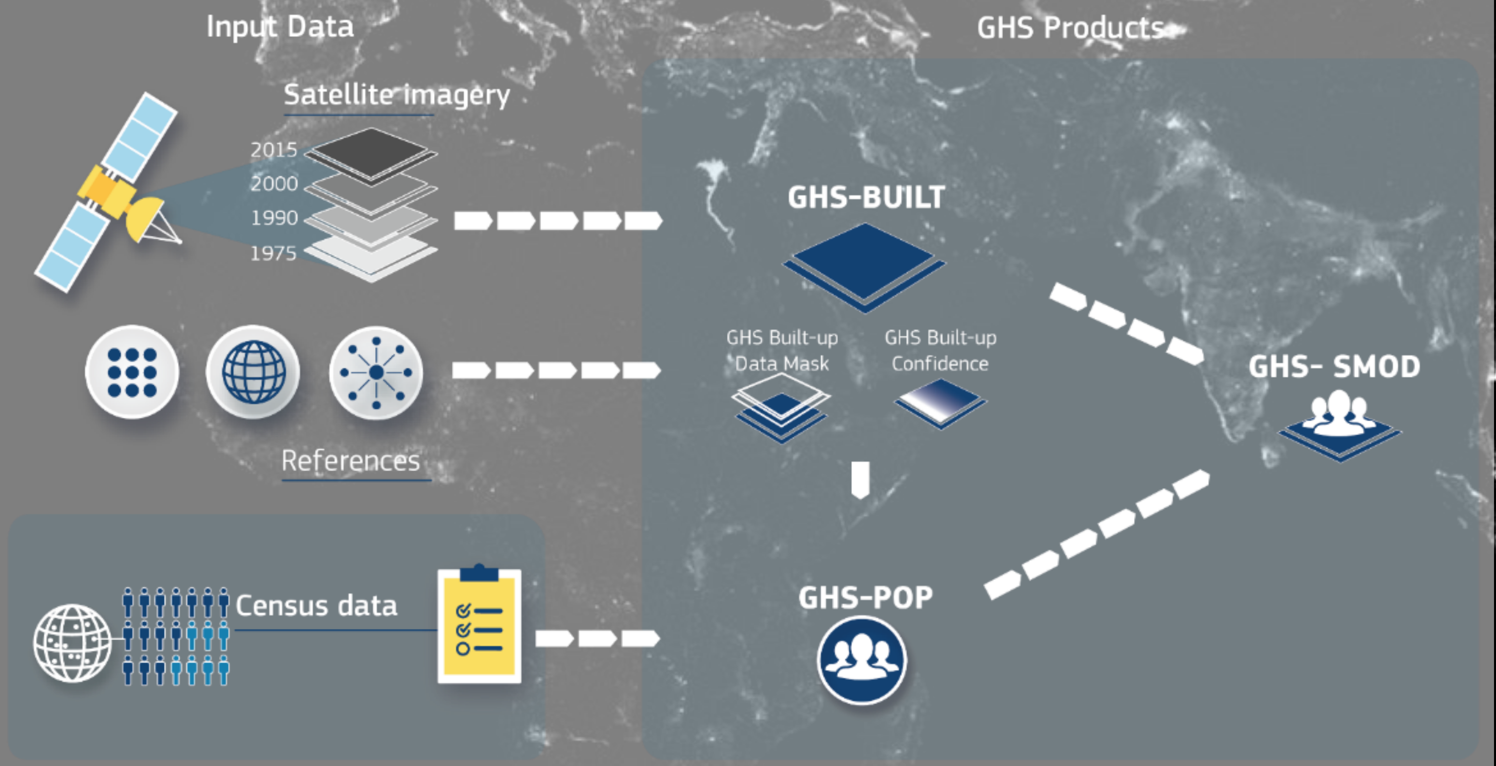


Intrinsic Ground Class Value						
Max UAS Characteristic Dimension		1m	3m	8m	20m	40m
	Max cruise speed	25m/s	35m/s	75m/s	150m/s	200m/s
Max population density [ppl/km2]	Controlled	1	2	3	4	5
	< 25	3	4	5	6	7
	< 250	4	5	6	7	8
	< 2500	5	6	7	8	9
	< 25000	6	7	8	9	10
	Assembly of people	7	Not part of SORA			

The maximum population density in Poland in relation to a 100m-by-100m grid is 25,000 people per km2

Global Human Settlement Layer

- Monitoring the human presence on planet Earth:
  - Population
  - Built-up areas
  - Settlements
- Free & open data
- Operational service



https://ghsl.jrc.ec.europa.eu

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GHSL data in a nutshell

- **Population density** [number of resident population, 100 m]
- **Built-up surface** [m^2, 10 m]
- **Building height/volume** [m (height), m^3 (volume), 100 m]
- **Degree of Urbanization** [cities, towns/suburbs, villages, 1 km]
- **5 year time series 1975-2030**
- **Global coverage**

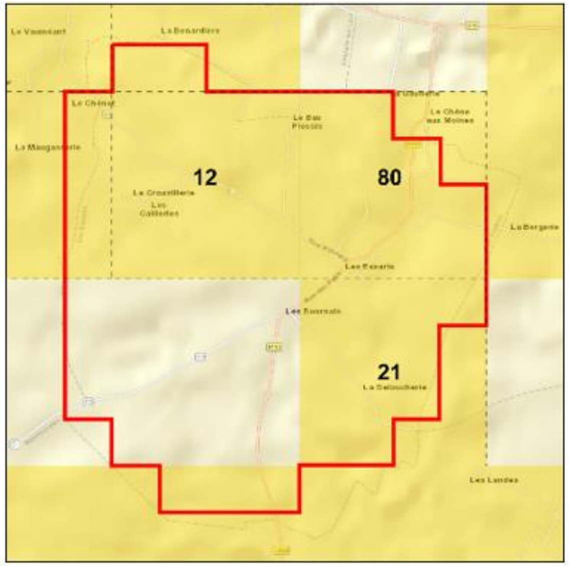
https://ghsl.jrc.ec.europa.eu

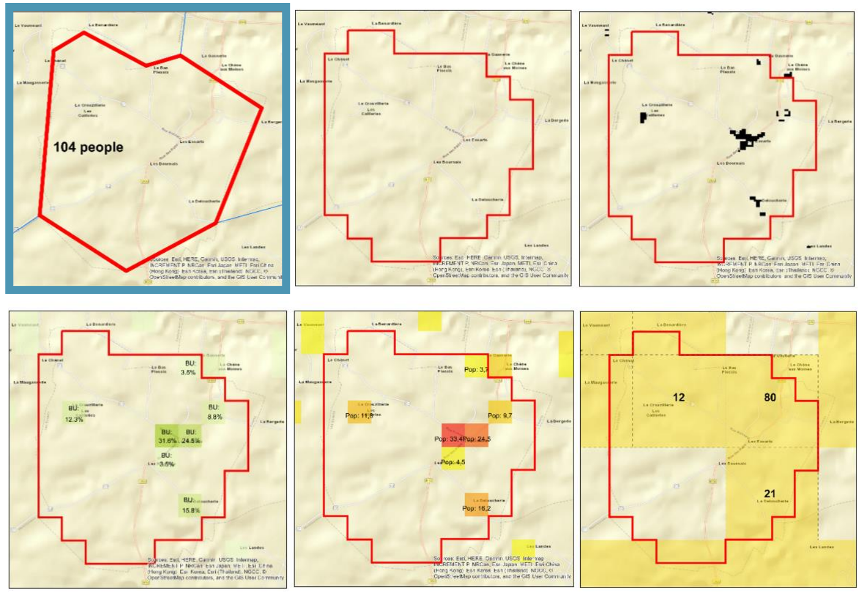
- Operational Data Production under the Copernicus Programme
  - Bi-annual updates 2022, 2024, 2026
    - for built-up areas most recent Sentinel-2 imagery
    - for population density latest census projected to the reference year of the built-up surface
    - Quality controlled and validated

Producing a Population Grid

A population grid is generally produced through **disaggregation of population counts attached to census/administrative units**.

The disaggregation in GHSL environment is driven by the density of **built-up areas as proxy for locations of residential population**





GHSL Population data source

- Socioeconomic Data and Applications Centre (SEDAC)
- Gridded Population of the World (GPWv4.11) at polygon level

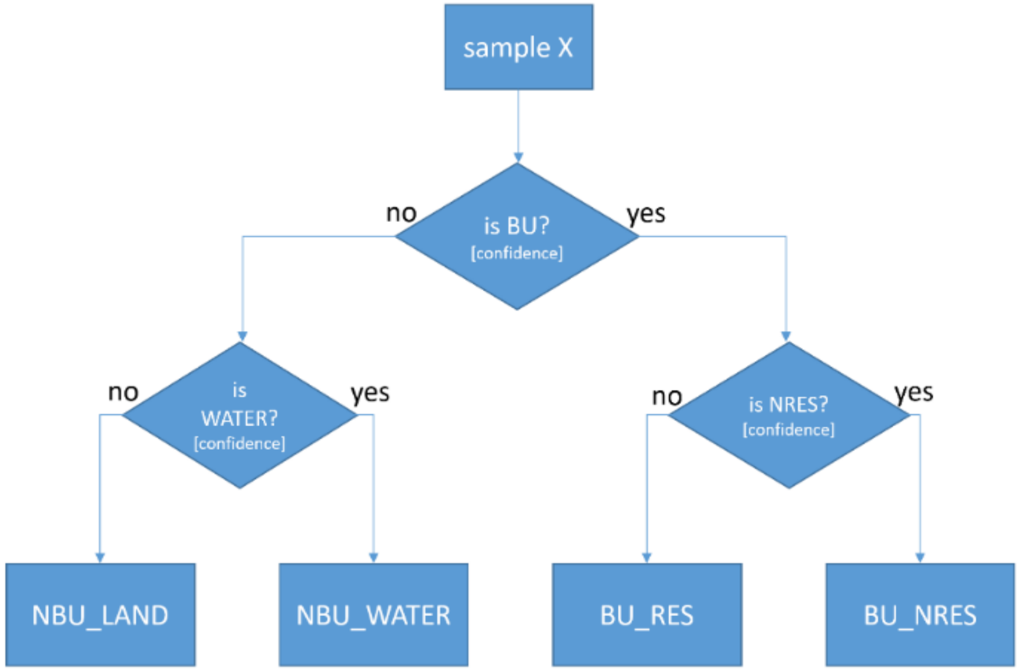
Input census data provided by National Statistical Offices

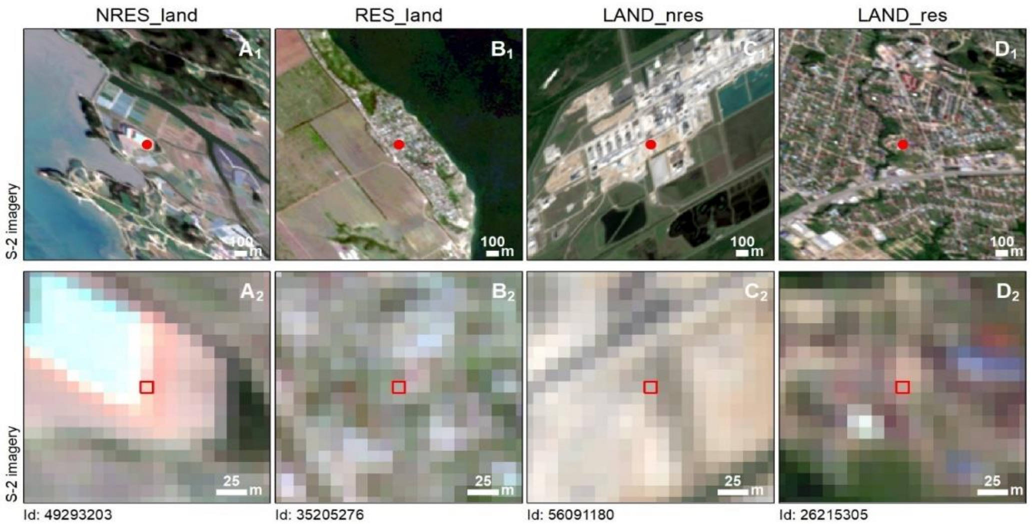
Columbia Climate School
Center for International Earth Science Information Network

Country	Census Year	Admin Level	Number of Units
Botswana	2011	2	29
Finland	2011	2	320
France	2009	5	36610
Germany	2011	3	11556
Italy	2011	4	399214
Kenya	2009	5	7150
Poland	2011	4	2500

Built-up surface validation

- 1 million points
- stratified uniform random sampling equalized number of samples
- uniformly distributed globally
- 3 independent visually inspections by 9 photo-interpreters
- high (H) and low (L) confidence scores





Built-up surface validation

- 1 million points
- stratified uniform random sampling equalized number of samples
- uniformly distributed globally
- 3 independent visually inspections by 9 photo-interpreters
- high (H) and low (L) confidence scores

		GHSL R2019	GHSL R2023	
BU vs NBU	N samples	Overall accuracy	Overall accuracy	**Increase Overall Accuracy**
Asia	43,821	70.51%	94.05%	**23.54%**
Africa	24,596	70.37%	93.06%	**22.69%**
Oceania	9,505	76.95%	98.04%	**21.09%**
ALL	155,649	75.47%	94.04%	**18.56%**
America	50,094	78.34%	94.48%	**16.14%**
Europe	27,633	80.53%	94.09%	**13.55%**

Quality Assessment (QA) - Population

- **QA of POP grids with independent reference data**
  - Reference data:
    - NSO-provided 1km vector grids, some multi-temporal
    - JPN, FIN, BEL, BRA, EU 18 countries (no DC)

		Japan	Finland	Belgium	Brazil	EU 18C
INPUT	ASR km2 populated	212.6	1047.4	52.0	25.1	
	# units populated	1,750	320	589	310,046	
REF	ASR km2	1	1	1	1	1
	# units	409,391	352,885	30,081	8,521,062	3,255,934
	Pop Max	32,706	19,781	29,219	45,936	53,119
	Pop Mean	308.0	15.4	378.2	21.7	76.5
	CV (Std/mean)	4.6	11.3	2.8	15.9	8.2

- QA metrics: Mean Absolute Error (MAE), Total Absolute Accuracy (TAA)
  - MAE = TAE / #units
  - TAA = 1 - (TAE / (POPref * 2))
  - (By Pdens class relevant for SMOD)

- FOR POP GRIDS:
  - GHS-POP R2022
  - GHS-POP R2019
  - WorldPop if INPUT census is same as GHSL

Quality Assessment - Population

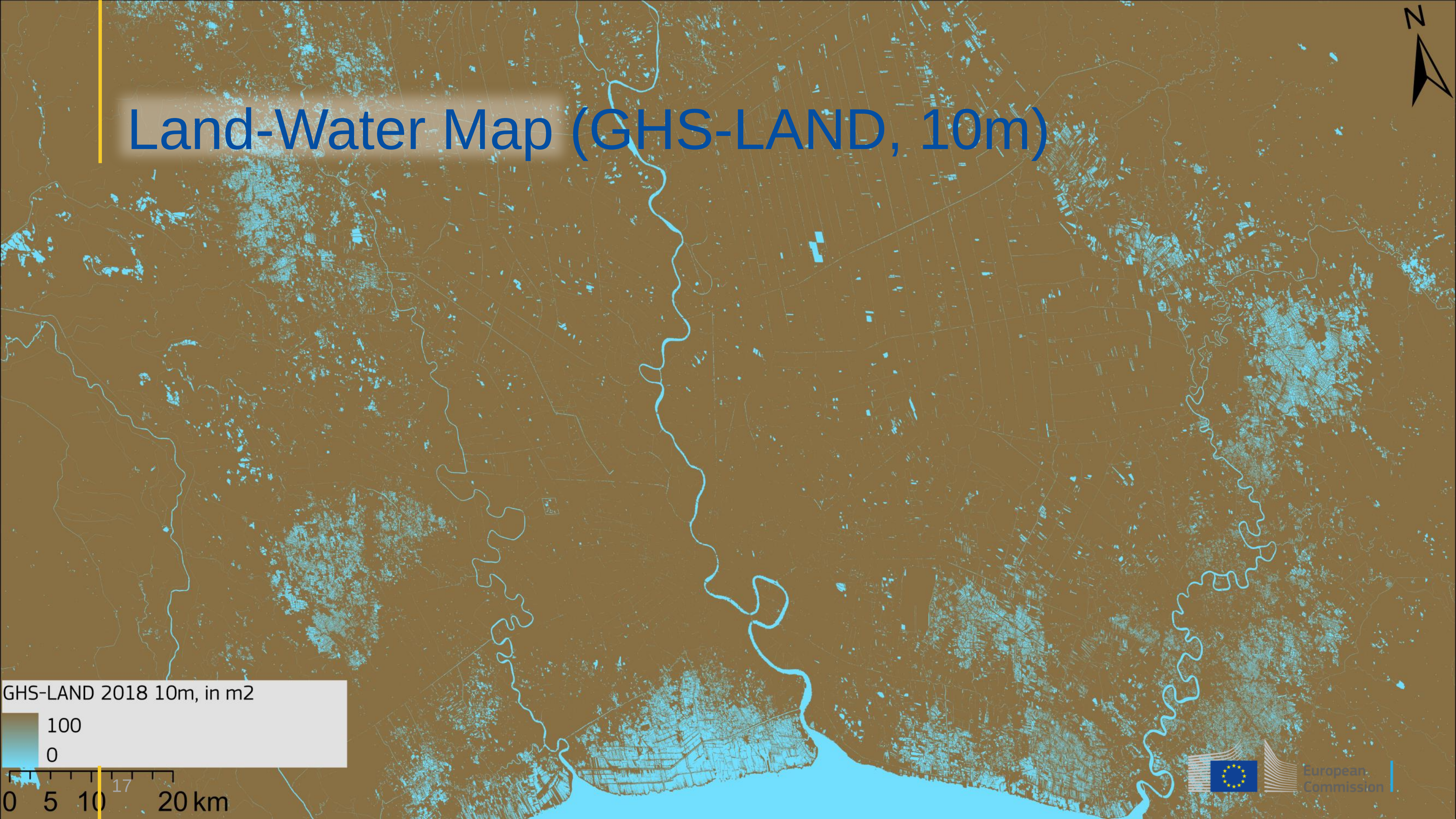
- **Results: Total Absolute Accuracy [%]**

	Japan				Finland			Belgium	Brazil	EU 18C
Dataset	2020	2015	2000	1995	2020	2015	2005	2020	2010	2011
GHS R2023	80.7	82.3	82.2	81.7	72.8	73.2	66.6	81.0	89.8	78.2
GHS R2019		78.5	78.0			59.5			81.2	71.4
WPOP Unc	77.0	77.1	72.7		58.1	59.0	53.5	75.7	87.7	
WPOP Con	80.0				68.3			77.9		

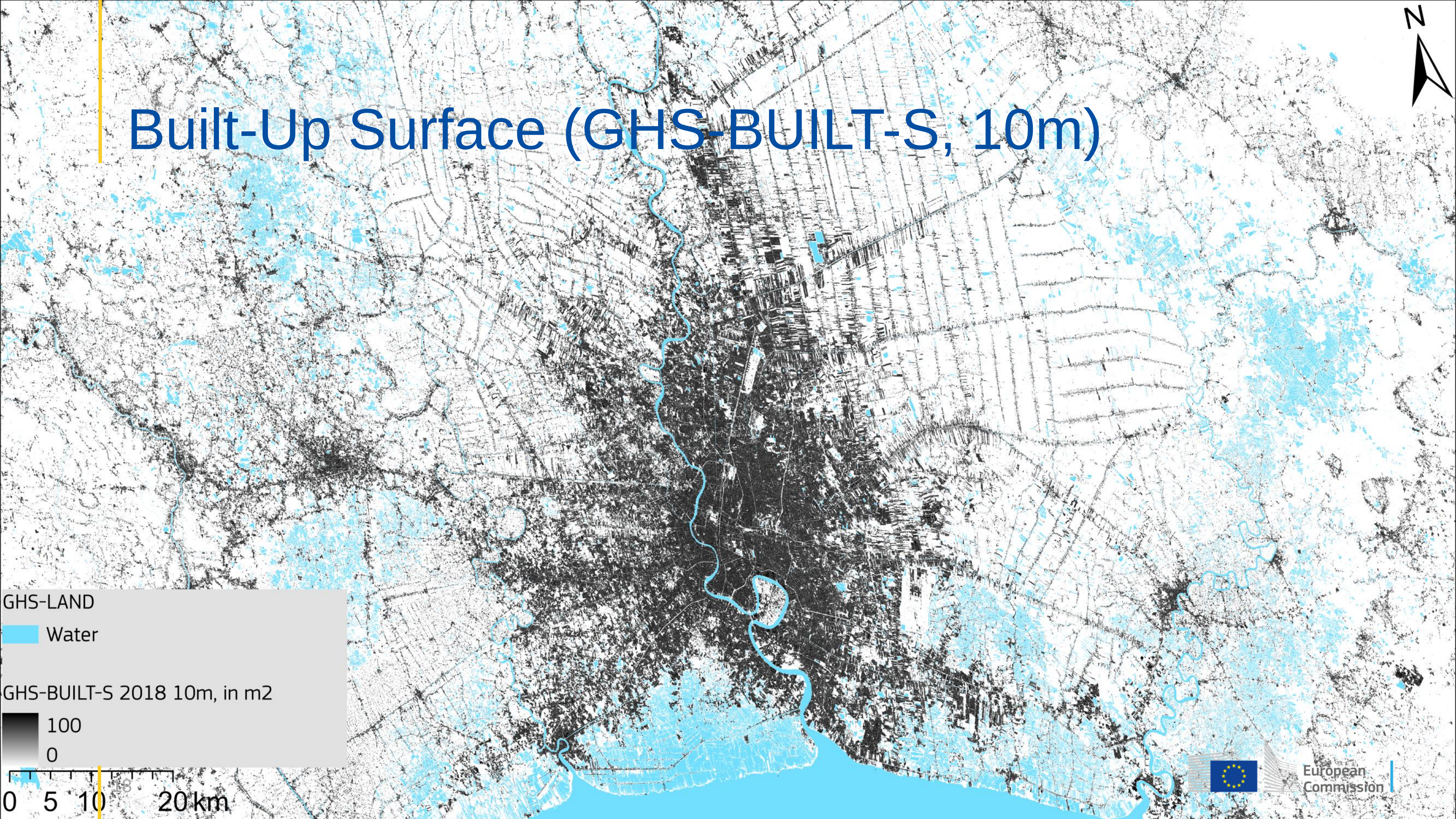
- GHS R2023 performs best, across countries & epochs
- GHS R2019 is second best, with exception of BRA (grid 2015 vs REF 2010, $Tpopd_{2015\text{-}2010}$ = 5.5.%)
- In JPN, FIN, all grids best in 2015 (due to grids closest to census year?)

Satellite imagery

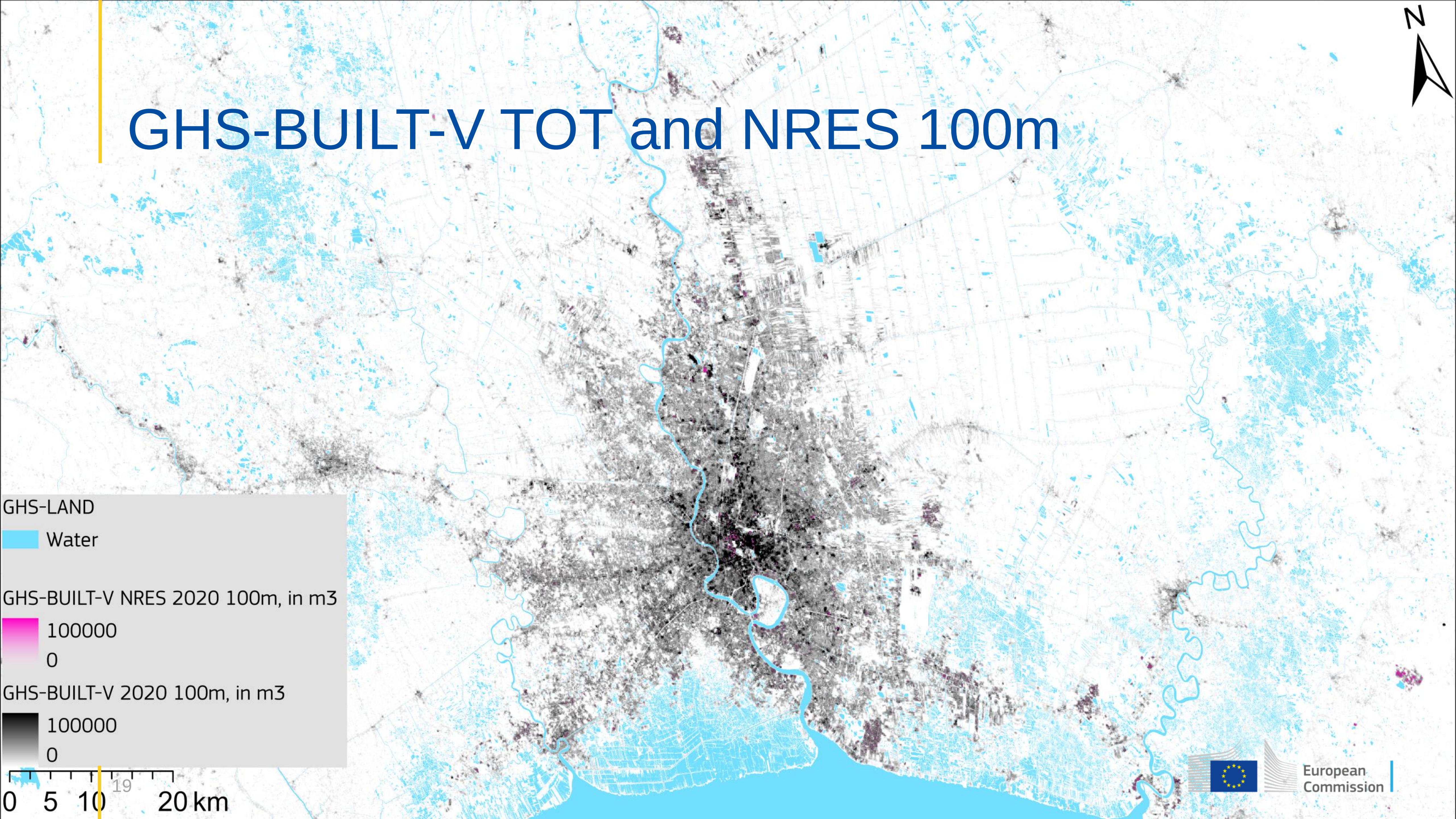
Land-Water Map (GHS-LAND, 10m)



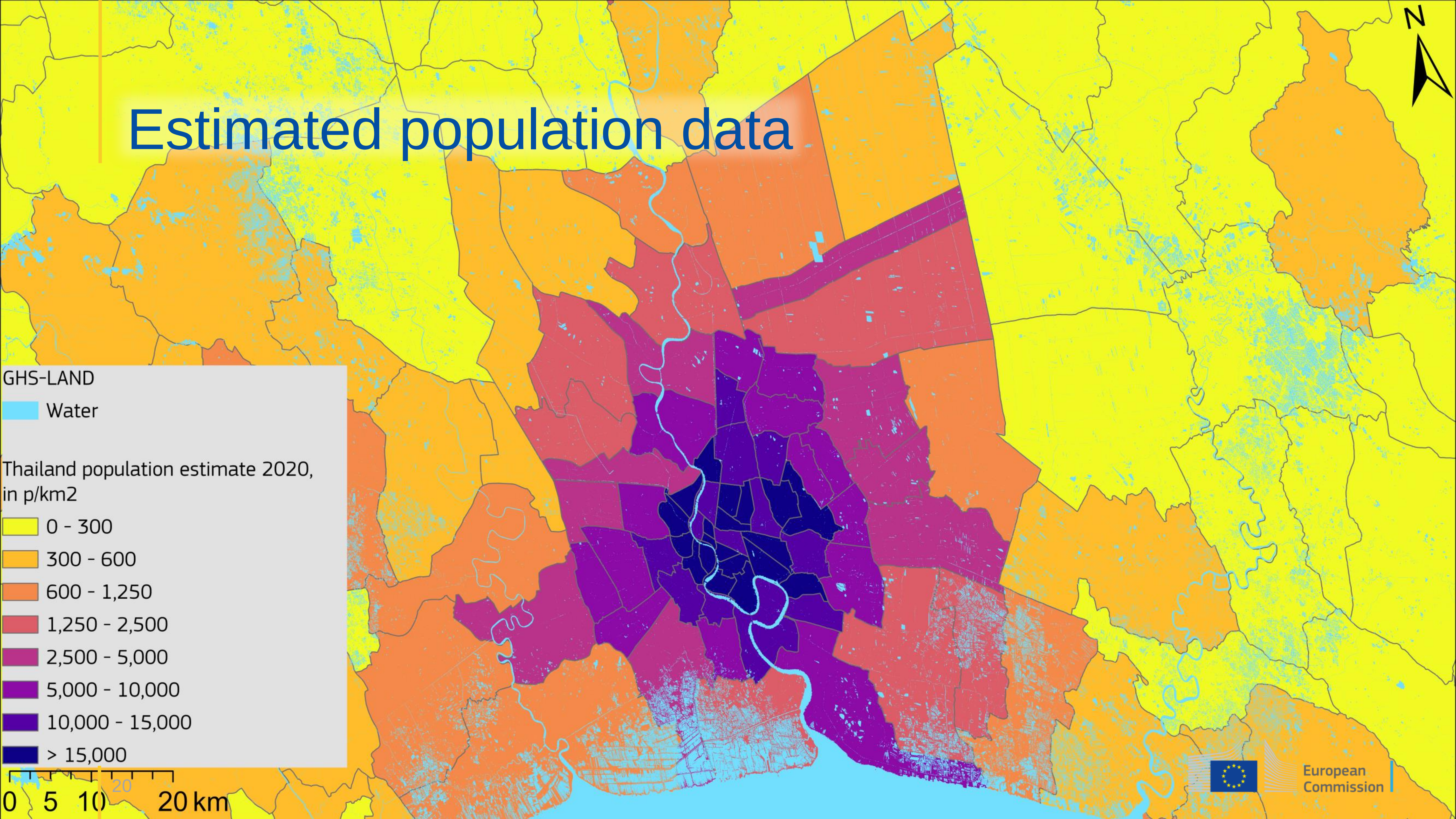
Built-Up Surface (GHS-BUILT-S, 10m)



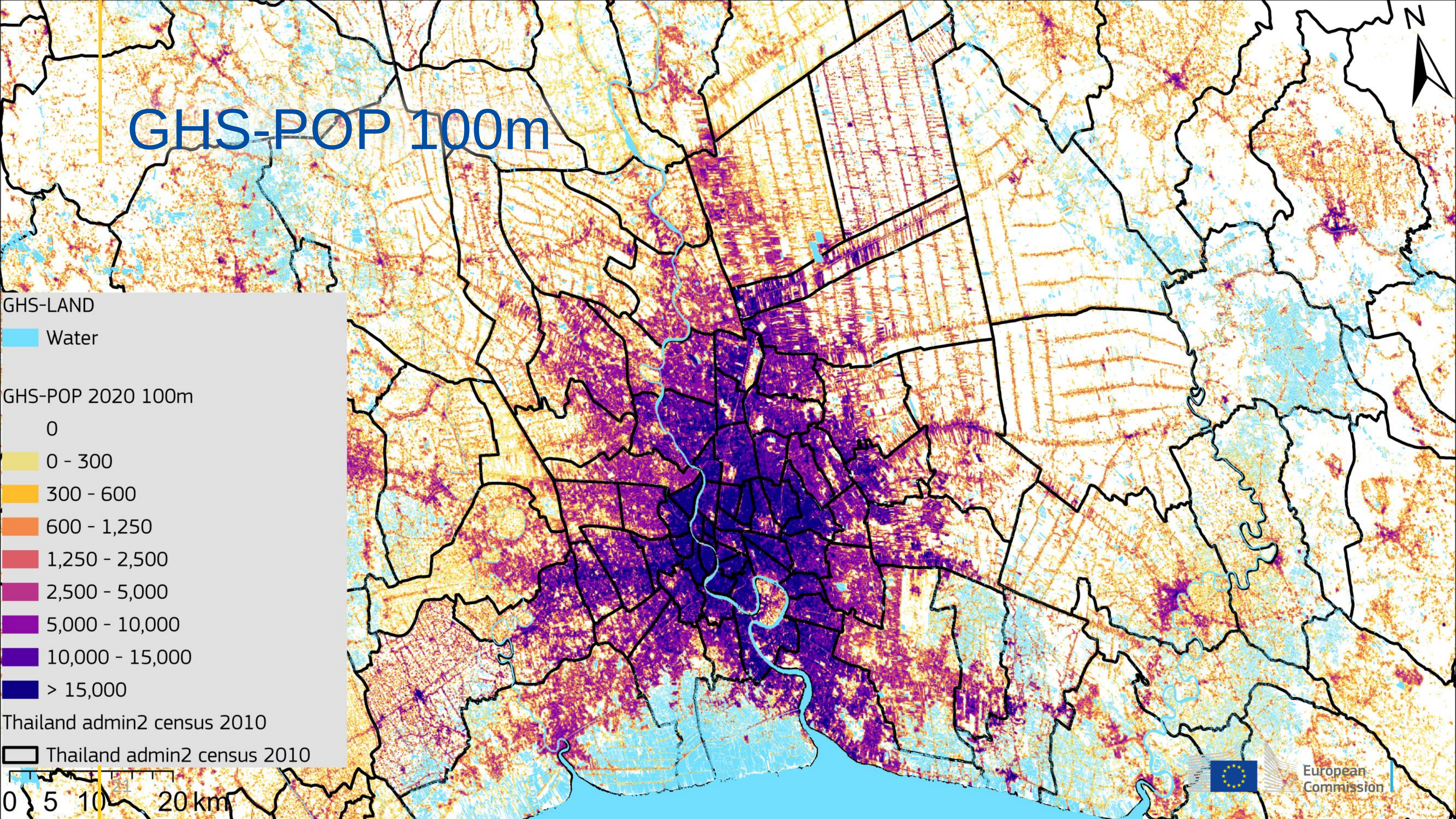
GHS-BUILT-V TOT and NRES 100m



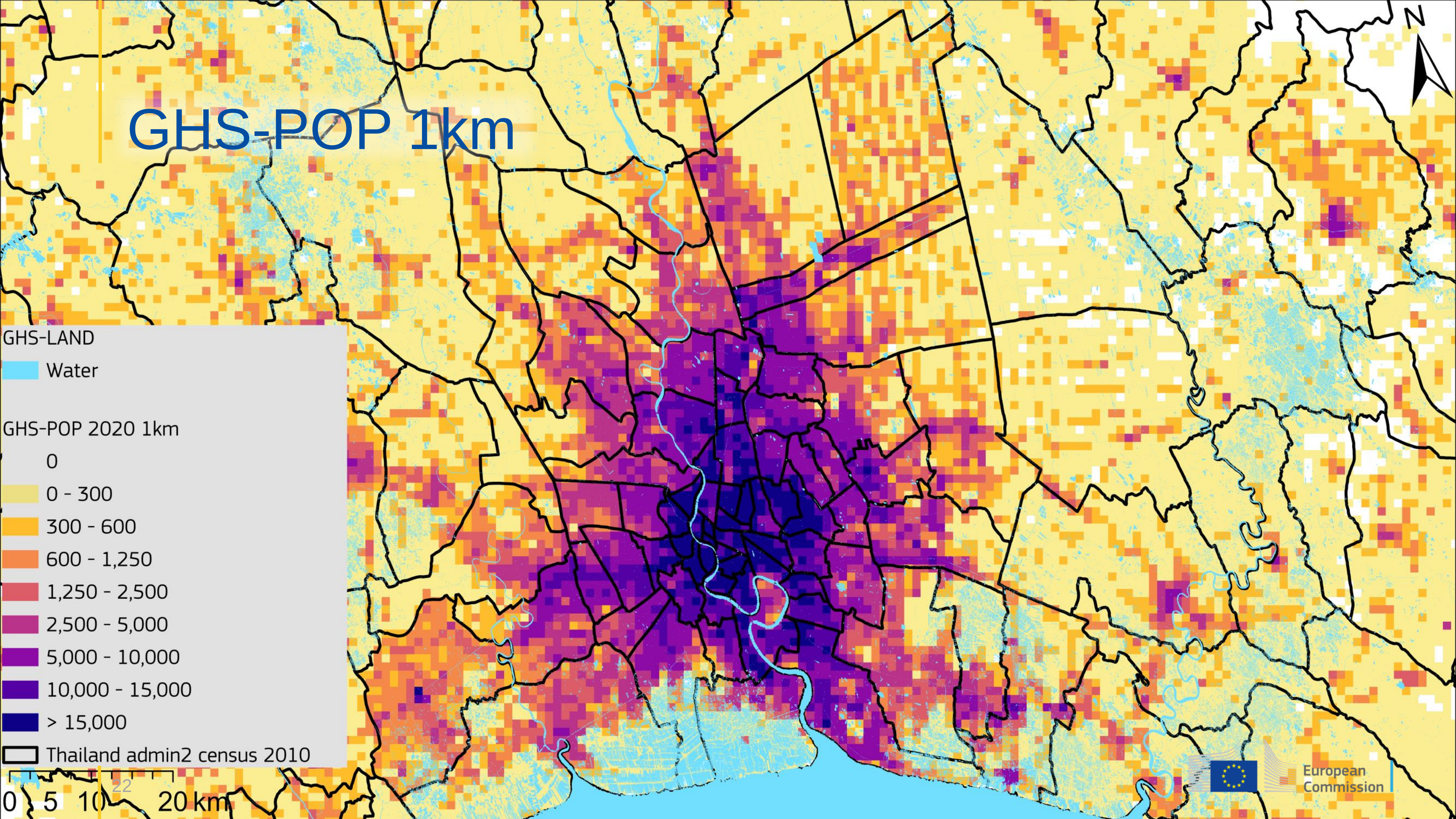
Estimated population data

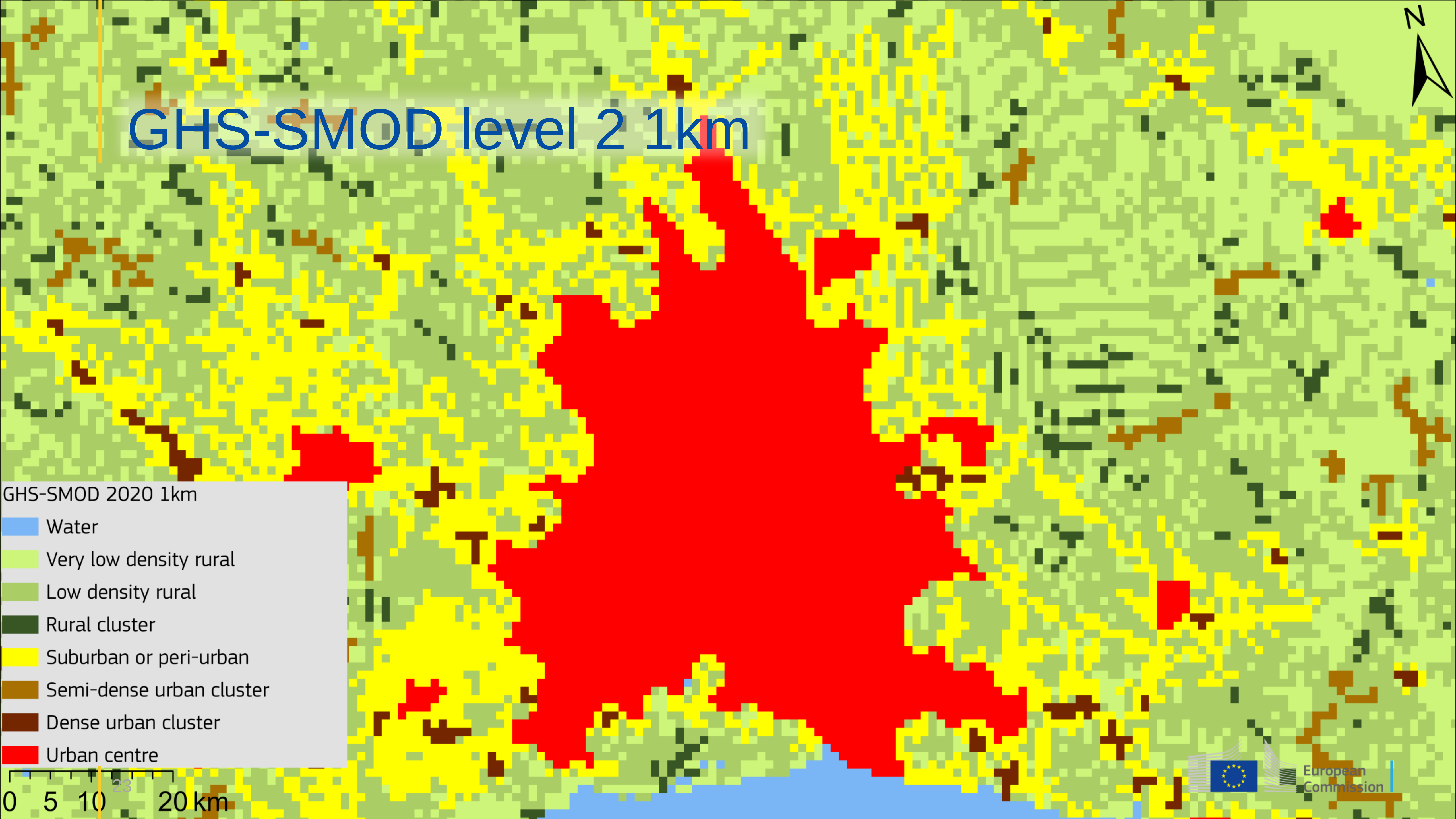


GHS-POP 100m


N
GHS-LAND
Water
GHS-POP 2020 100m
0
0 - 300
300 - 600
600 - 1,250
1,250 - 2,500
2,500 - 5,000
5,000 - 10,000
10,000 - 15,000
> 15,000
Thailand admin2 census 2010
Thailand admin2 census 2010
0 5 10 20 km
European Commission

GHS-POP 1km


GHS-LAND
Water
GHS-POP 2020 1km
0
0 - 300
300 - 600
600 - 1,250
1,250 - 2,500
2,500 - 5,000
5,000 - 10,000
10,000 - 15,000
> 15,000
Thailand admin2 census 2010
0 5 10 20 km
N
European Commission

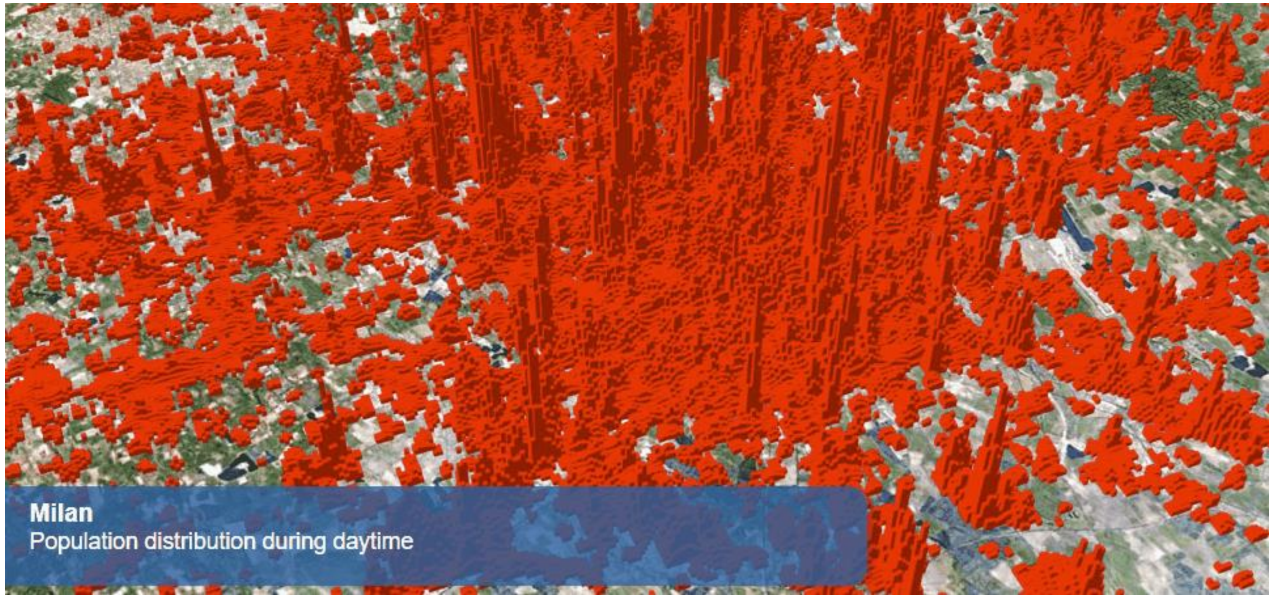

GHS-SMOD level 2 1km
N
GHS-SMOD 2020 1km
Water
Very low density rural
Low density rural
Rural cluster
Suburban or peri-urban
Semi-dense urban cluster
Dense urban cluster
Urban centre
0 5 10 20 km
European Commission

ENACT exploratory research project

- Grid maps with estimated **population in daytime and nighttime per month**

- considering the presence of residents, workers per different sectors, students, and tourists, and locations of residence and activity

- combining official statistical data at regional level with geospatial data from conventional and non-conventional data sources, for the reference year of 2011



- Details & data:

https://ghsl.jrc.ec.europa.eu/enact.php

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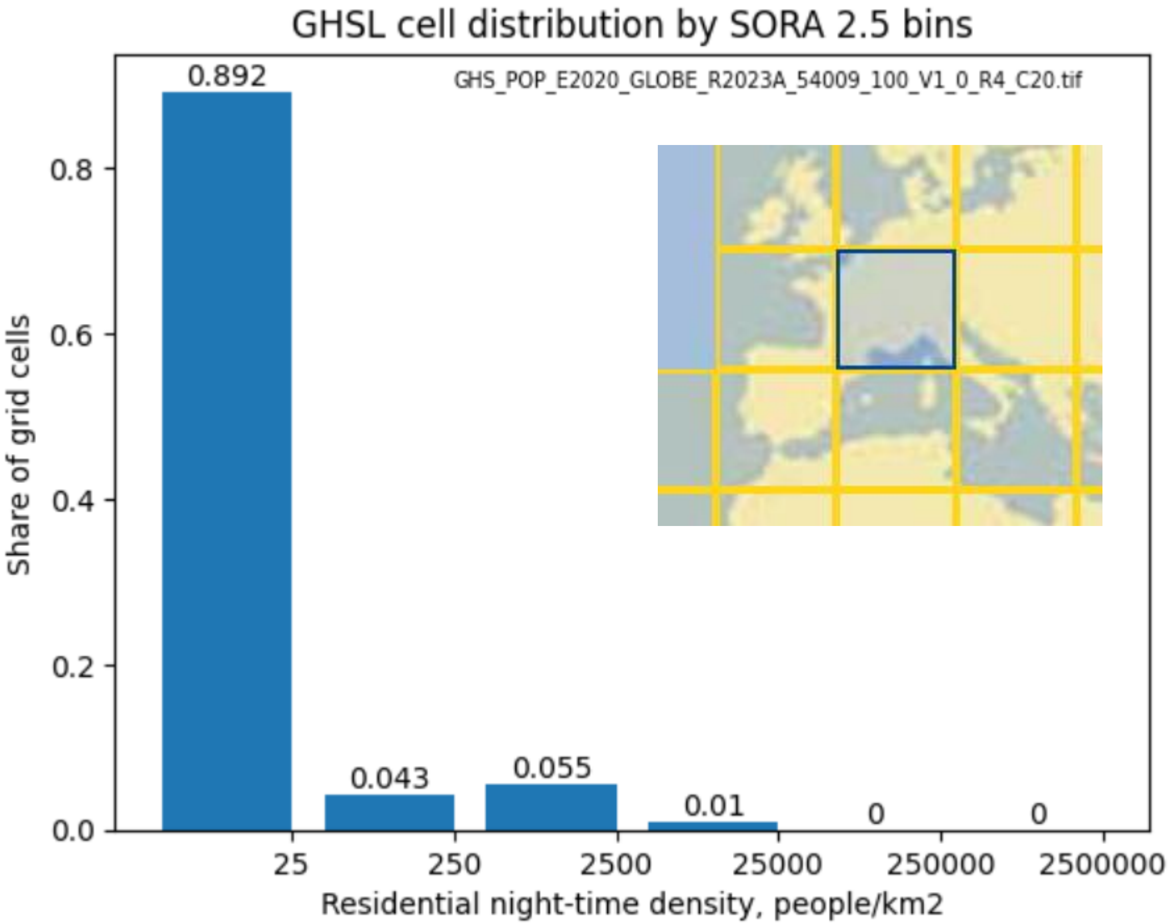
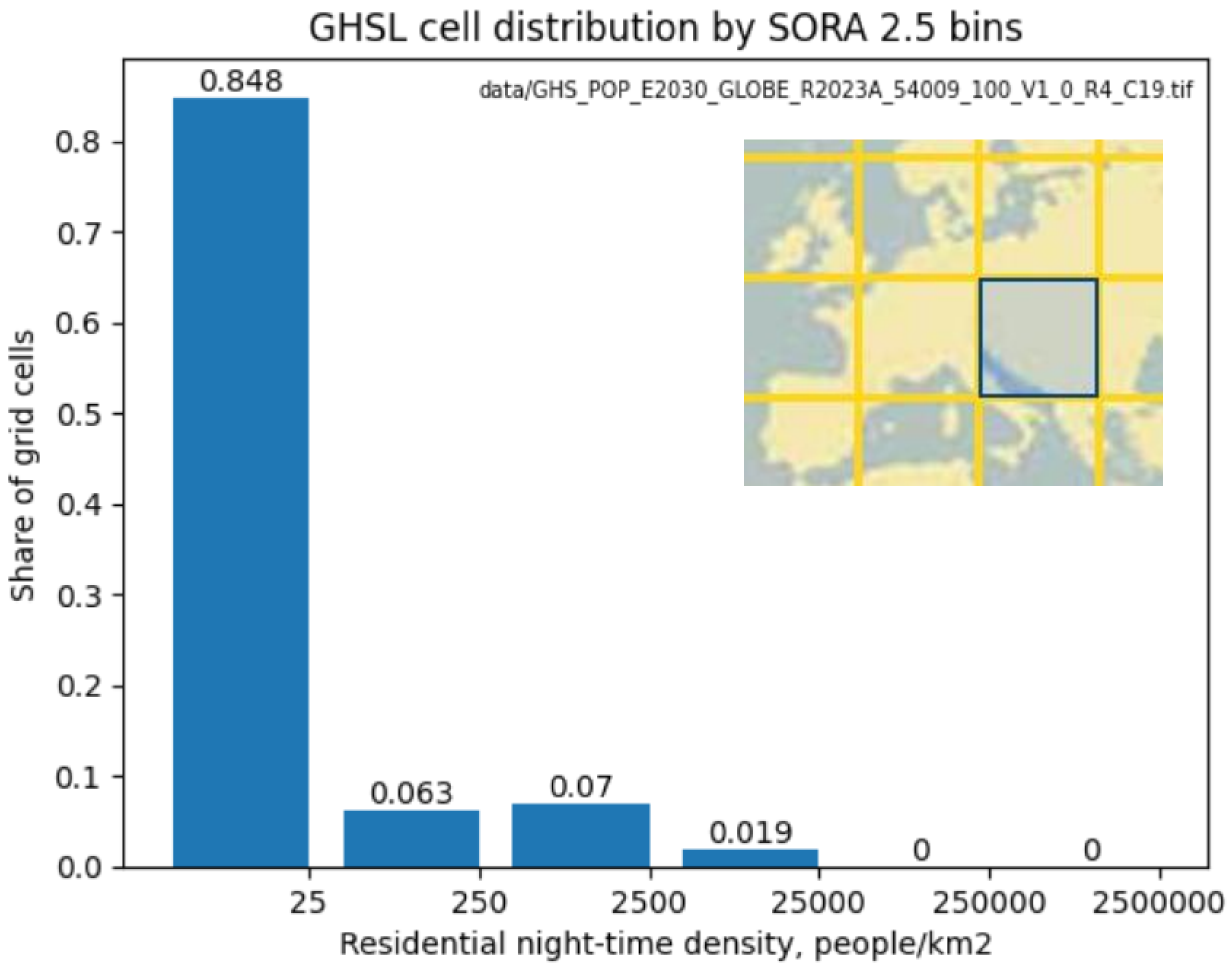
Most of the land has no night-time residents





Analysis: EUSPA, data: Copernicus GHSL by JRC

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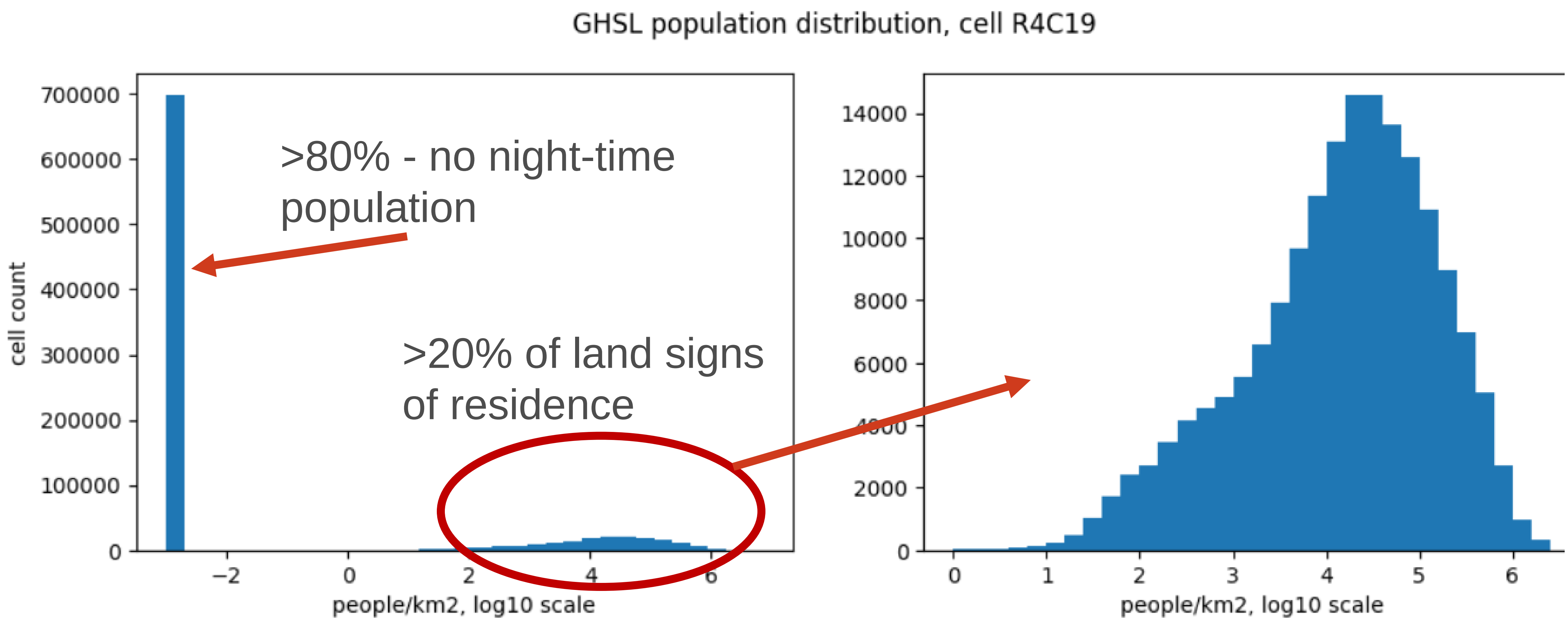
Nobody lives there, but is it really empty?



Analysis: EUSPA, data: Copernicus GHSL by JRC

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Night-time population (GHSL) by land use/cover class. Ordered by territory.

Corine Land Cover class	area_share %	mean density pop/km2	stdev	stdev/mean
Non-irrigated arable land	39.4	19	51	2.68
Coniferous forest	22.2	5	17	3.4
Pastures	9.3	21	50	2.38
Land principally occupied by agriculture, with significant areas of natural vegetation	7.9	63	105	1.67
Mixed forest	7.4	9	27	3
Discontinuous urban fabric	4.4	549	351	0.64
Broad-leaved forest	3.5	11	29	2.64
Transitional woodland-shrub	2.2	8	19	2.38
Industrial or commercial units	0.7	643	466	0.72
Complex cultivation patterns	0.6	195	205	1.05
Water bodies	0.6	9	25	2.78
Fruit trees and berry plantations	0.3	22	54	2.45
Natural grasslands	0.3	7	17	2.43
Water courses	0.2	176	274	1.56
Sport and leisure facilities	0.2	164	177	1.08
Mineral extraction sites	0.2	92	137	1.49
Vineyards	0.2	9	29	3.22
Green urban areas	0.1	675	687	1.02
Road and rail networks and associated land	0.1	632	495	0.78

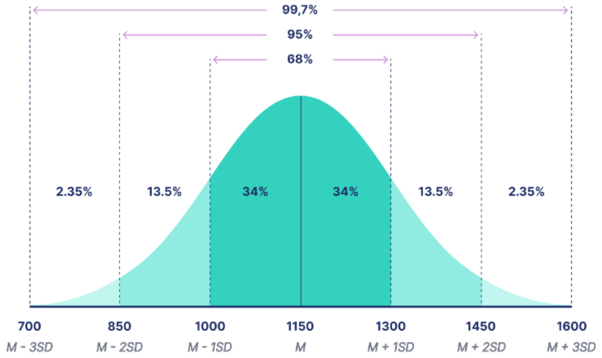
Source: EUSPA using Copernicus GHSL (by JRC) and Corine Land Cover (by EEA) data. Area: Czech Republic, CLC year:2018, GHSL year 2020 edition2023.

Night-time population (GHSL) by land use/cover class. Ordered by population density.

Corine Land Cover class	area_share %	mean density pop/km2	stdev	stdev/mean
Continuous urban fabric	0.02	5108	1853	0.36
Port areas	0	726	720	0.99
Green urban areas	0.1	675	687	1.02
Industrial or commercial units	0.7	643	466	0.72
Road and rail networks and associated land	0.1	632	495	0.78
Discontinuous urban fabric	4.4	549	351	0.64
Complex cultivation patterns	0.6	195	205	1.05
Water courses	0.2	176	274	1.56
Construction sites	0	174	175	1.01
Sport and leisure facilities	0.2	164	177	1.08
Mineral extraction sites	0.2	92	137	1.49
Dump sites	0.1	88	130	1.48
Land principally occupied by agriculture, with significant areas of natural vegetation	7.9	63	105	1.67
Airports	0.1	56	115	2.05
Fruit trees and berry plantations	0.3	22	54	2.45
Pastures	9.3	21	50	2.38
Non-irrigated arable land	39.4	19	51	2.68

Source: EUSPA using Copernicus GHSL (by JRC) and Corine Land Cover (by EEA) data. Area: Czech Republic, CLC year:2018, GHSL year 2020 edition2023.

Uncertainty



- *Semantics:* “uncertainty” means doubt about the validity of the result of a measurement/forecst. Quantitatively expressed as distribution.

- Annex F does not explicitly accommodate uncertainty data inputs. Is it due to implicit assumption total risk will average out? Is averaging out across different operations within the spirit of SORA?

- Implication: there is a reasonable chance that come cells will have higher iGRC. Strict application of max(density) becomes very difficult.

- All forecasts, 'real time' measurements have uncertainty. Is it known?

- **Proposal:** require **uncertainty to be known**, incorporate uncertainty into theorethical model of iGRC assignment and/or mitigation measure requirements

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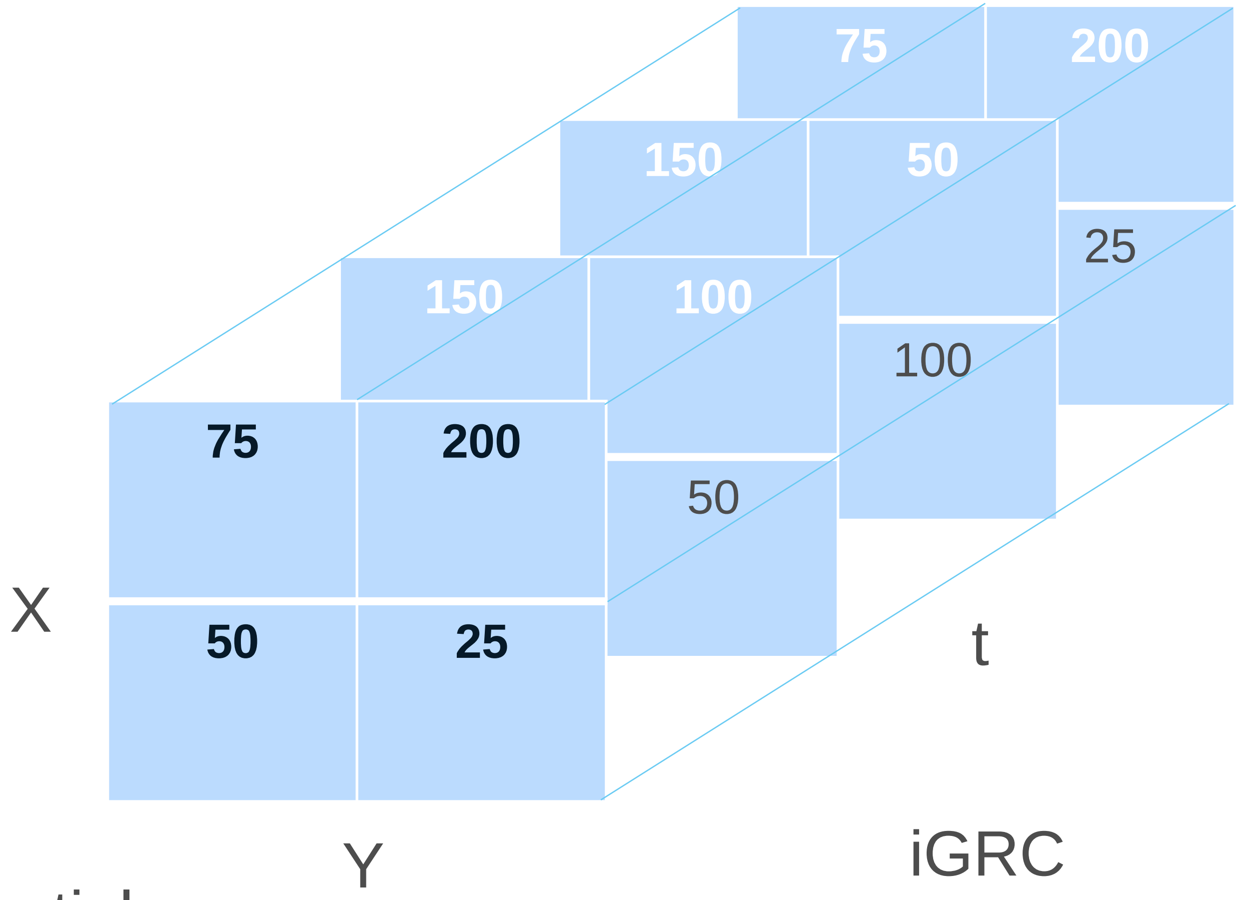
Quantization of the spatio-temporal data

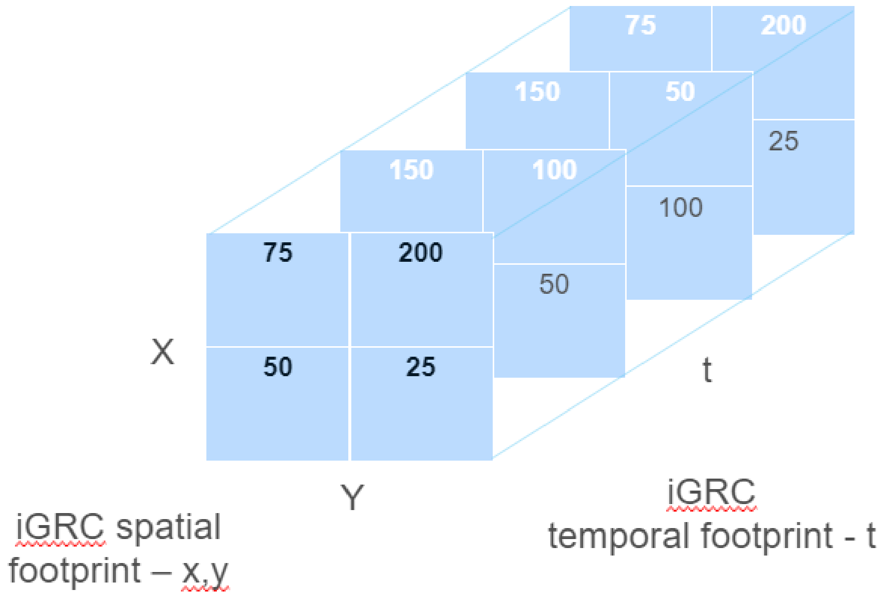


iGRC spatial footprint – x,y

iGRC temporal footprint - t

- The smaller the grid-cell, the higher the variance
- Implication: higher max density and iGRC
- Practical limit: trade-off between cell size and accuracy(uncertainty)

Size of spatial grid cell



- Proposal:

smallest dimension of iGRC footprint

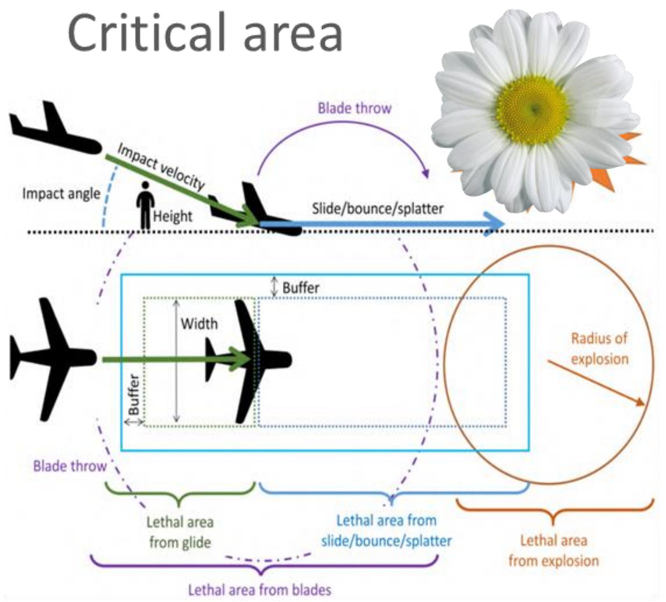
- Rationale:
  - Assumption that Critical Area would be allocated randomly in the iGRC footprint
  - Therefore averaging iGRC makes sense – low-pop sub-areas will even out high-pop sub-areas
- Limitations:
  - Vulnerability to 'gerrymandering', including low density areas to lower the average iGRC, MAUP Problem

Size of spatial grid cell – Critical Area

Alternative: minimum dimension of Critical Area.

Rationale:
- ?

Limitations:
- Challenging production (grid cell/uncertainty trade-off)
- Overestimates risk of operation if max-pop density cell determines iGRC
- Illustration: <1m multicopter with CA of 10x10m would yield iGRC 7 with 3 people sitting on the same bench



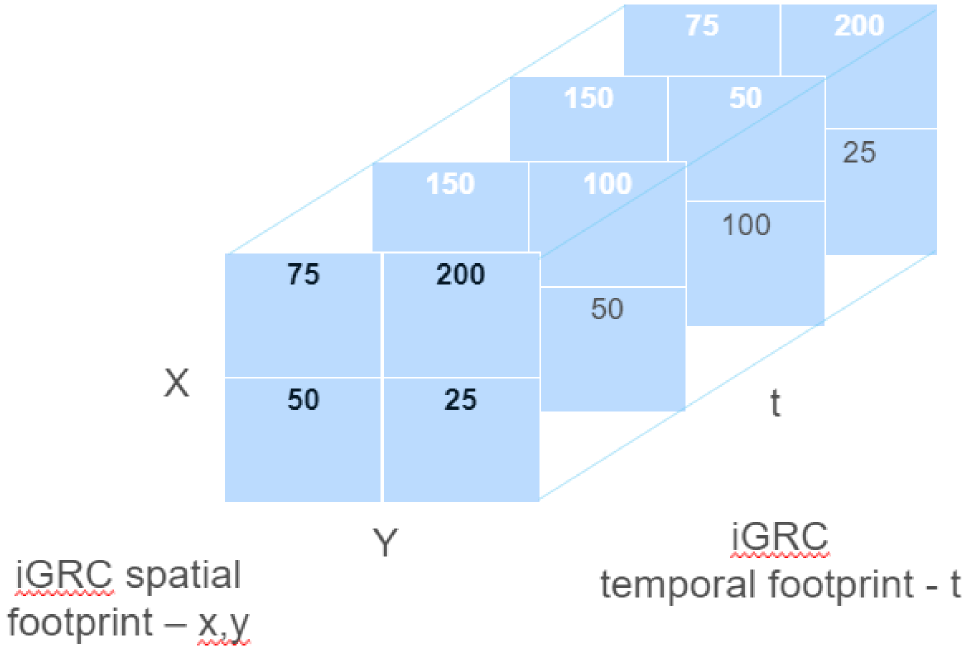
Function of:
- Velocity of aircraft
- Maximum dimension (e.g. wingspan)

- Drawing by JARUS, draft SORA 2.5 Annex F v0.3

Size of temporal grid cell

Extreme options:

- A: **Weighted average** over **entire duration** of operation across all iGRC footprint
- B: **Maximum** at any moment of the operation across all cells of operation
- Options in between the two extremes:
  - Separate operation in distinct spatio-temporal blocks, apply option A for each.



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Quality attributes of service/method/data

Prerequisite: unambiguous description of target metric

Fitness for purpose – a catch-all attribute, that encompasses:

Non-functional attribute requirements

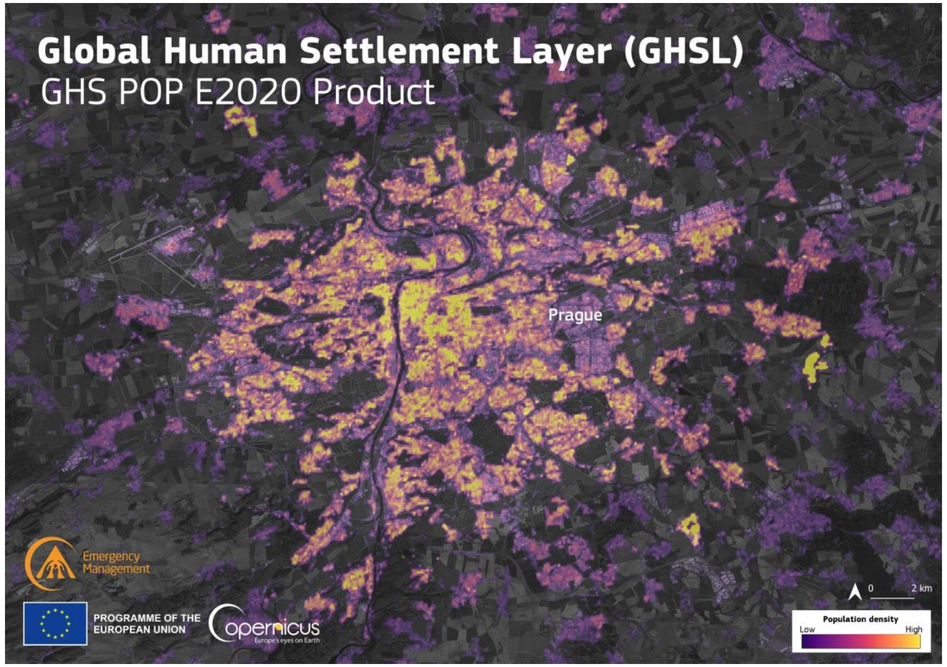
- **Alignment** between what's forecast/measured and what's needed.
- **Robustness** - ability to perform in varied and changing circumstances
- **Scientific reference** - transparent and peer reviewed workflow
- **Integrity –** data is not corrupted along the way
- **Resistence to abuse –** can not be easily gamed (applies to data and application method)
- **FAIR** – Findable, Accessible, Interoperable, Reusable

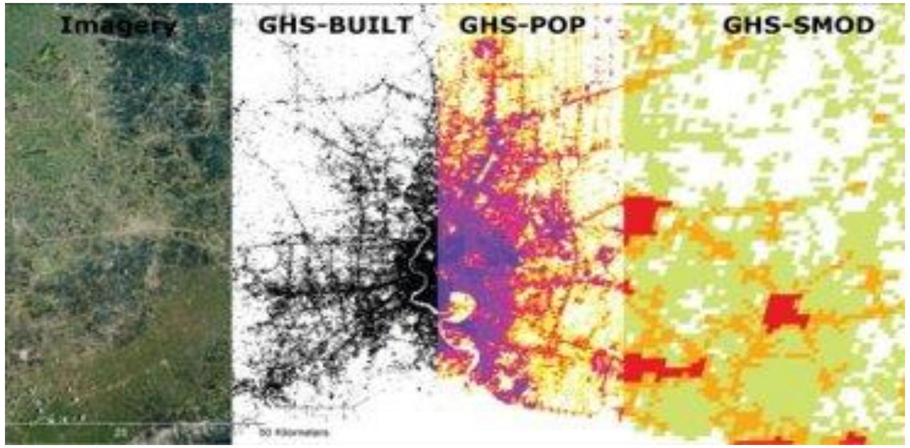
Metrics for quality attributes

- Be wary with self-declared and non-reviewed accuracy claims! They can be gamed.
- Quality metrics for inputs
  - Provenance, traceability (see process by GHSL)
  - Age of data
- Quality of outputs
  - Accuracy metrics – **relative** errors would better convey the risk of 'jumping' an order of magnitude
  - Quantification of uncertainty also relative (as a fraction of expected value)

Wrap-up, takeaways

- Copernicus GHSL – available globally, for **free** and used by operators and NAAs today.
- Low density areas, night time operations
- Long-term commitment backed by EC funding and JRC competence
- Build your last-mile product on top of GHSL!
- Quantitative fitness-for-purpose evaluation study an opportunity.
- EUSPA is open to contribute
- Contact EUSPA and JRC





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and keep in touch

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