Near-real-time Country-wide Estimation of Susceptibility and Settlement Exposure from Norwegian Mass Movements via Inter-graph Representation Learning

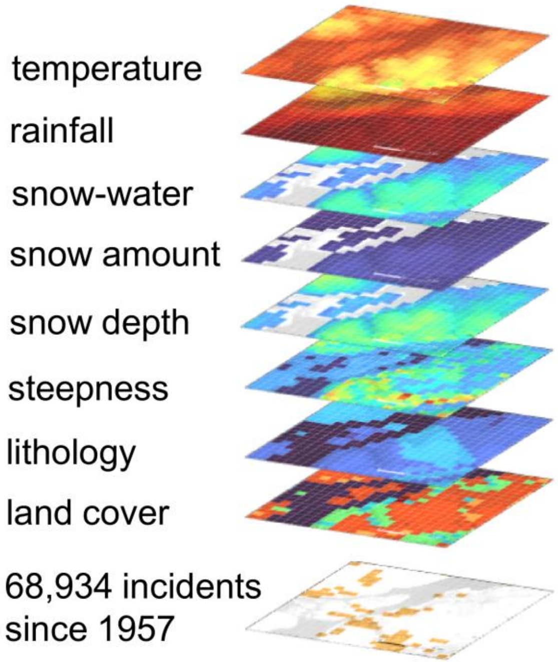
Daily Mass Movement Susceptibility Map

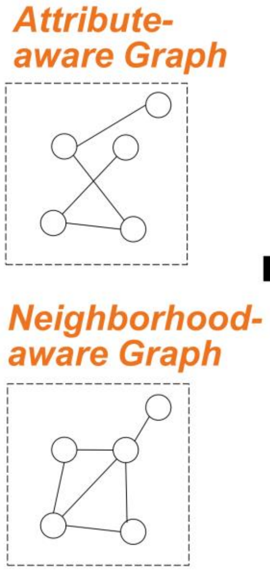
Intra-Settlement Exposure Probability of being a Mass-Movement-Susceptible Area

Minimum Triggering Exposure Probability of Mass-Movement-Susceptible Roads for **Inter-Settlement** Isolation

Supervised Ensemble Graph Neural Network

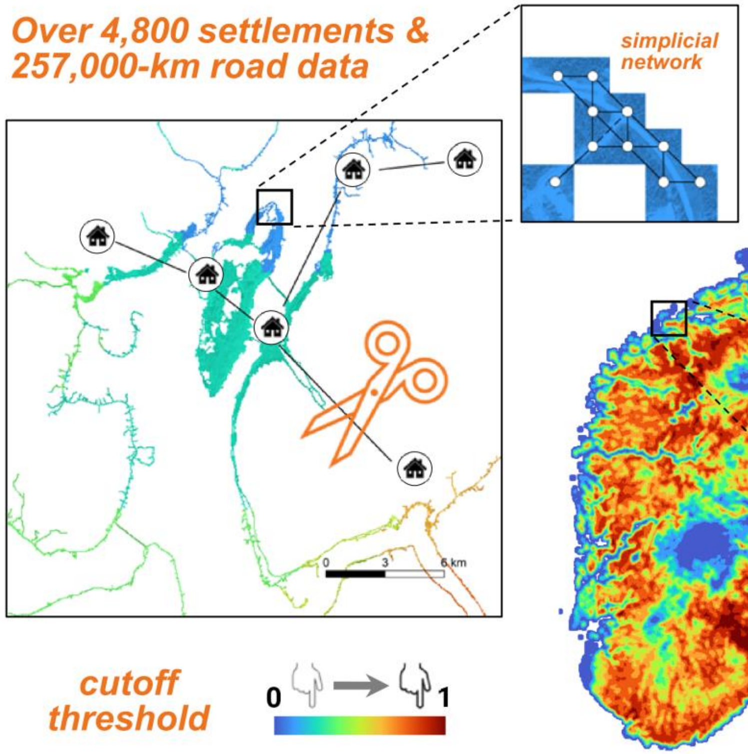
Geospatial features

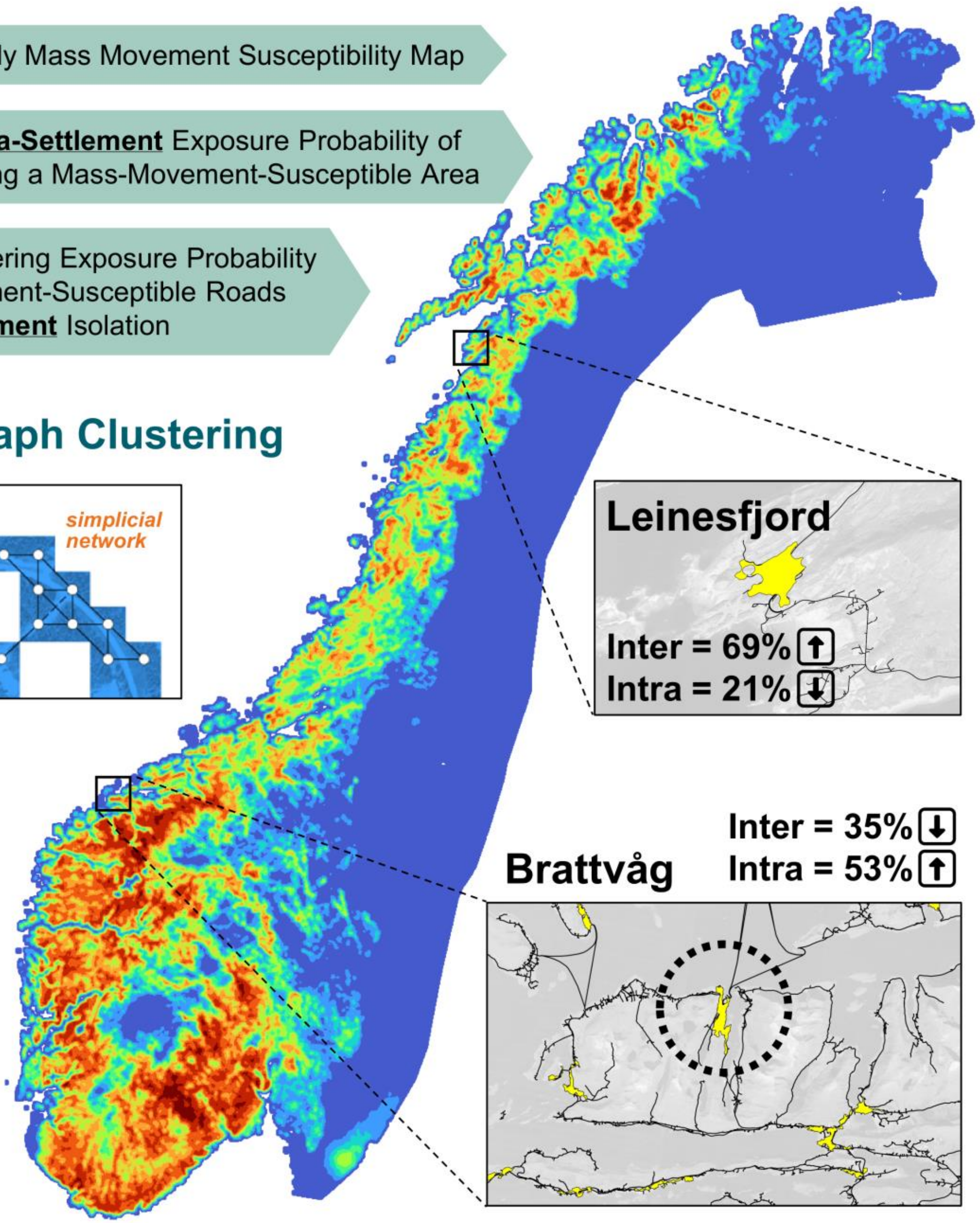




Unsupervised Spectral Graph Clustering

Over 4,800 settlements & 257,000-km road data





Joshua Dimasaka, Sakthy Selvakumaran, Andrea Marinoni

Code & Data: https://doi.org/10.5281/zenodo.8099811

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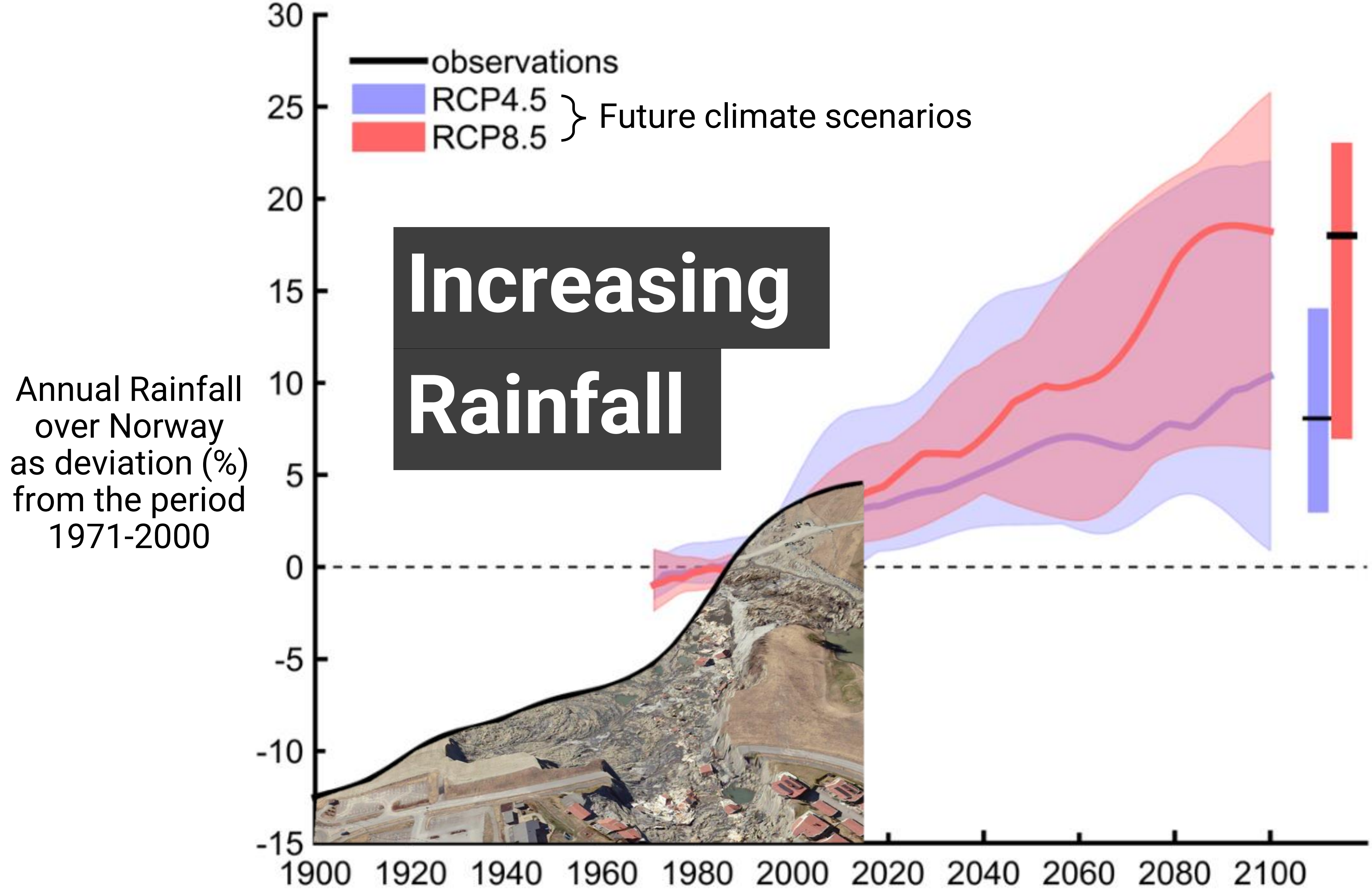
AI4ER Application of AI to the Study of Environmental Risk

Photo: Dhruv Suri

Connecting Roads

Photo: Fredrik Høgaas



Climate in Norway 2100

Challenge

Solution

1 Green	2 Yellow	3 Orange	4 Red
very low	*low*	*high*	*very high*

- **HIGHLY CONSERVATIVE ESTIMATES**
  Simple matrix-based approach with limited classes of susceptibility and daily rainfall intensity.

→ **Instead of four classes alone, what if we provide estimates with values from 0 to 100% with uncertainty?**

- **LIMITED REFINED INFORMATION**
  Too aggregated and no detailed information along road networks or within the vicinity of settlements.

→ **Instead of aggregated information, what if we extend the analysis at the detail of roads and settlements?**

- **LACK OF SPATIAL CORRELATION**
  Complex region-specific characteristics.

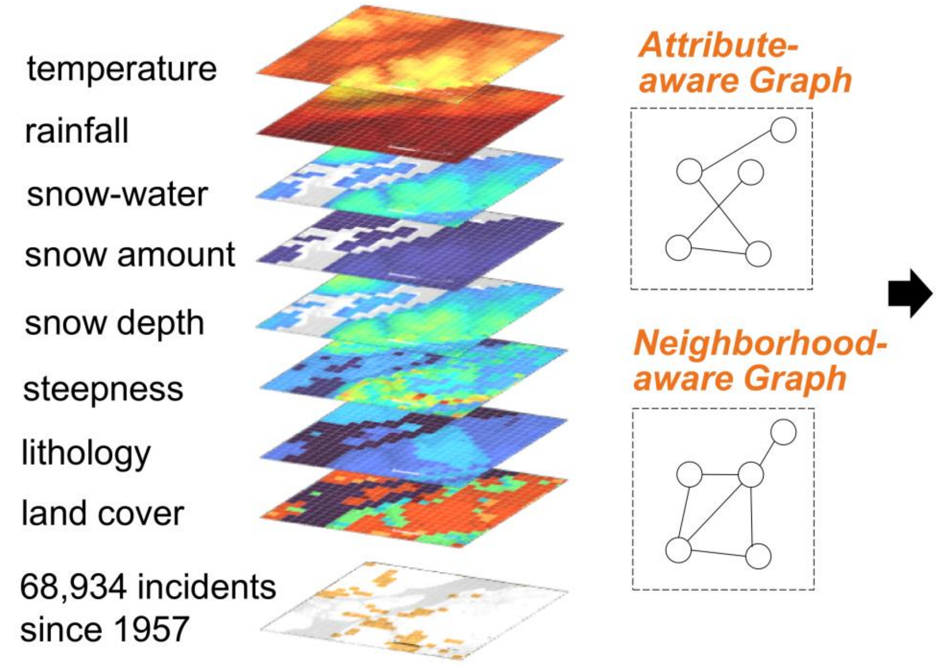
→ **Instead of no spatial correlation, what if we include it?**

Inter-graph Representation Learning

Near-real-time Country-wide Estimation of Susceptibility and Settlement Exposure from Norwegian Mass Movements via Inter-graph Representation Learning

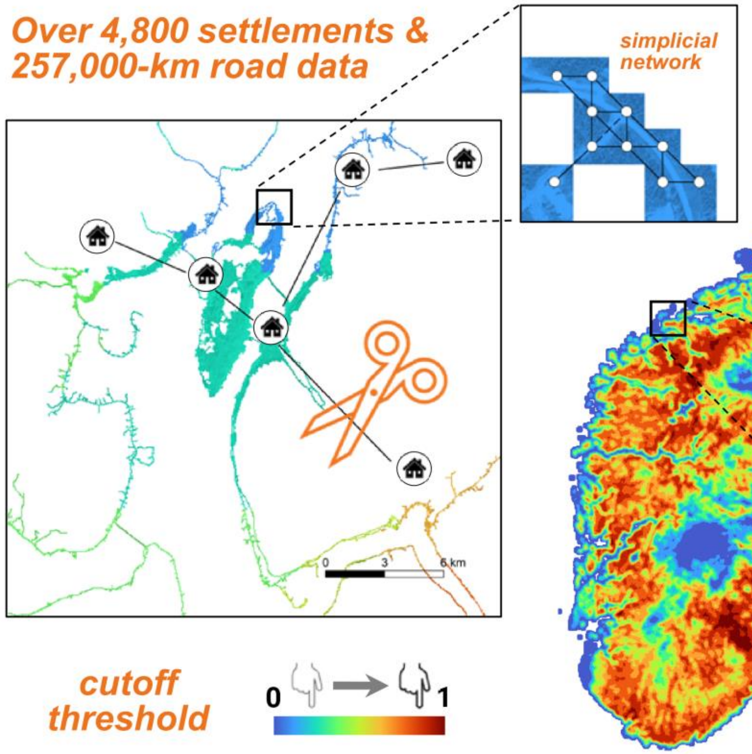
Supervised Ensemble Graph Neural Network

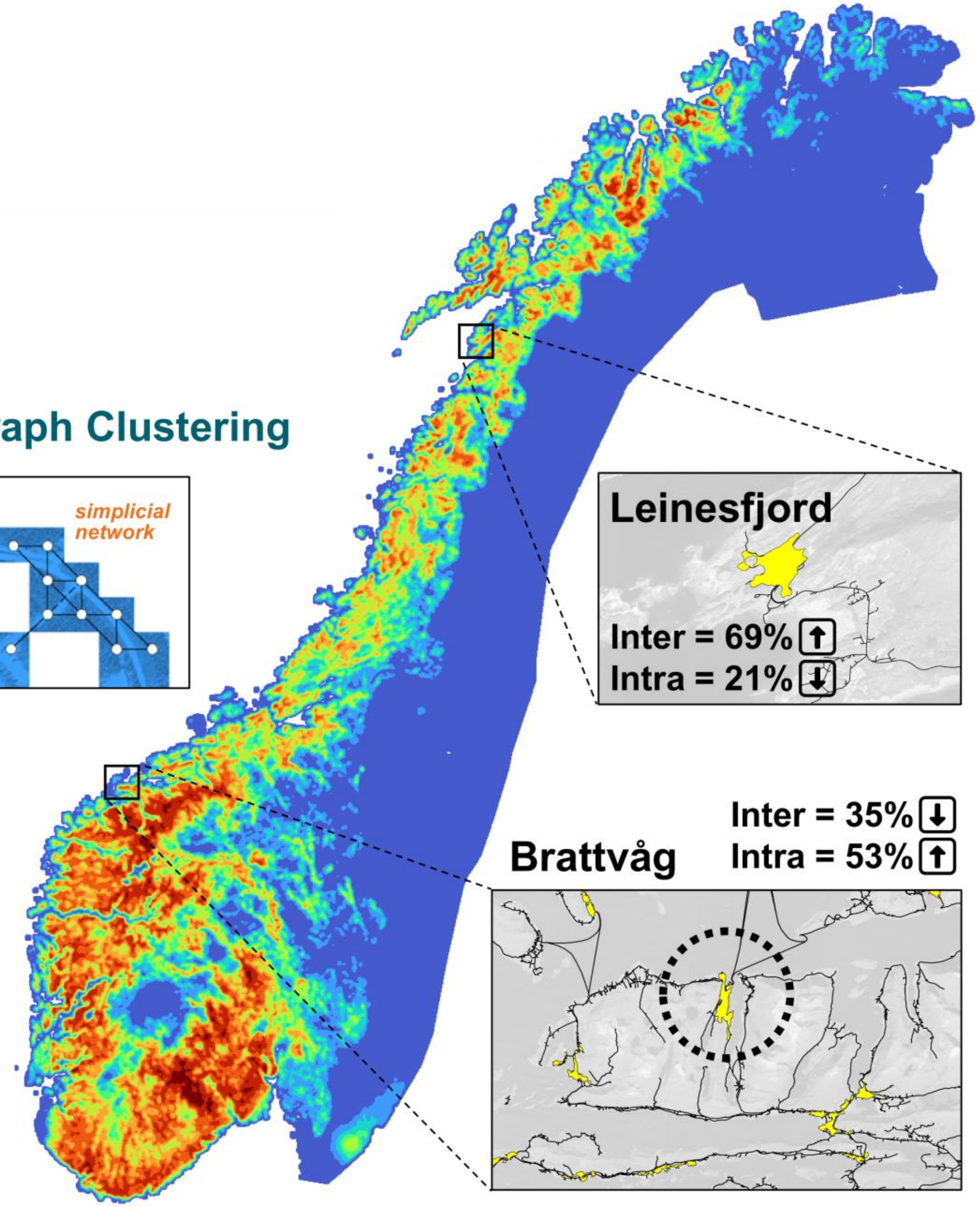
Geospatial features



Unsupervised Spectral Graph Clustering

Over 4,800 settlements & 257,000-km road data





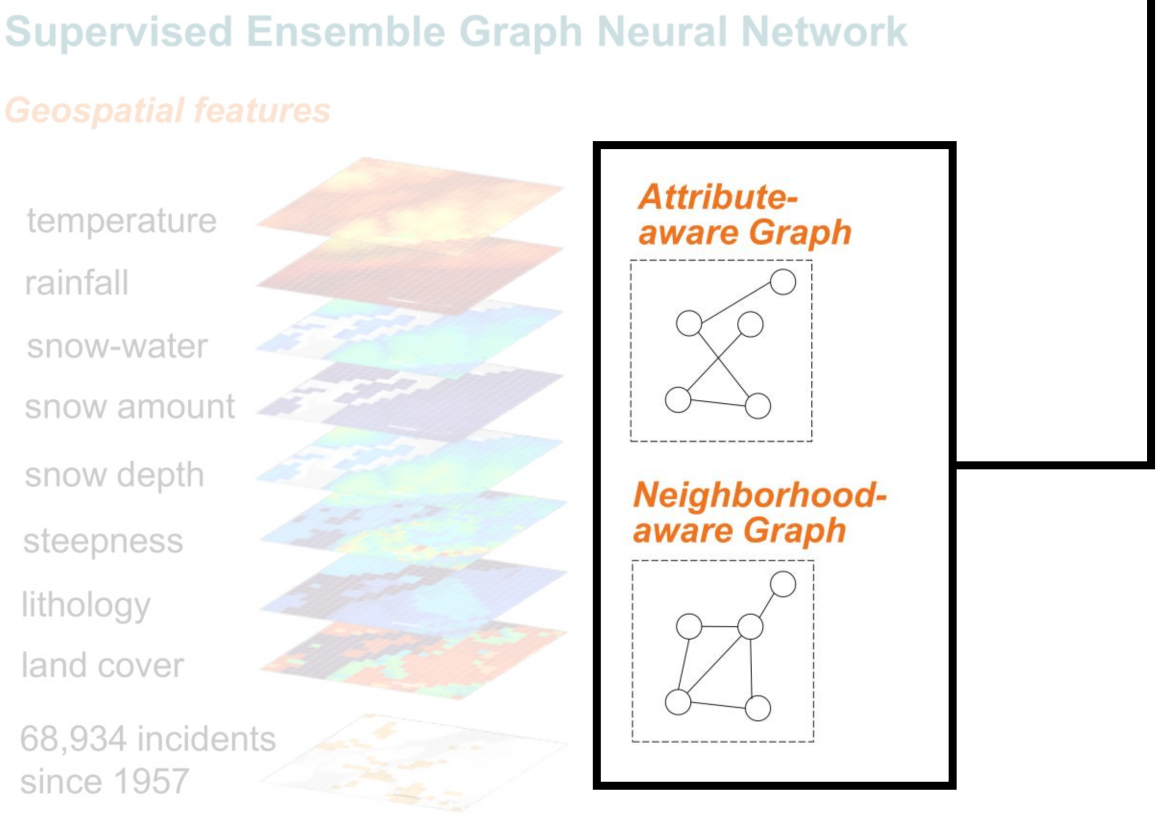
UNIVERSITY OF CAMBRIDGE

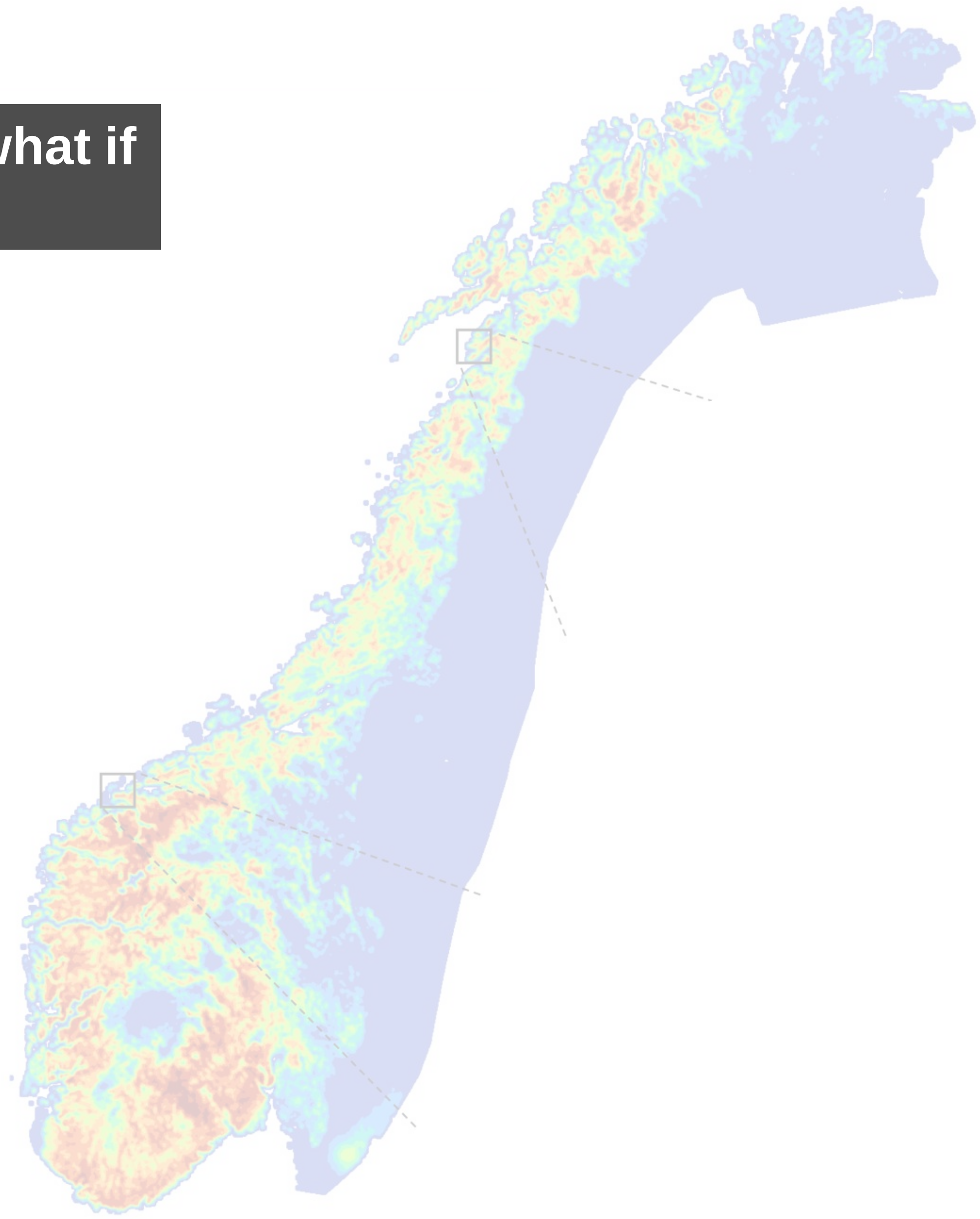
AI4ER *Application of AI to the Study of Environmental Risk*

Joshua Dimasaka, Sakthy Selvakumaran, Andrea Marinoni

Code & Data: https://doi.org/10.5281/zenodo.8099811

Instead of no spatial correlation, what if we include it?

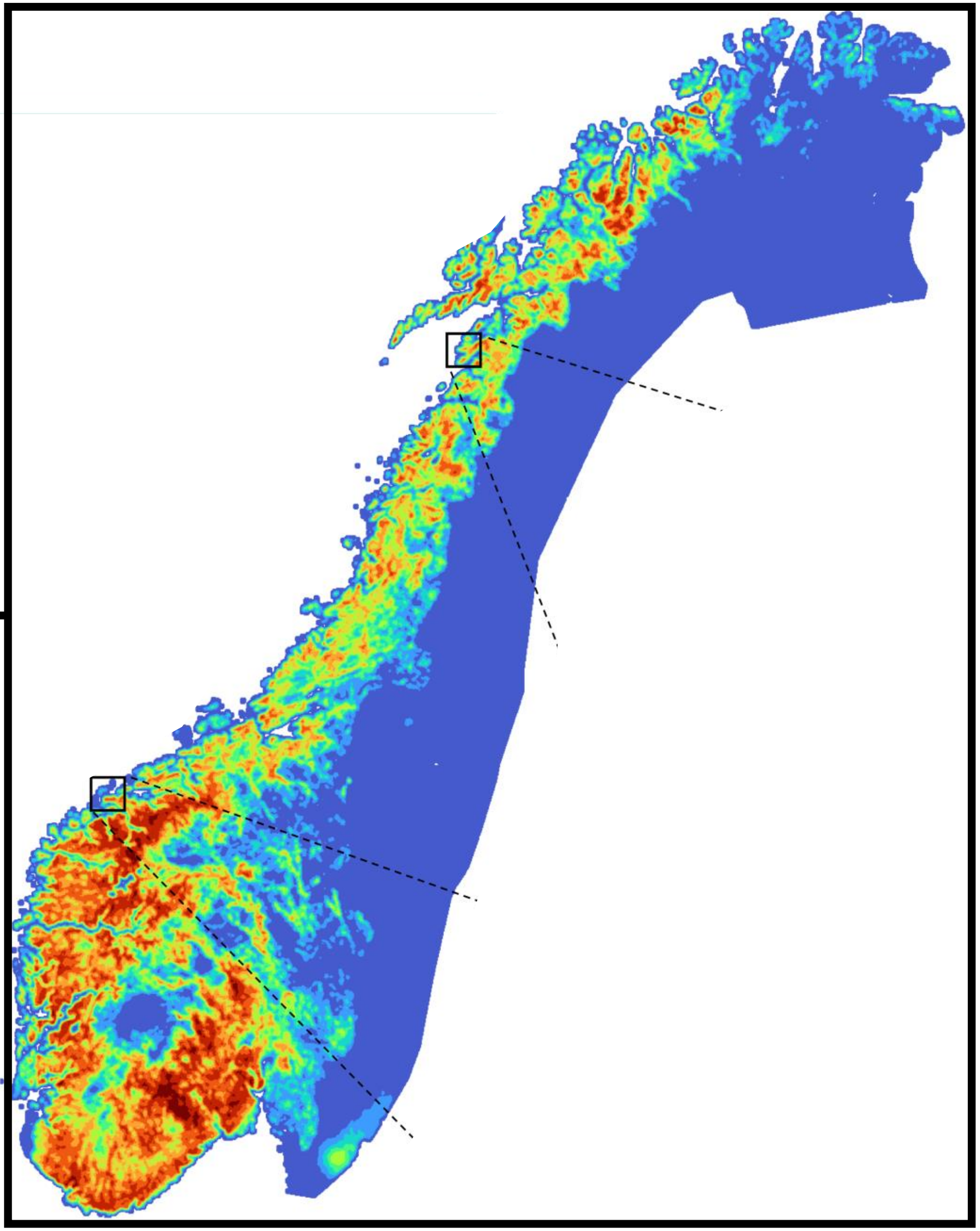


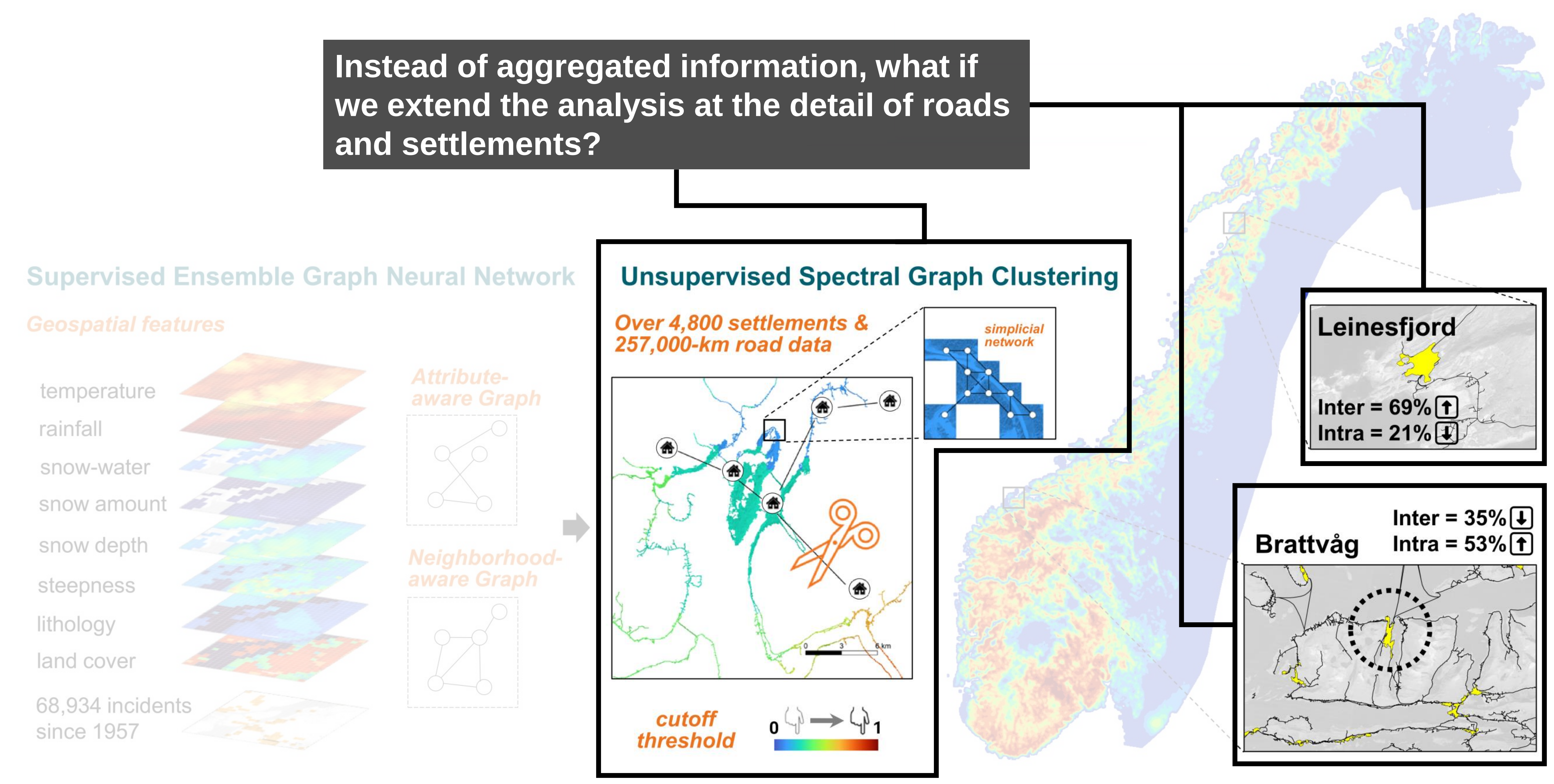


Instead of four classes alone, what if we provide estimates with values from 0 to 100% with associated uncertainty?

Supervised **Ensemble** Graph **Neural Network**

Geospatial features




Instead of aggregated information, what if we extend the analysis at the detail of roads and settlements?
Supervised Ensemble Graph Neural Network
Geospatial features
temperature
rainfall
snow-water
snow amount
snow depth
steepness
lithology
land cover
68,934 incidents since 1957
Attribute-aware Graph
Neighborhood-aware Graph
Unsupervised Spectral Graph Clustering
Over 4,800 settlements & 257,000-km road data
simplicial network
cutoff threshold
0
1
Leinesfjord
Inter = 69%
Intra = 21%
Brattvåg
Inter = 35%
Intra = 53%

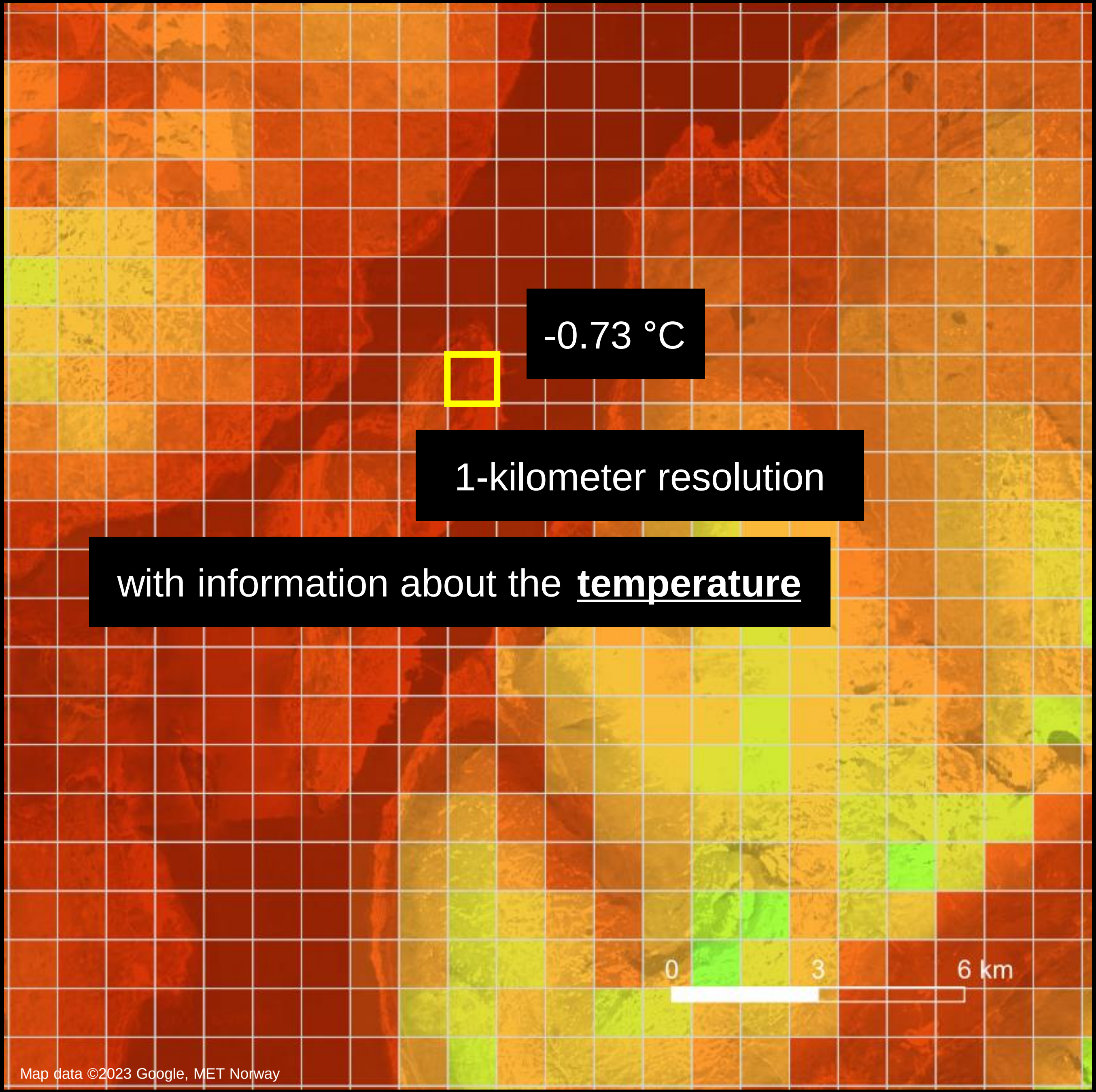

0
200
400 km
Map data ©2023 Google


0
200
400 km
Map data ©2023 Google, GADM

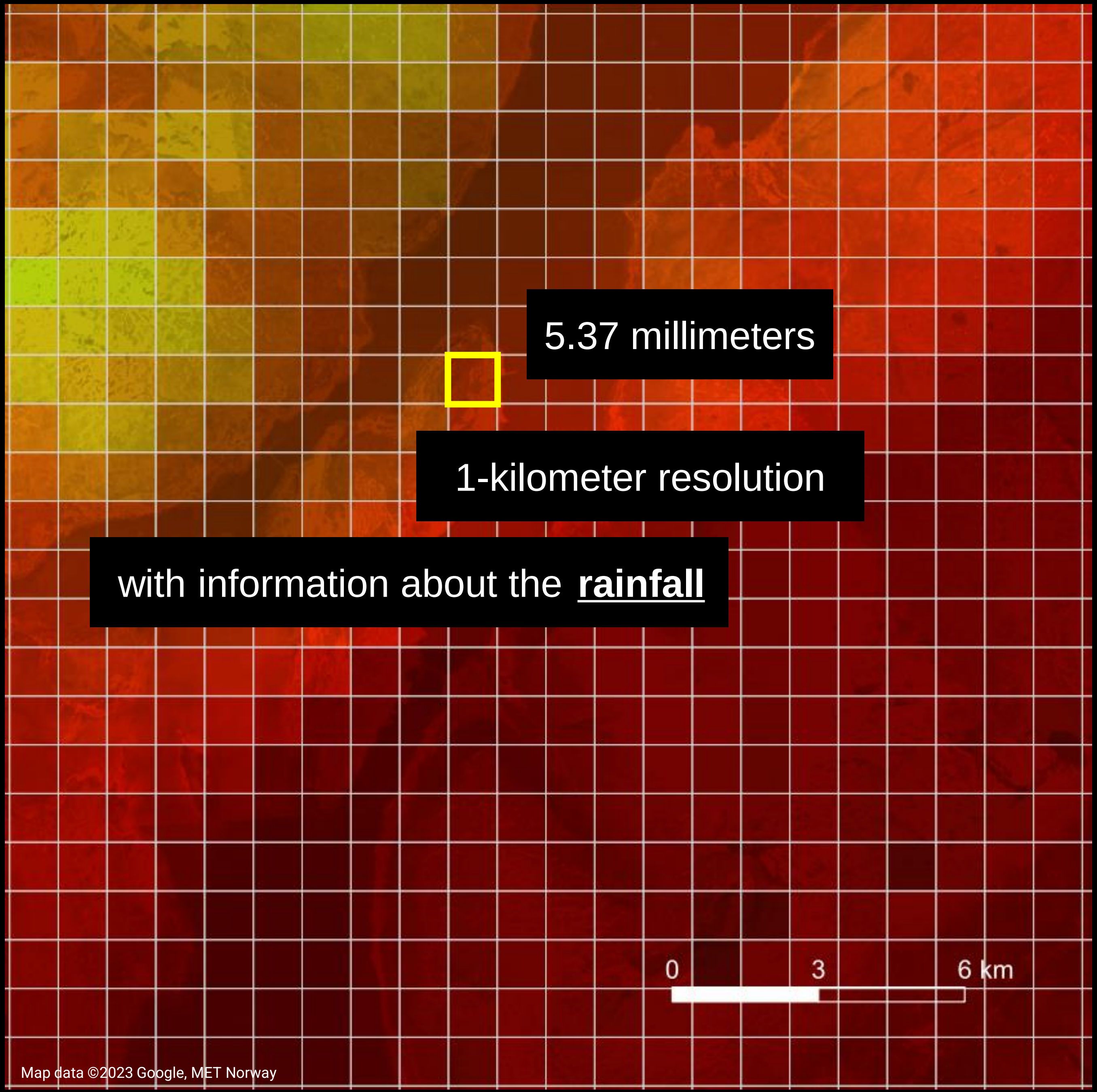
0
3
6 km
Map data ©2023 Google


City of Tromsø
0
3
6 km
Map data ©2023 Google

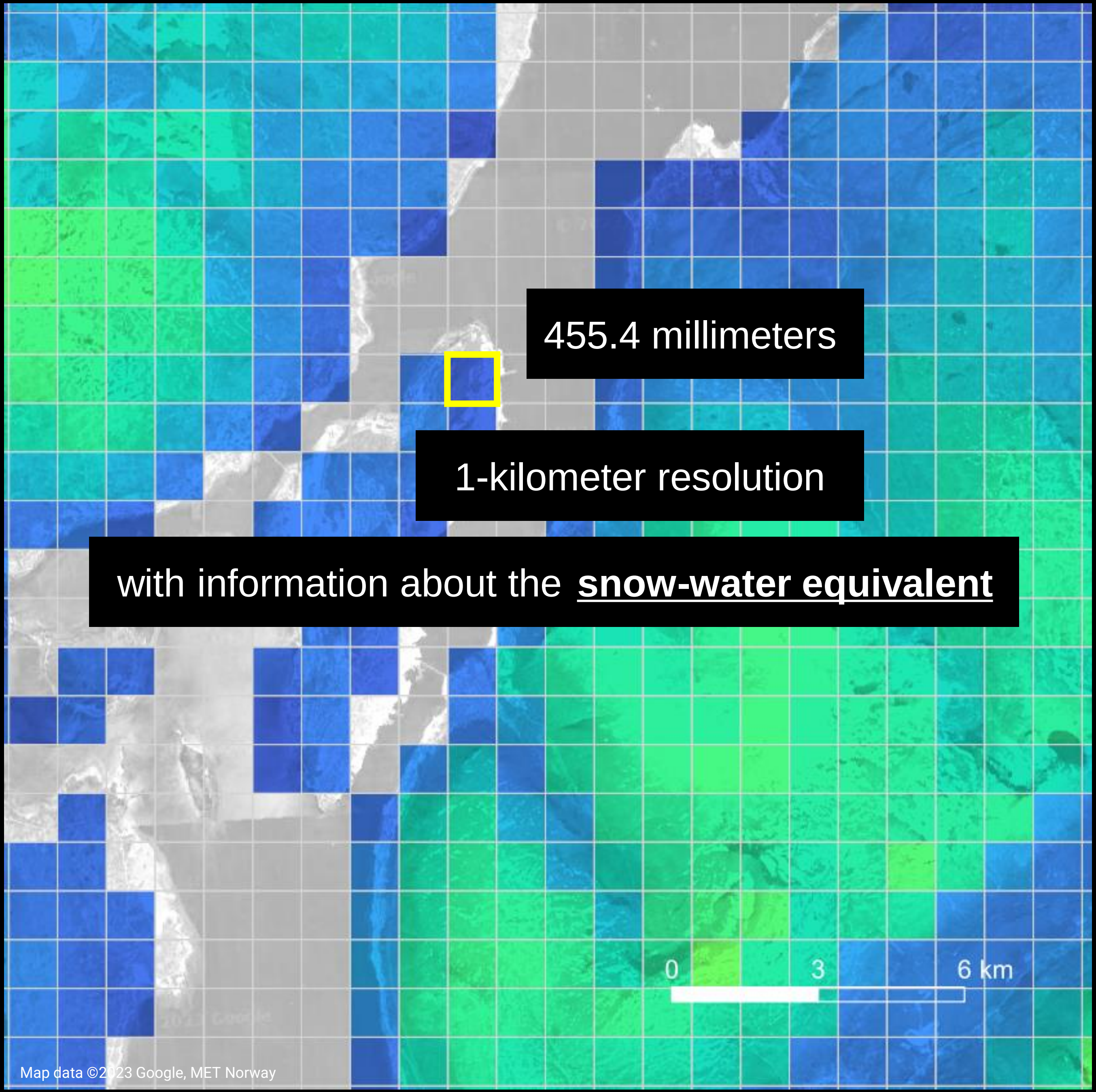

1-kilometer resolution
0
3
6 km
Map data ©2023 Google

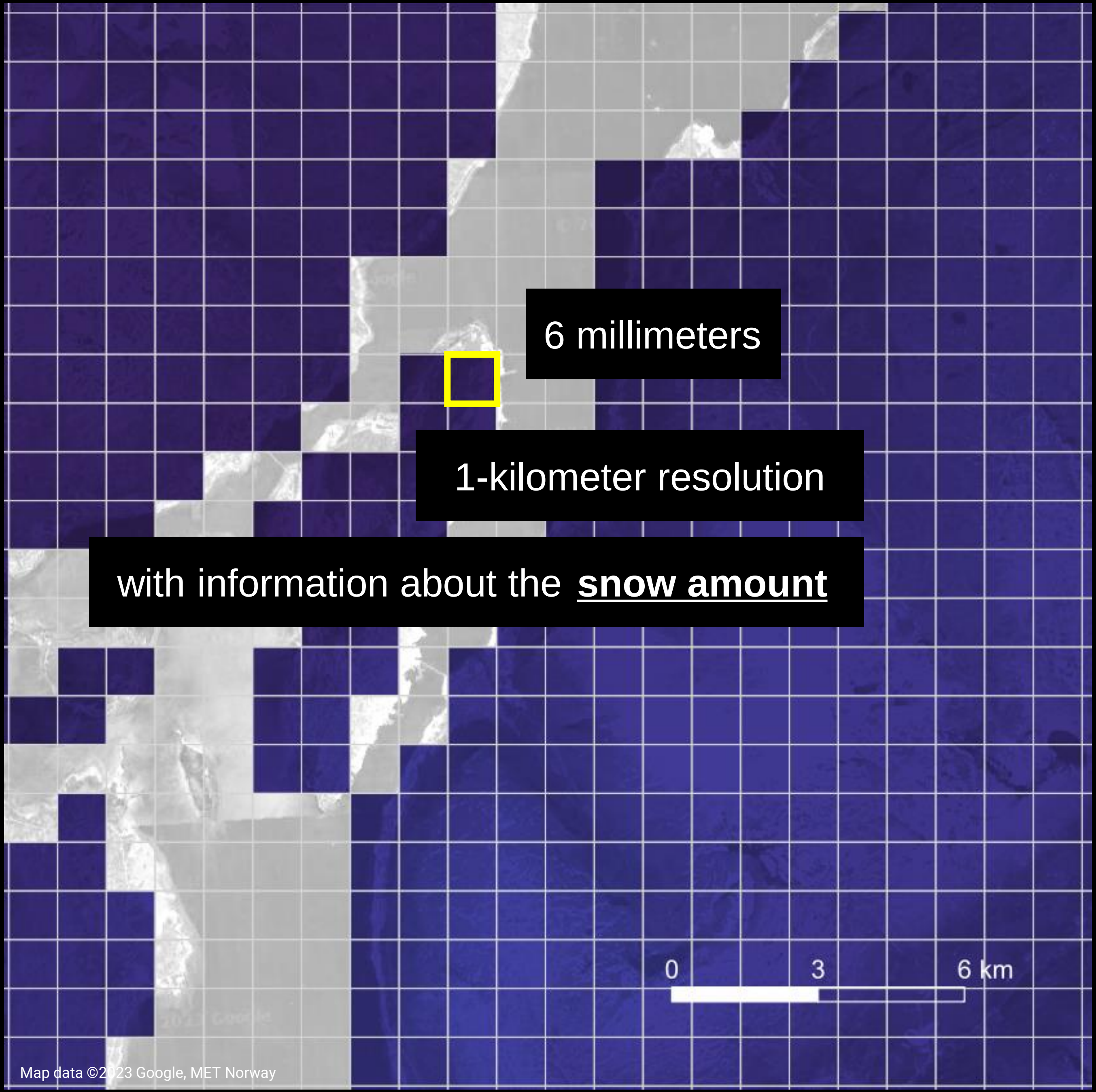


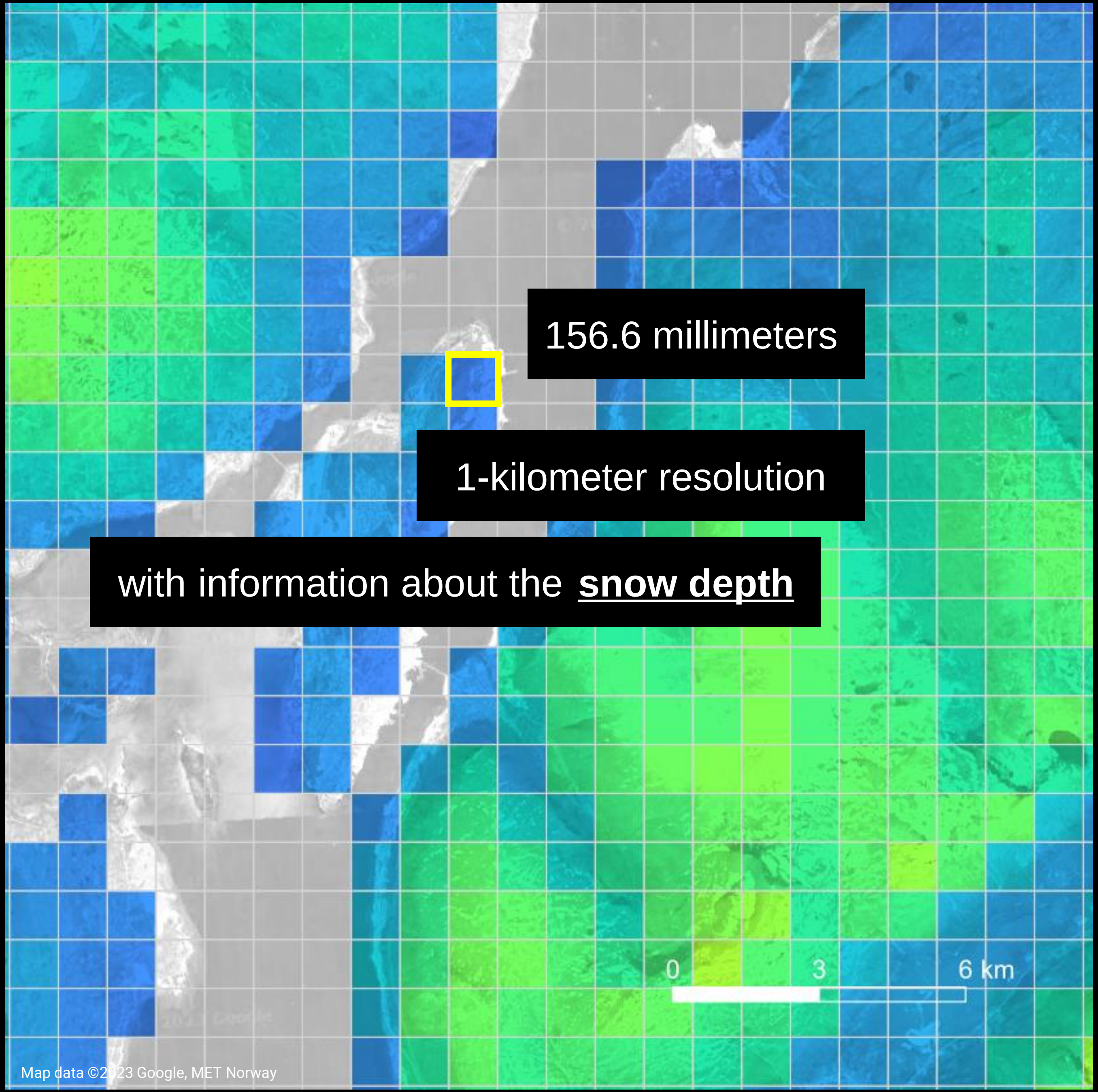
-0.73 °C
1-kilometer resolution
with information about the **temperature**
0
3
6 km
Map data ©2023 Google, MET Norway

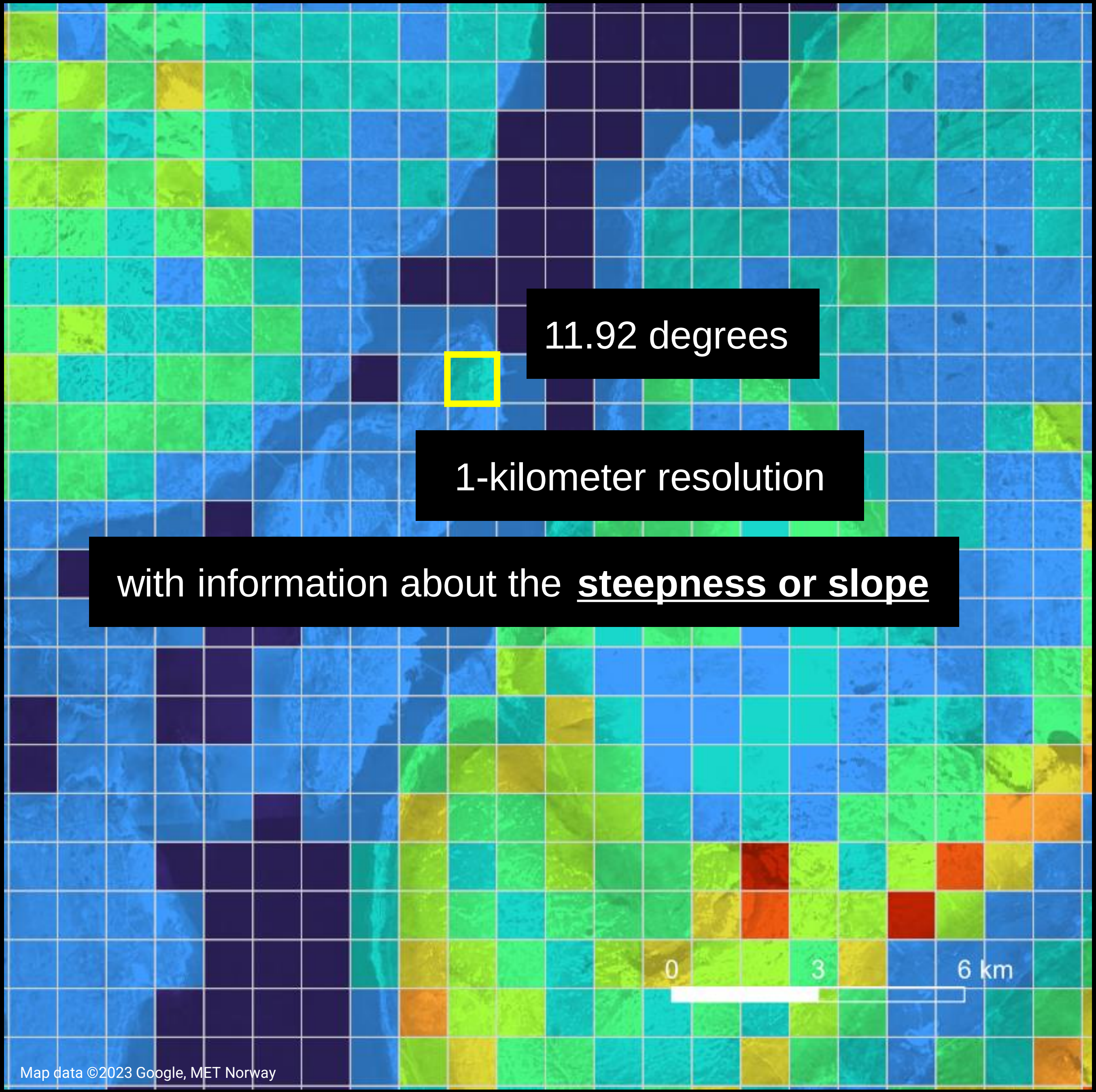


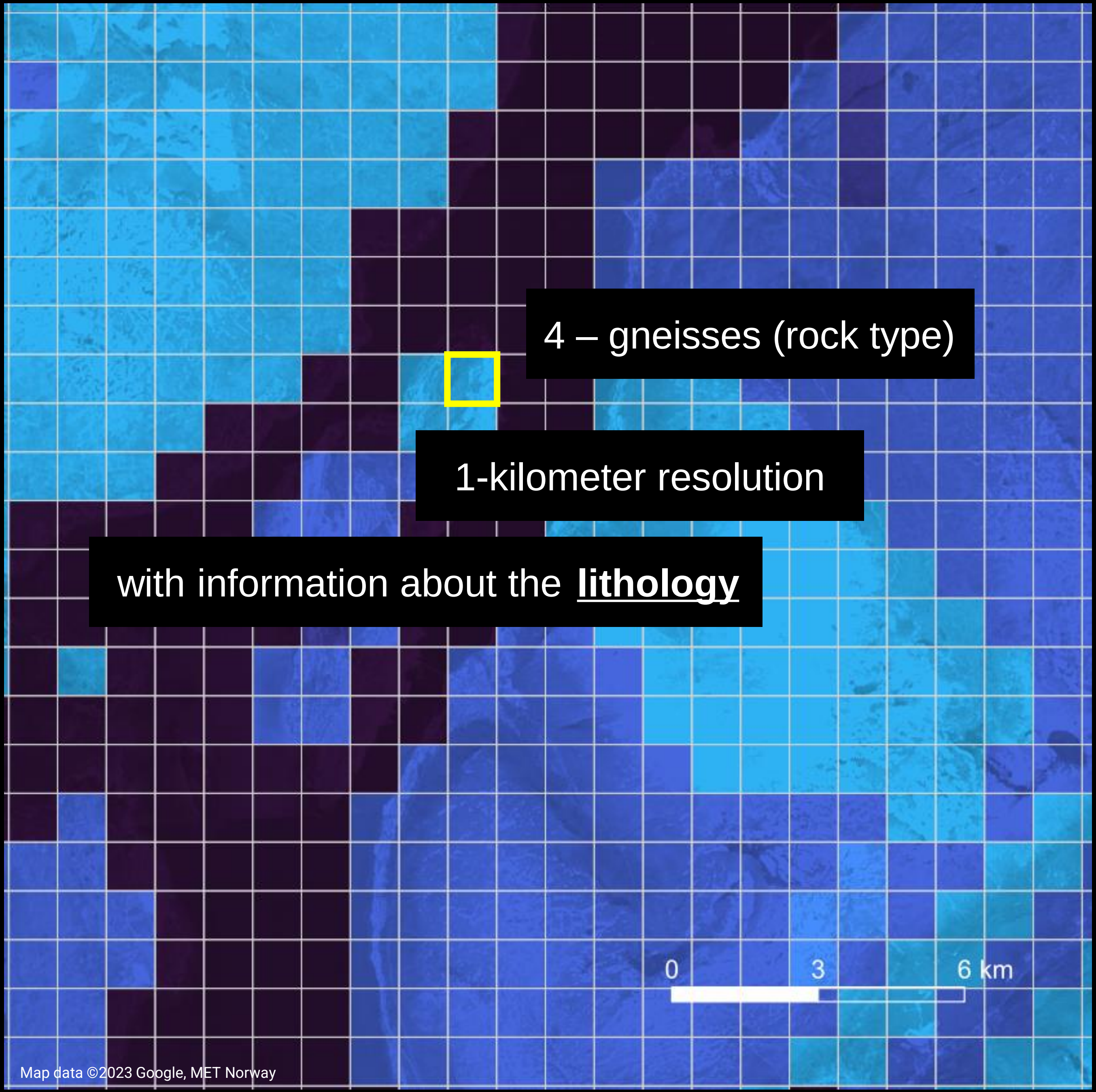
5.37 millimeters
1-kilometer resolution
with information about the **rainfall**
0
3
6 km
Map data ©2023 Google, MET Norway

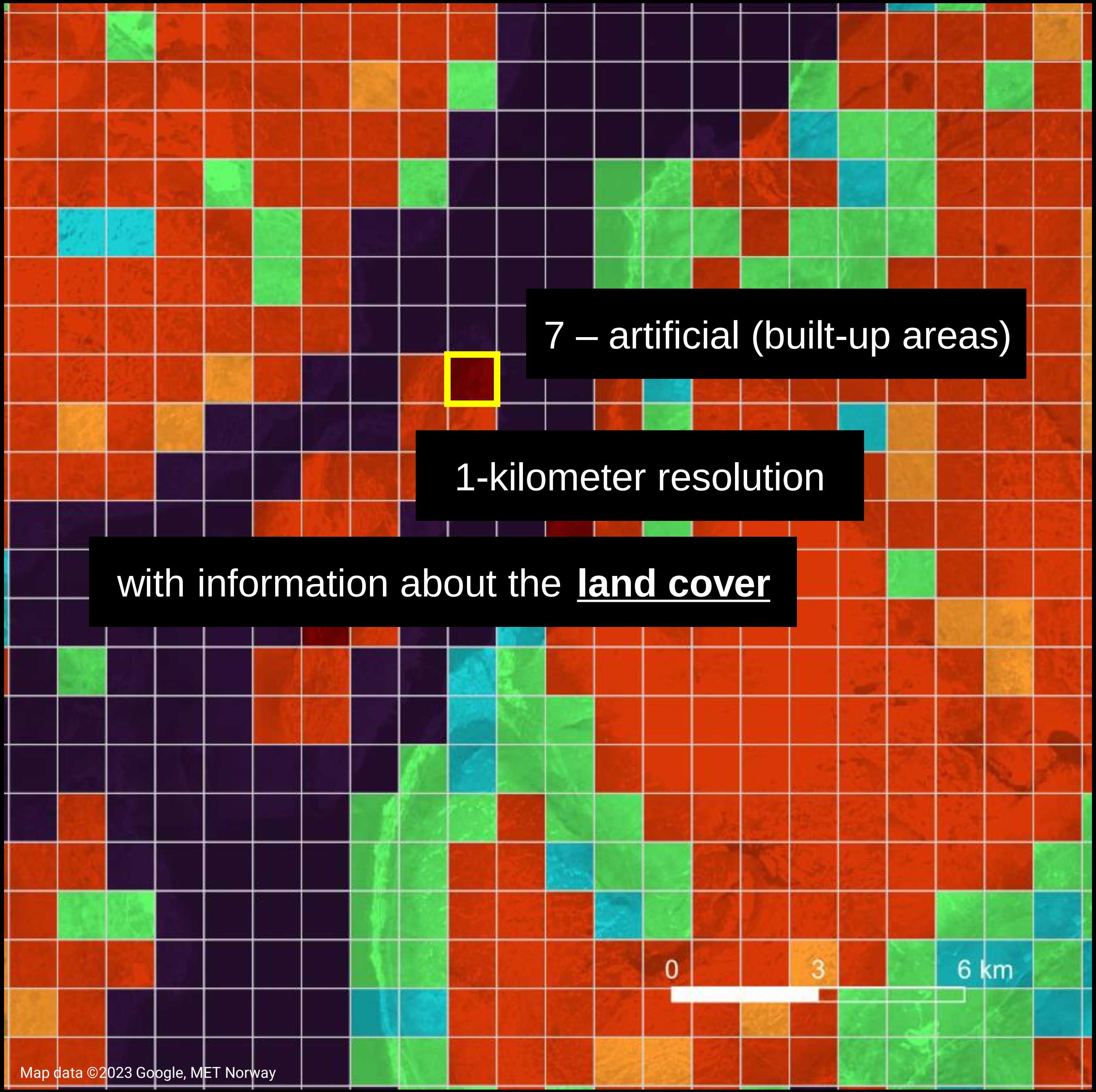

455.4 millimeters
1-kilometer resolution
with information about the **snow-water equivalent**
0
3
6 km
Map data ©2023 Google, MET Norway

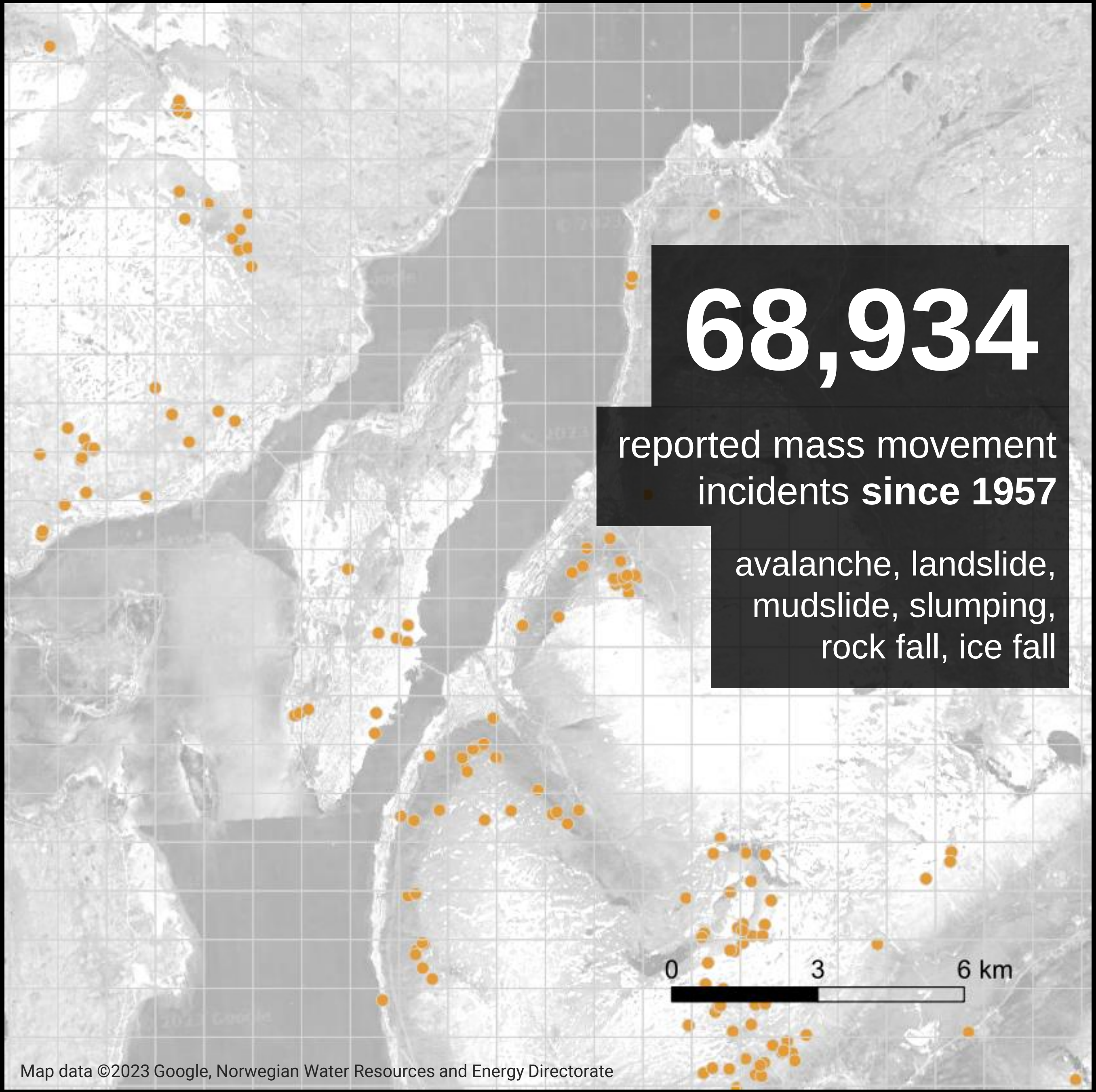

6 millimeters
1-kilometer resolution
with information about the **snow amount**
0
3
6 km
Map data ©2023 Google, MET Norway

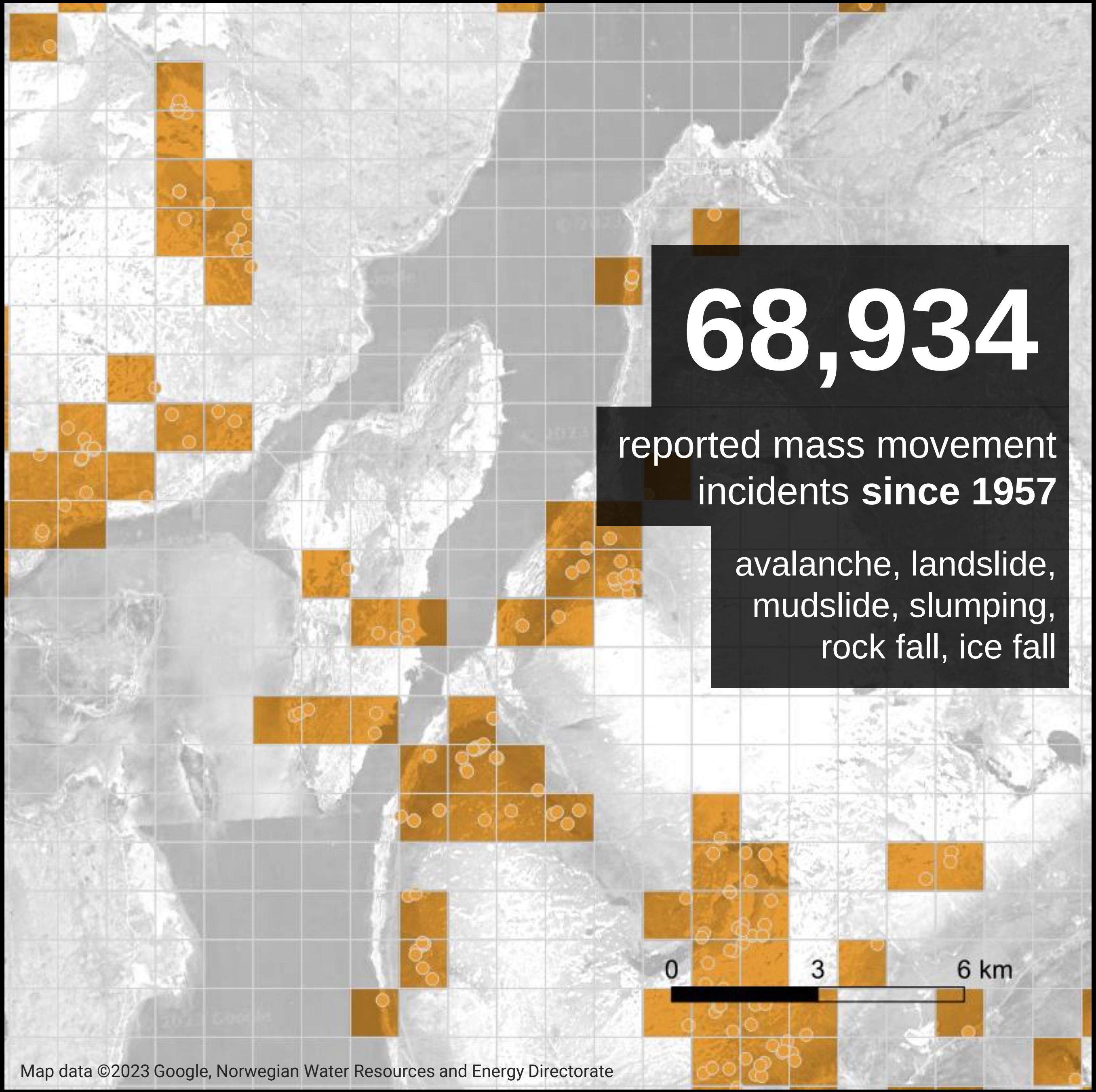

156.6 millimeters
1-kilometer resolution
with information about the **snow depth**
0
3
6 km
Map data ©2023 Google, MET Norway


11.92 degrees
1-kilometer resolution
with information about the **steepness or slope**
0
3
6 km
Map data ©2023 Google, MET Norway


4 – gneisses (rock type)
1-kilometer resolution
with information about the **lithology**
0
3
6 km
Map data ©2023 Google, MET Norway


7 – artificial (built-up areas)
1-kilometer resolution
with information about the **land cover**
0
3
6 km
Map data ©2023 Google, MET Norway


68,934
reported mass movement incidents **since 1957**
avalanche, landslide, mudslide, slumping, rock fall, ice fall
0
3
6 km
Map data ©2023 Google, Norwegian Water Resources and Energy Directorate


68,934
reported mass movement incidents **since 1957**
avalanche, landslide, mudslide, slumping, rock fall, ice fall
0
3
6 km
Map data ©2023 Google, Norwegian Water Resources and Energy Directorate


0
3
6 km
Map data ©2023 Google


0
200
400 km
Map data ©2023 Google


508,182
points to cover
the entire map of Norway
0
200
400 km
Map data ©2023 Google, GADM

Dataset

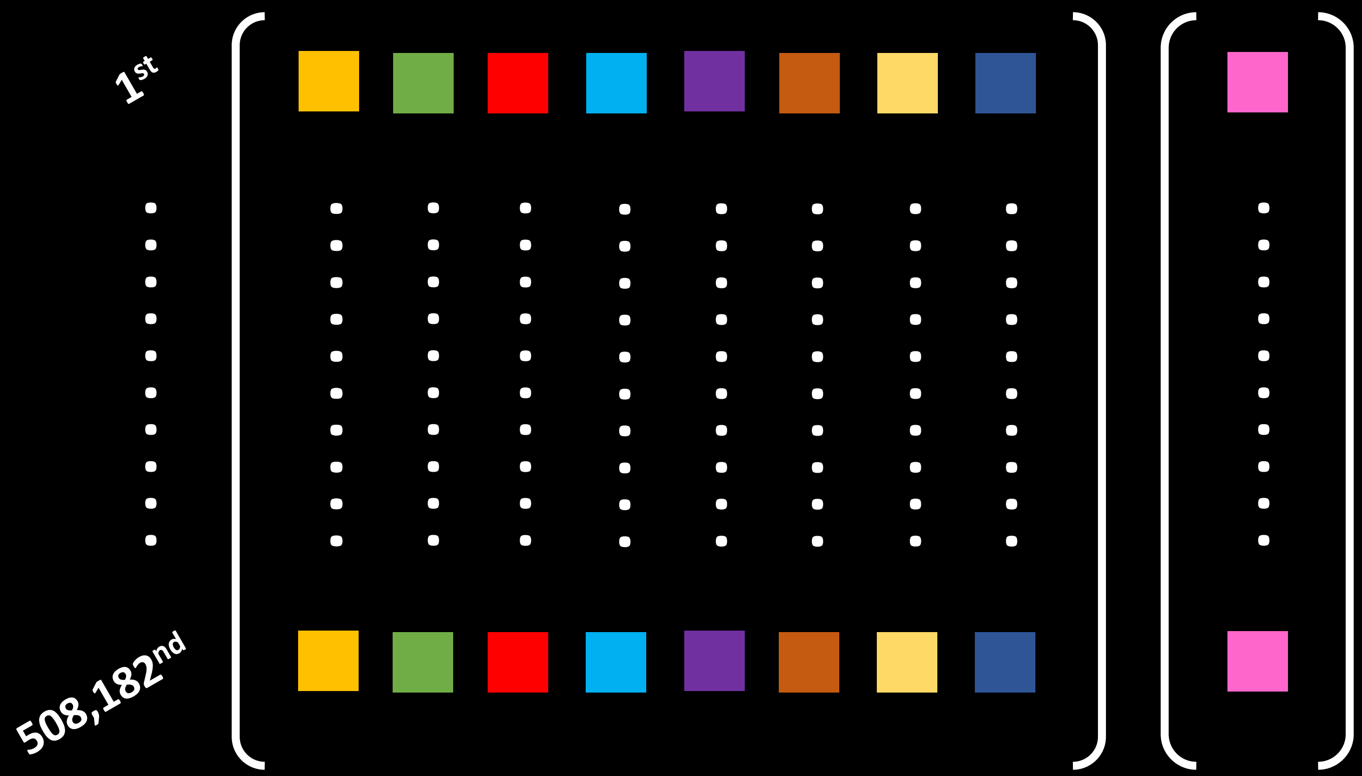
Dataset

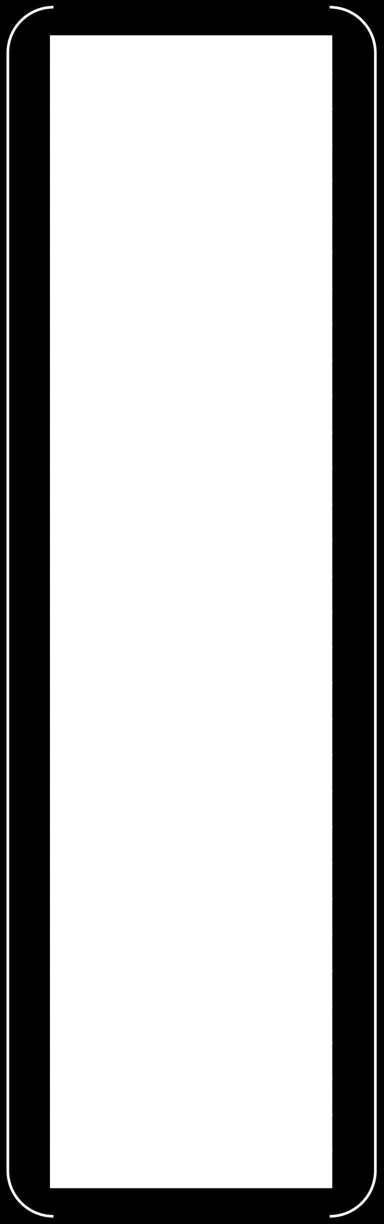
- temperature
- rainfall
- snow-water equivalent
- snow amount
- snow depth
- slope
- rock type
- land cover
- occurrence of mass movement

Dataset

Feature and Label Vectors

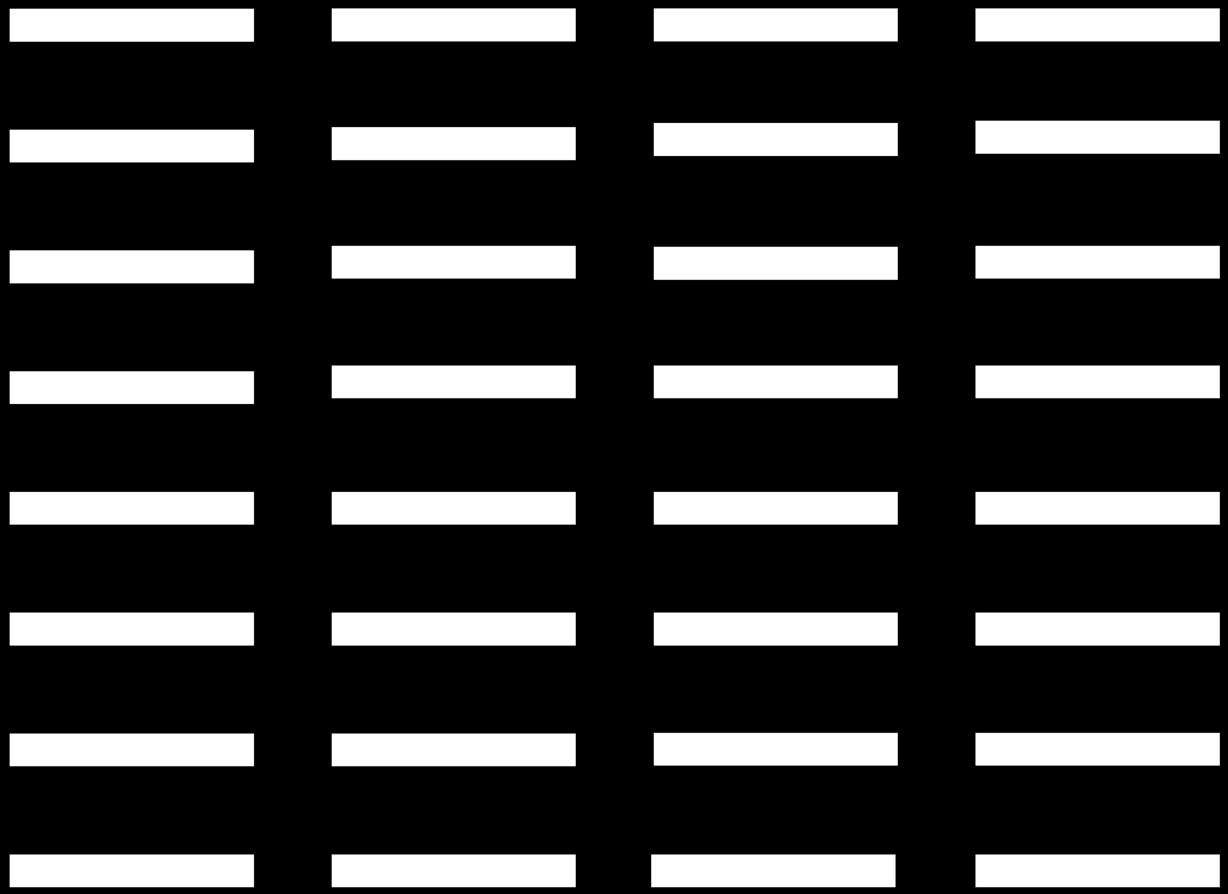
Feature and Label Vectors



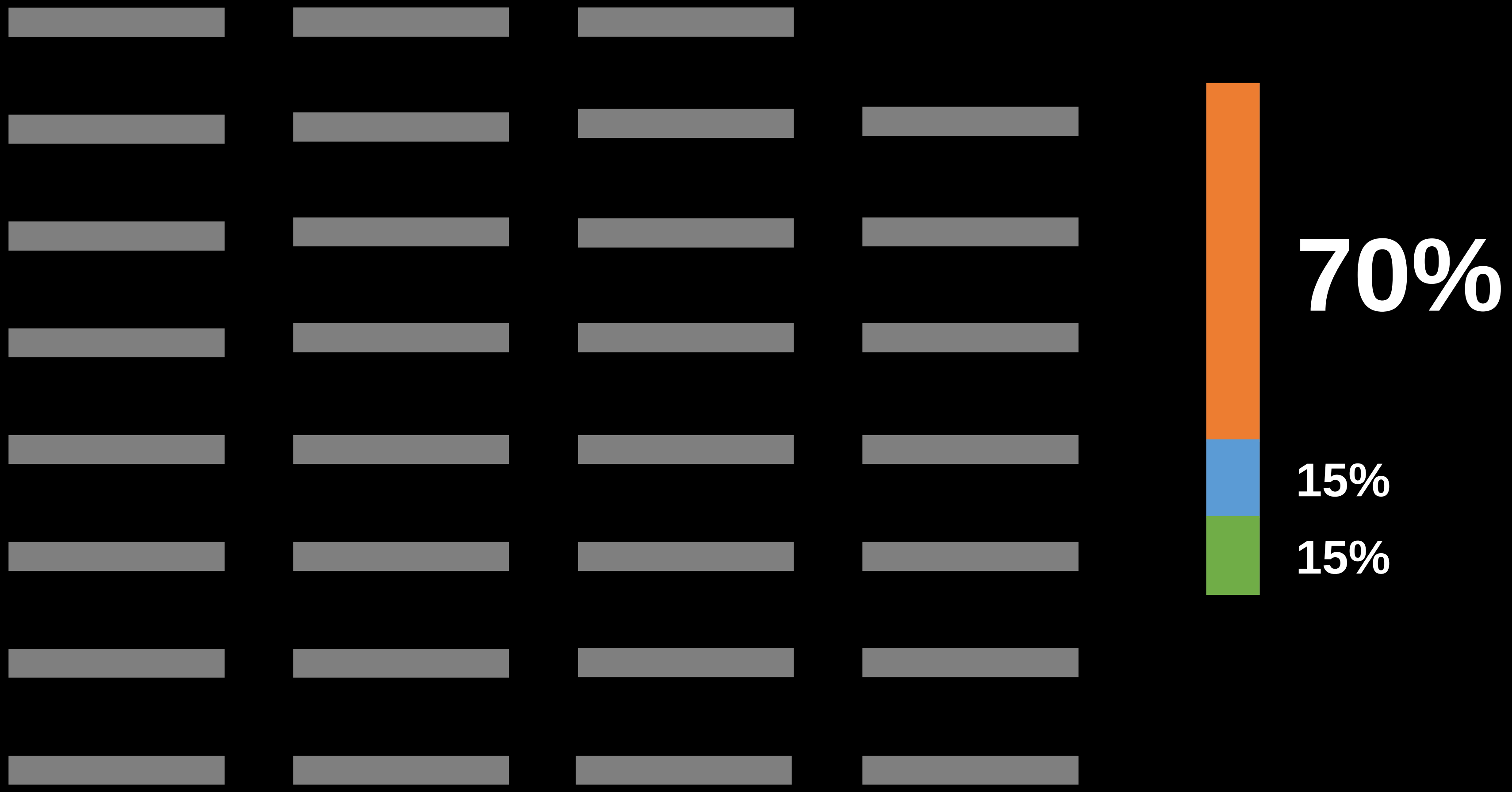


Very
Tall
Vector

Randomly subdivide into
32 smaller datasets



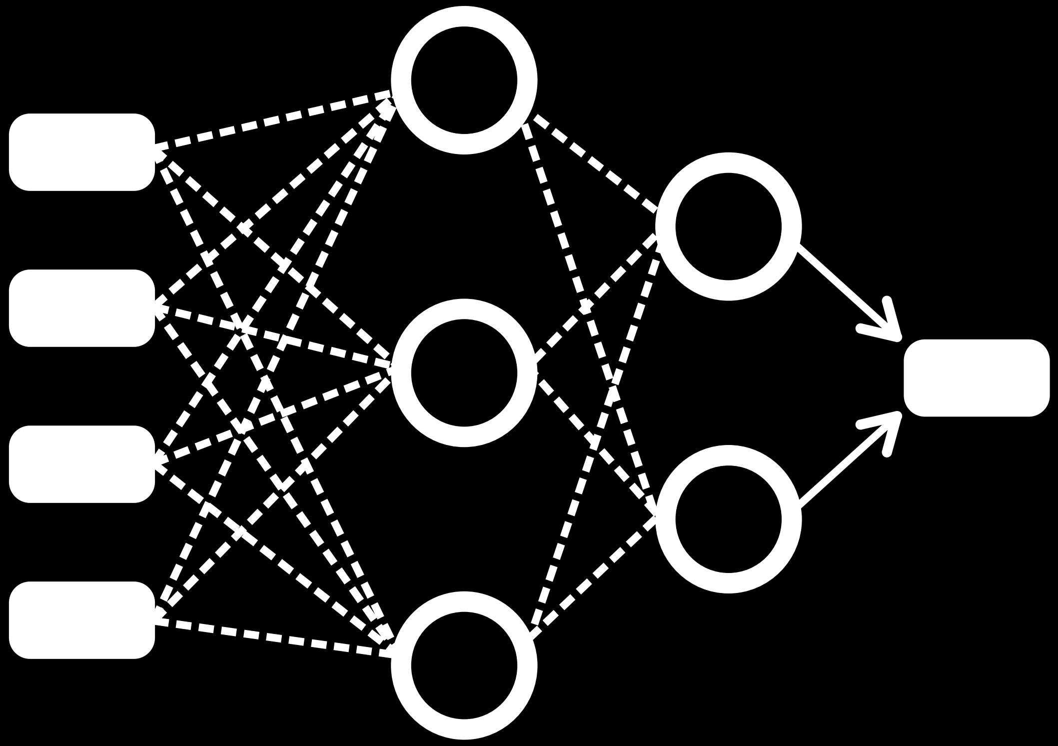
Each smaller dataset is split into training/validation/testing samples.



Each with own trained machine learning

Icon by Christensen (2019)

Each machine learning model is a graph neural network

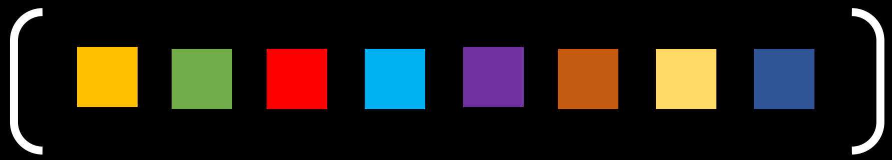


Icon by Christensen (2019)

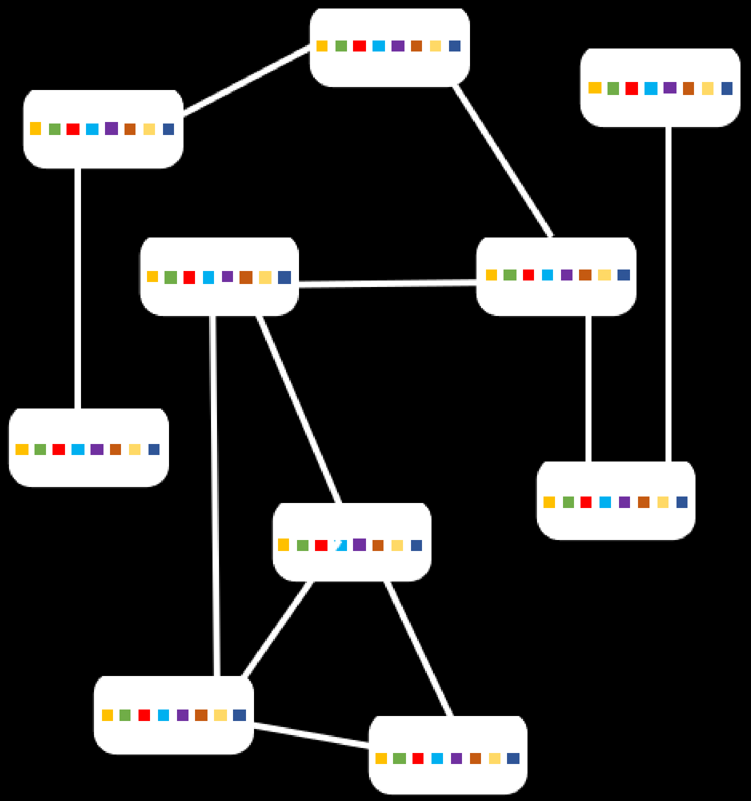
What is our graph?
Recall, each point ( ) has

1. Latitude and Longitude
(neighborhood)

2. Feature Vector
(attribute)



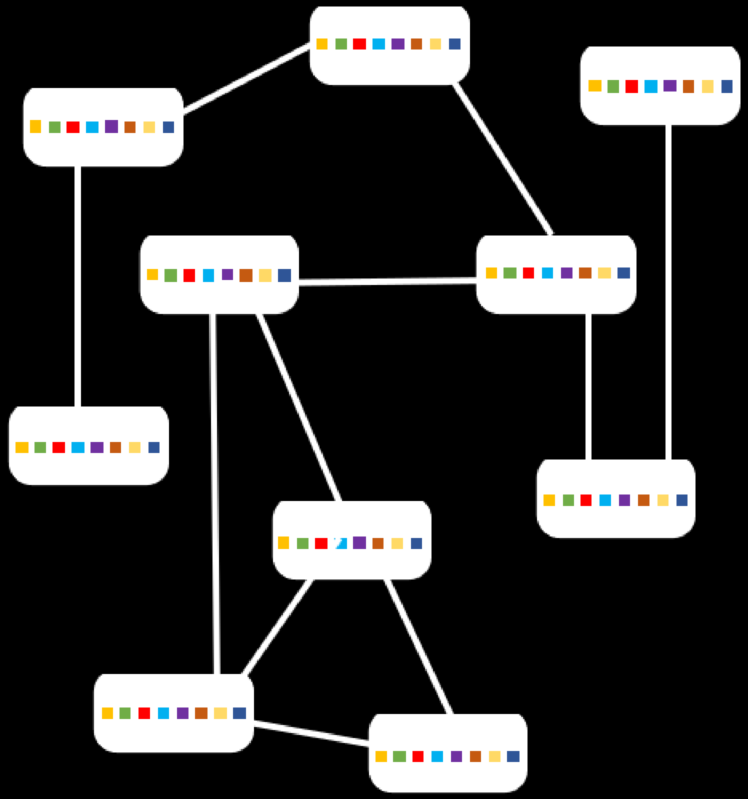
Imagine 10 samples of



neighborhood-aware graph

If they are close to each other *(say 12km-radius)*, we build a connection.

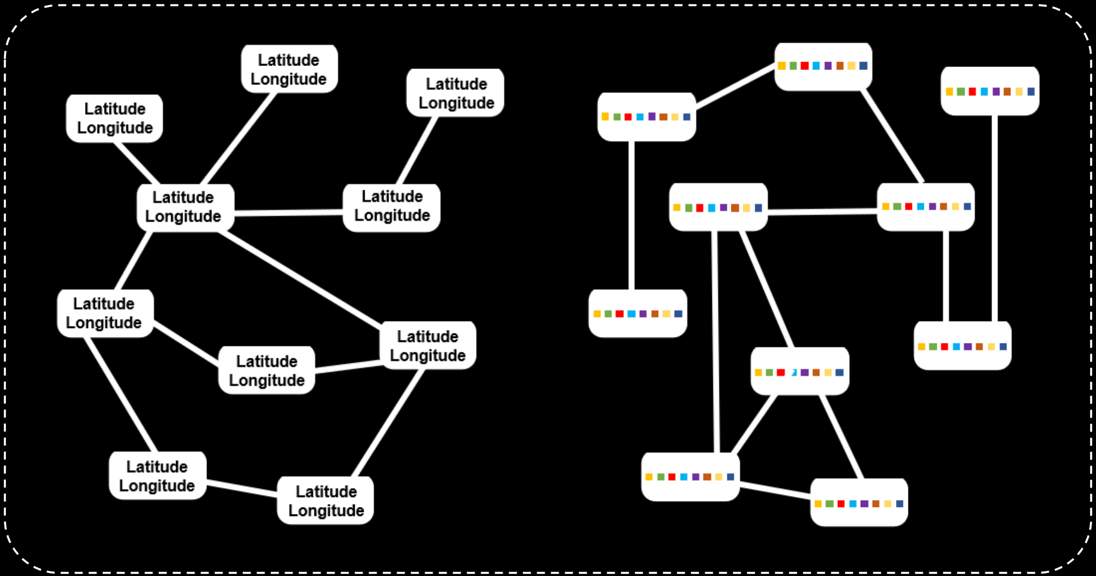
Imagine the same 10 samples of

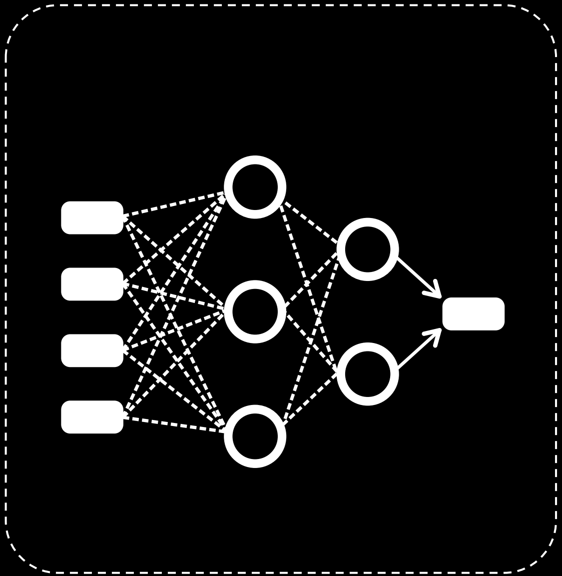


attribute-aware graph

If their feature vectors are similar (say cosine similarity of lithology, steepness, and land cover), we build a connection.

Train the neural network while the outputs respect the two graphs





Neighborhood-aware graph

Attribute-aware graph

Neural Network

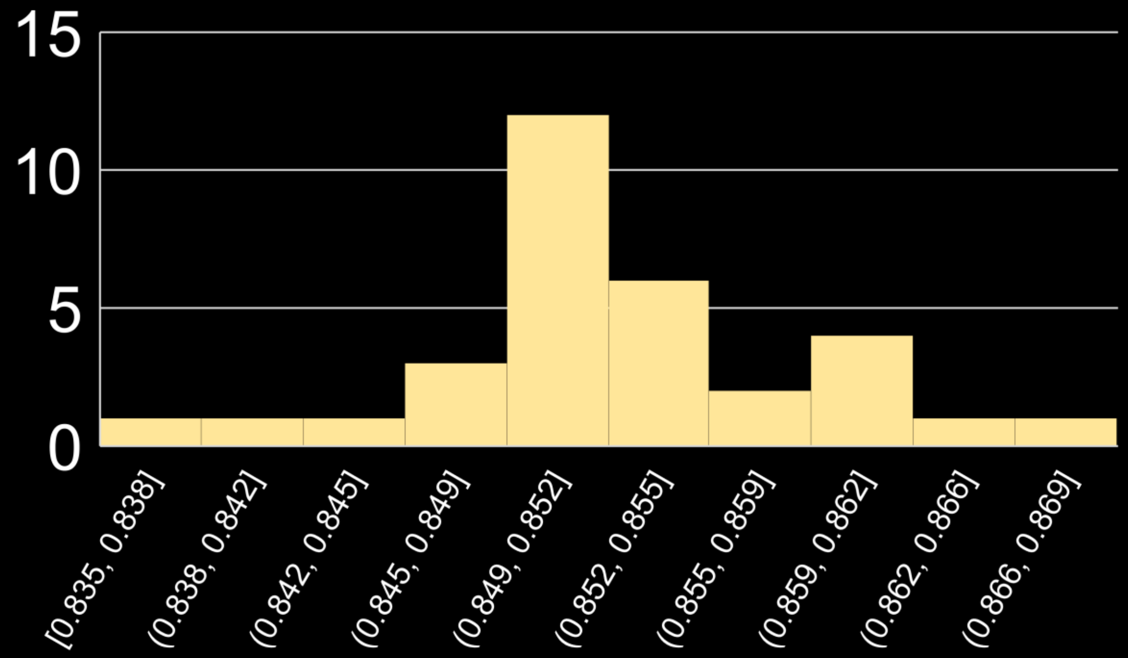
Icon by Christensen (2019)

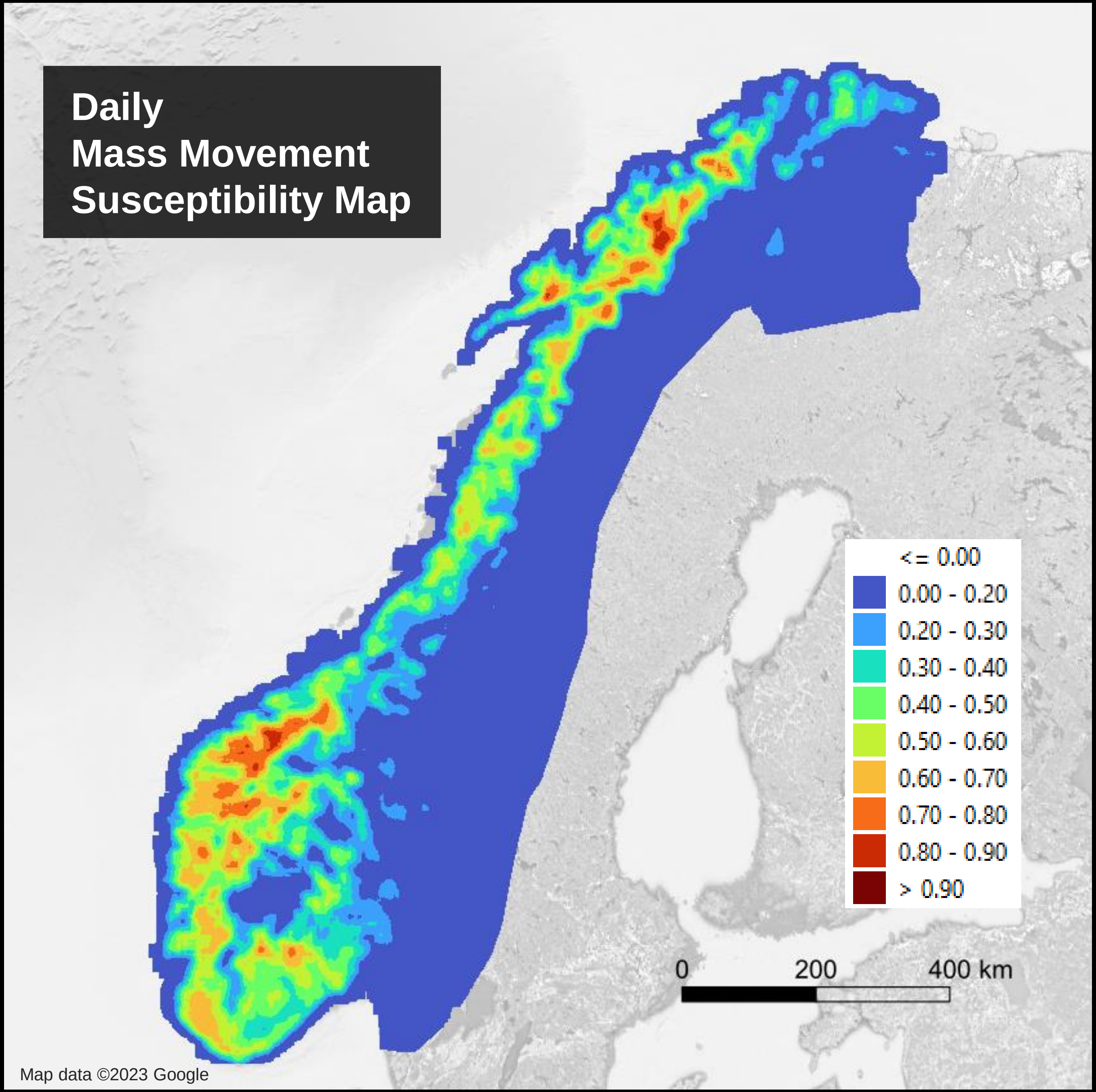
once trained, the ensemble of 32 models predict the probability of mass movement

0.851	0.850	0.862	0.855
0.849	0.855	0.855	0.835
0.848	0.849	0.860	0.869
0.852	0.855	0.865	0.859
0.856	0.849	0.848	0.847
0.854	0.849	0.850	0.851
0.861	0.857	0.850	0.855
0.845	0.849	0.840	0.848

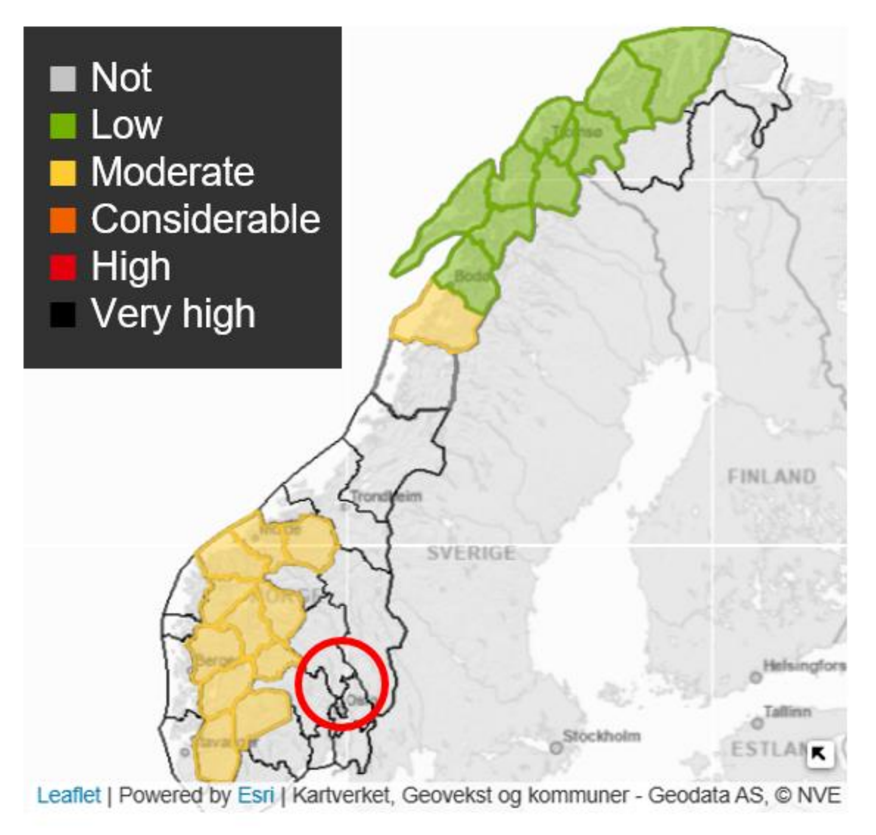
aggregating the predictions

Average = 0.853 ± 0.007




Daily
Mass Movement
Susceptibility Map
<= 0.00
0.00 - 0.20
0.20 - 0.30
0.30 - 0.40
0.40 - 0.50
0.50 - 0.60
0.60 - 0.70
0.70 - 0.80
0.80 - 0.90
> 0.90
0
200
400 km
Map data ©2023 Google

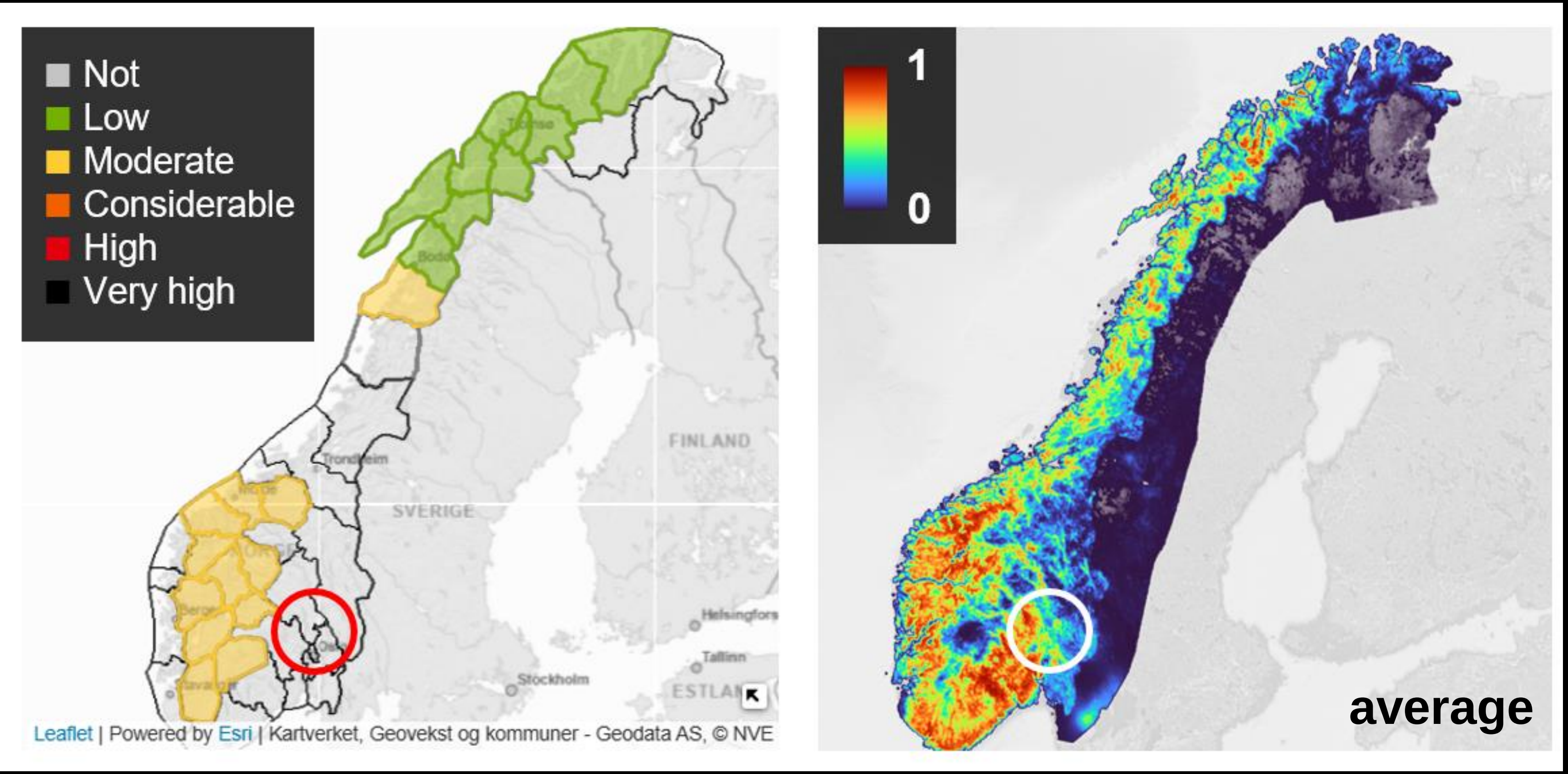
2020 Gjerdrum Mass Movement Incident

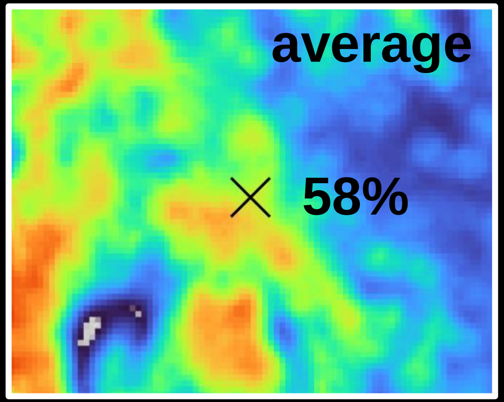


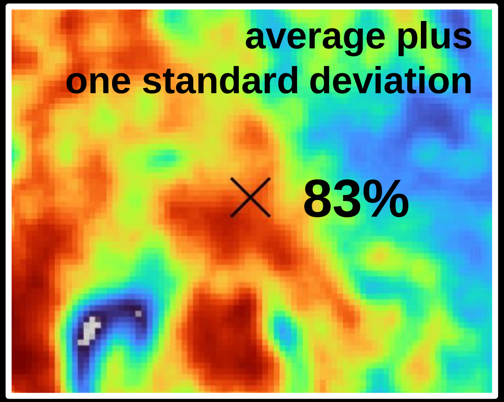
© NTB/AFP via GETTY Images

avalanche: no danger
landslides: low warning

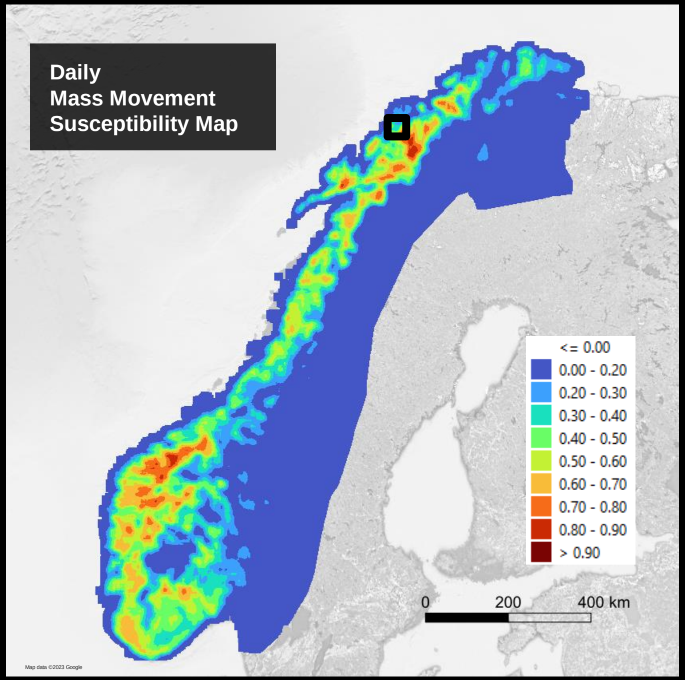
2020 Gjerdrum Mass Movement Incident

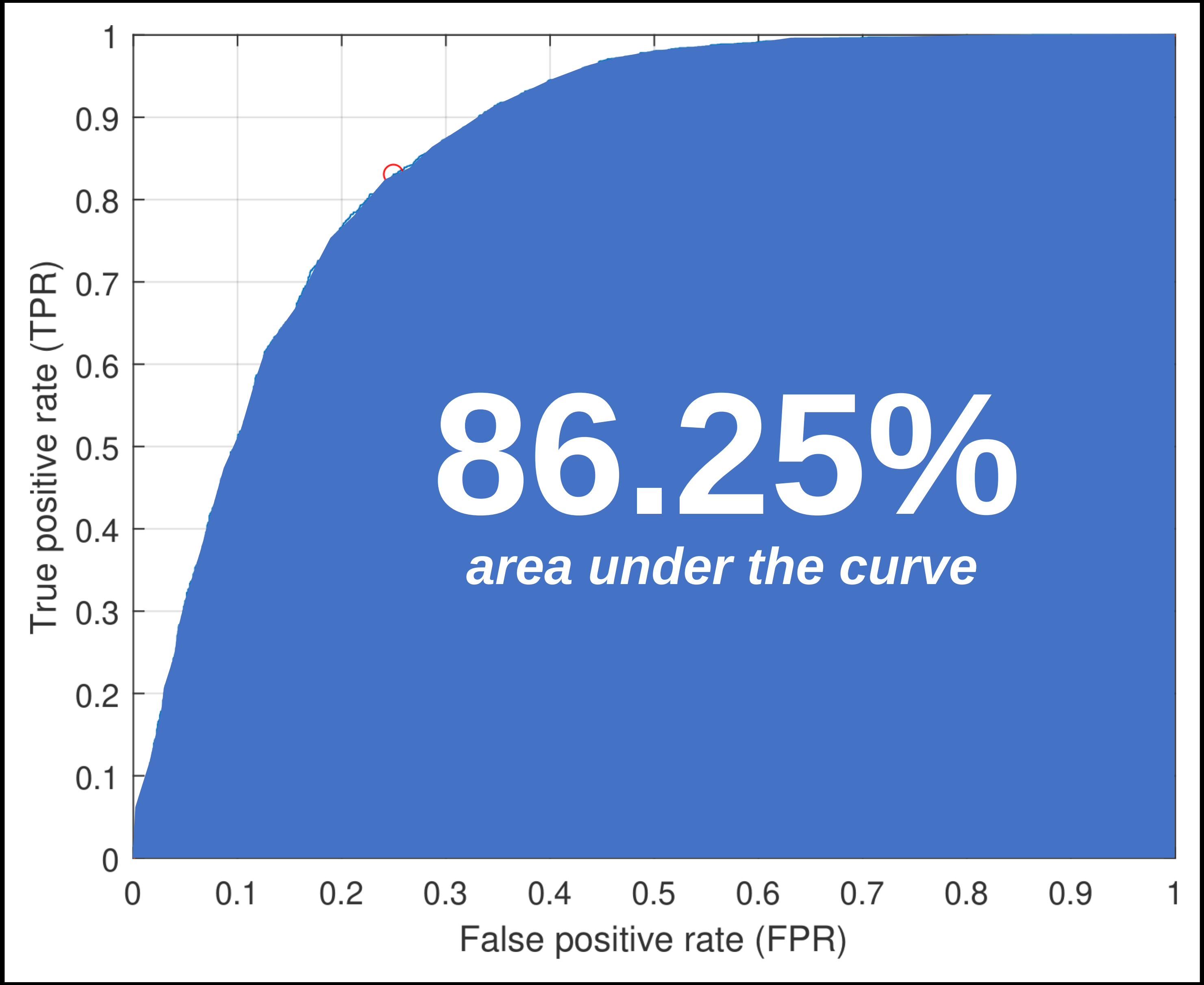


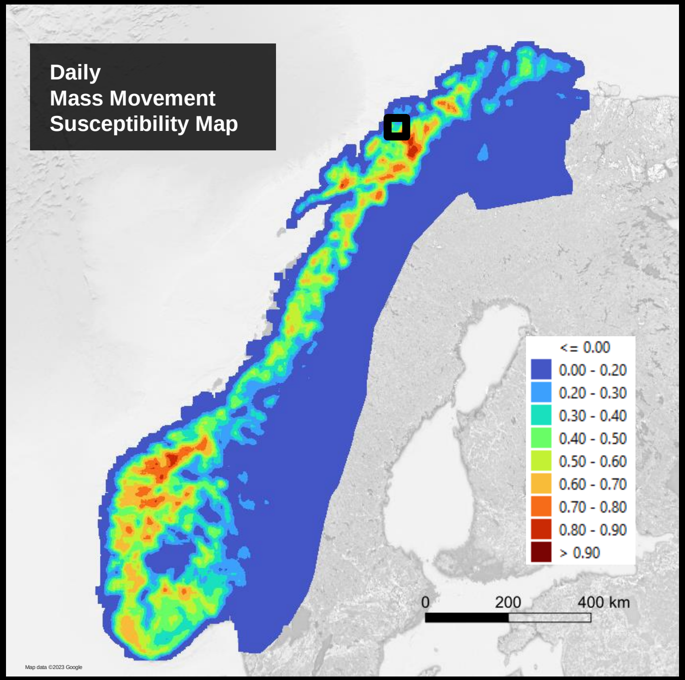


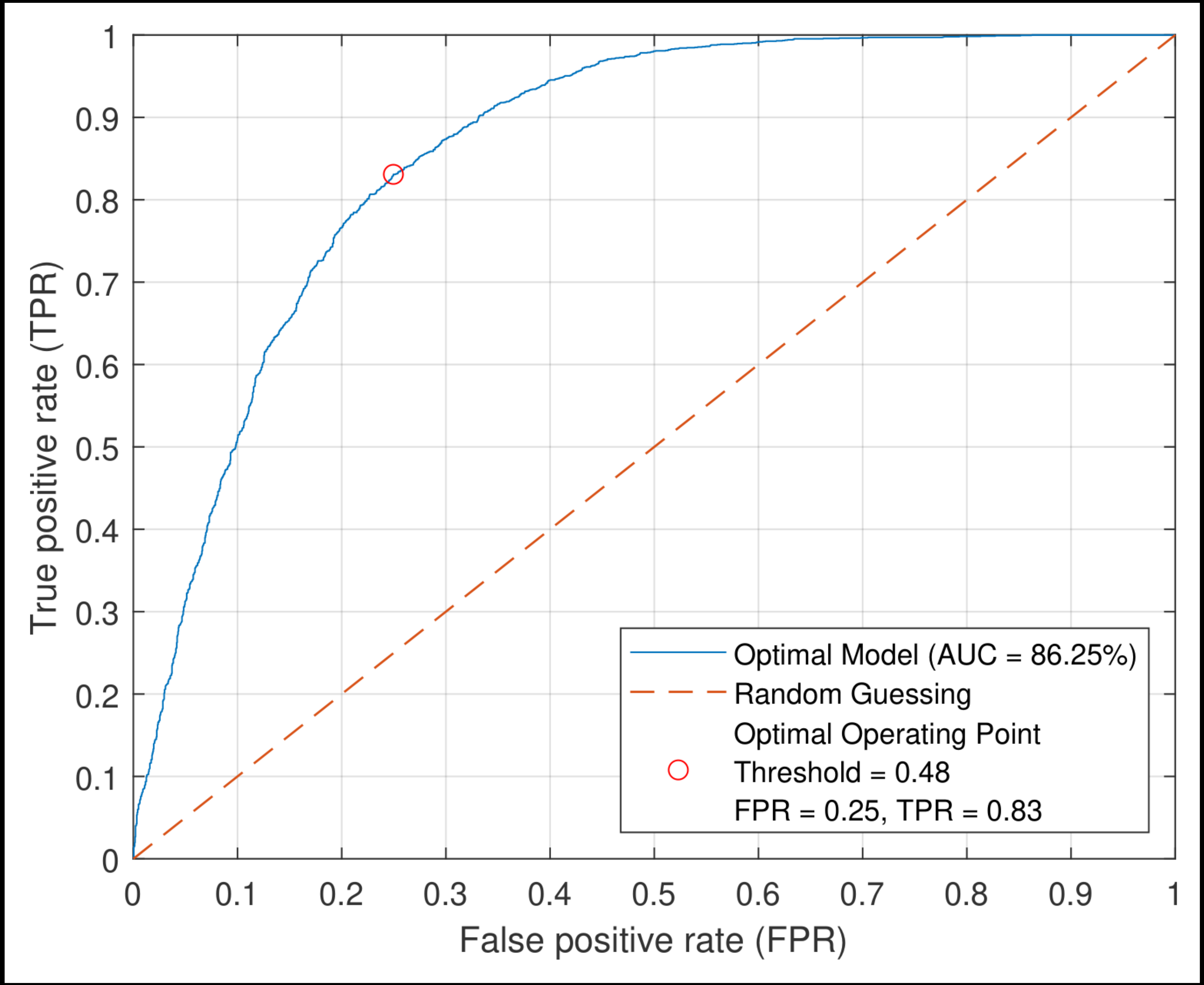


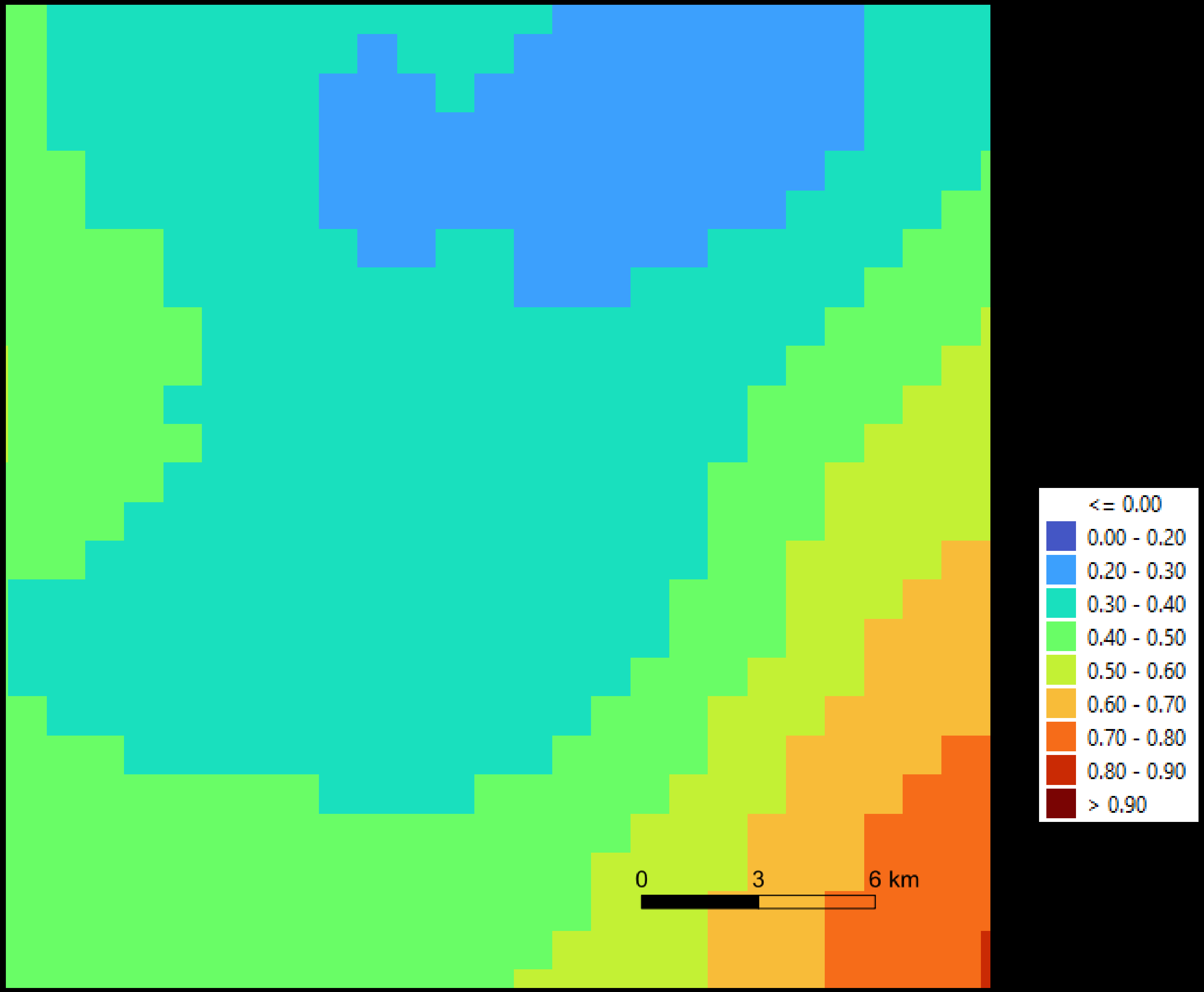
avalanche: no danger
landslides: low warning


Daily
Mass Movement
Susceptibility Map
<= 0.00
0.00 - 0.20
0.20 - 0.30
0.30 - 0.40
0.40 - 0.50
0.50 - 0.60
0.60 - 0.70
0.70 - 0.80
0.80 - 0.90
> 0.90
0
200
400 km

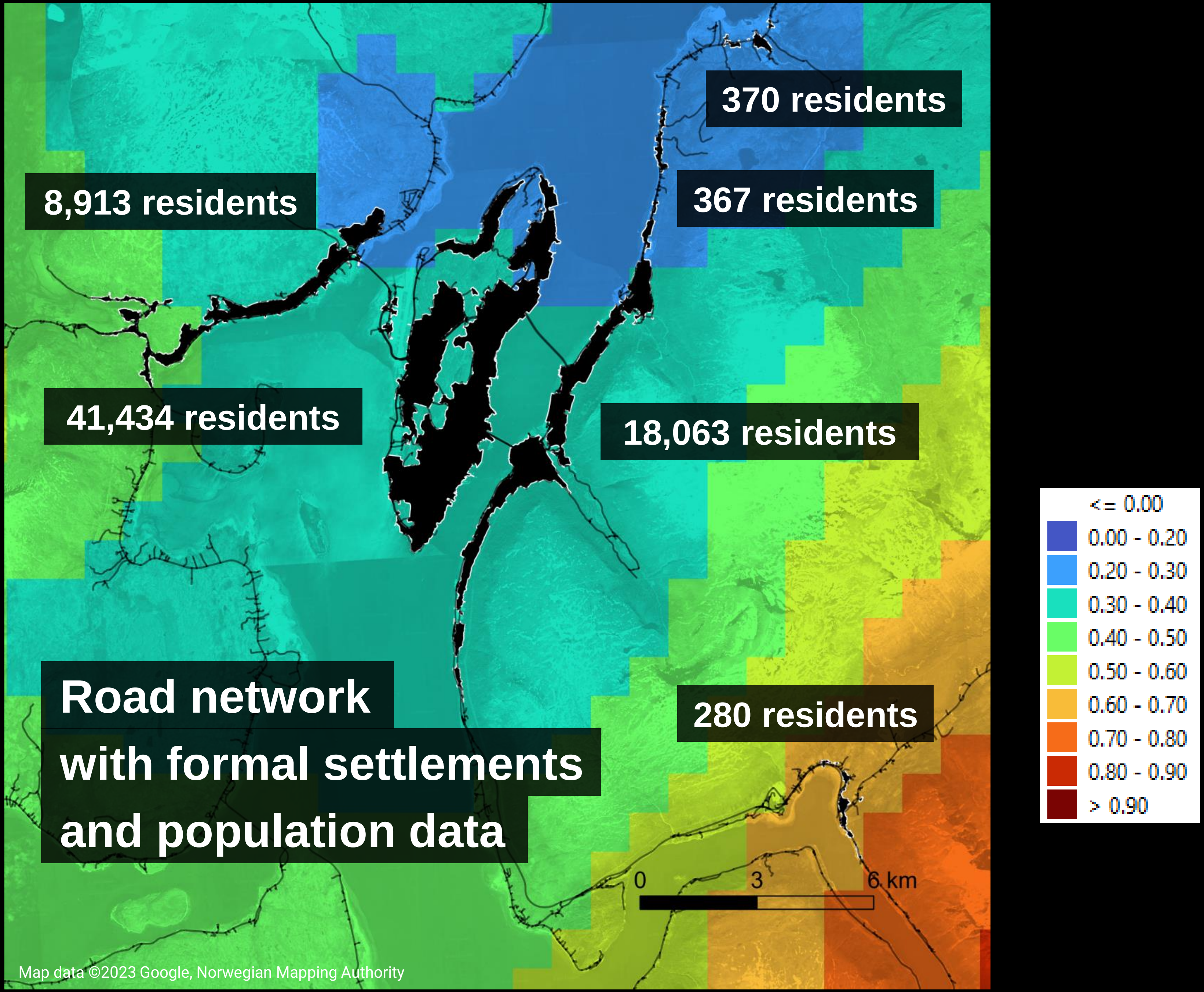

86.25%
area under the curve
True positive rate (TPR)
False positive rate (FPR)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1


Daily
Mass Movement
Susceptibility Map
<= 0.00
0.00 - 0.20
0.20 - 0.30
0.30 - 0.40
0.40 - 0.50
0.50 - 0.60
0.60 - 0.70
0.70 - 0.80
0.80 - 0.90
> 0.90
0
200
400 km

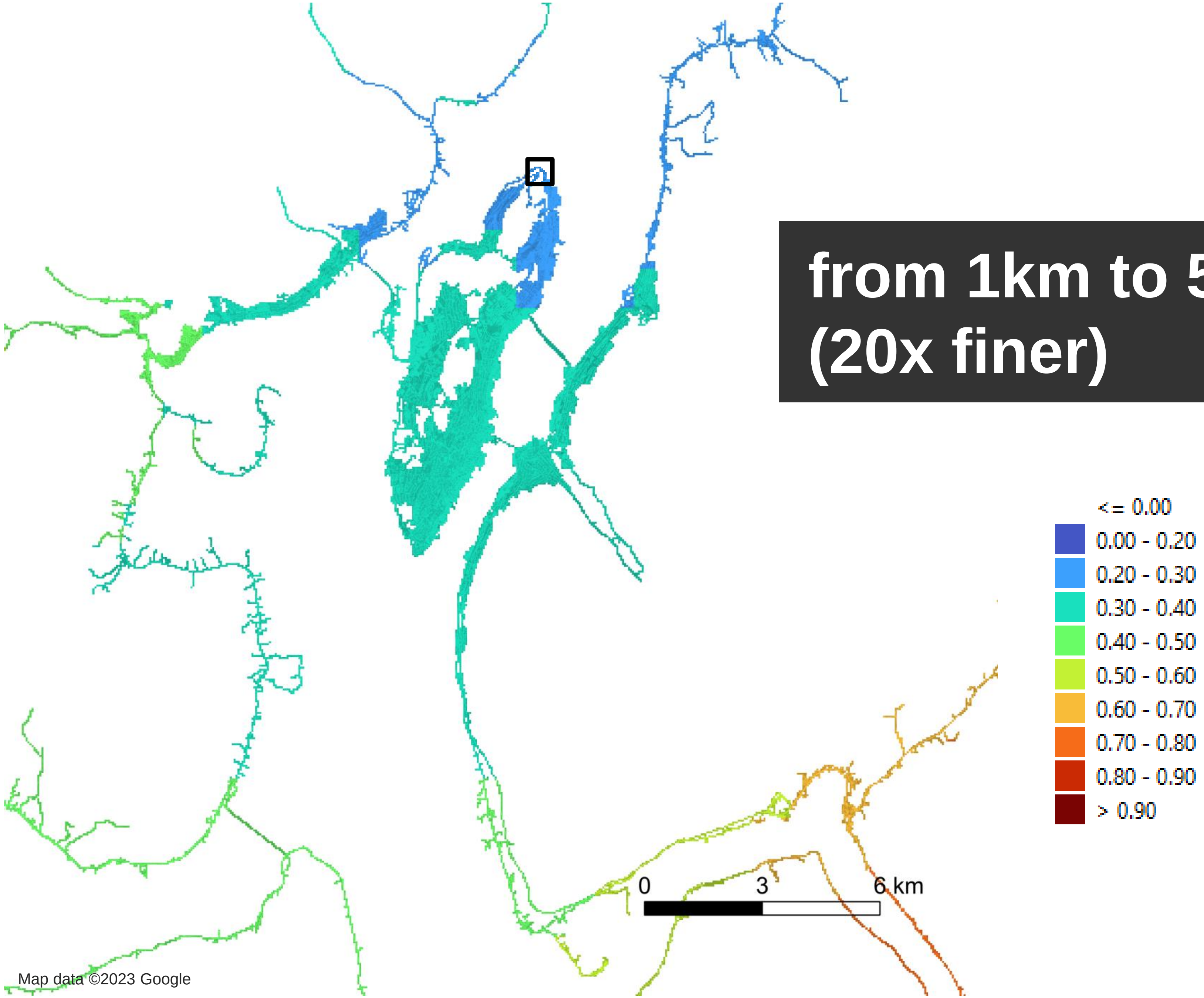

True positive rate (TPR)
False positive rate (FPR)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Optimal Model (AUC = 86.25%)
Random Guessing
Optimal Operating Point
Threshold = 0.48
FPR = 0.25, TPR = 0.83



<= 0.00
0.00 - 0.20
0.20 - 0.30
0.30 - 0.40
0.40 - 0.50
0.50 - 0.60
0.60 - 0.70
0.70 - 0.80
0.80 - 0.90
> 0.90
0
3
6 km



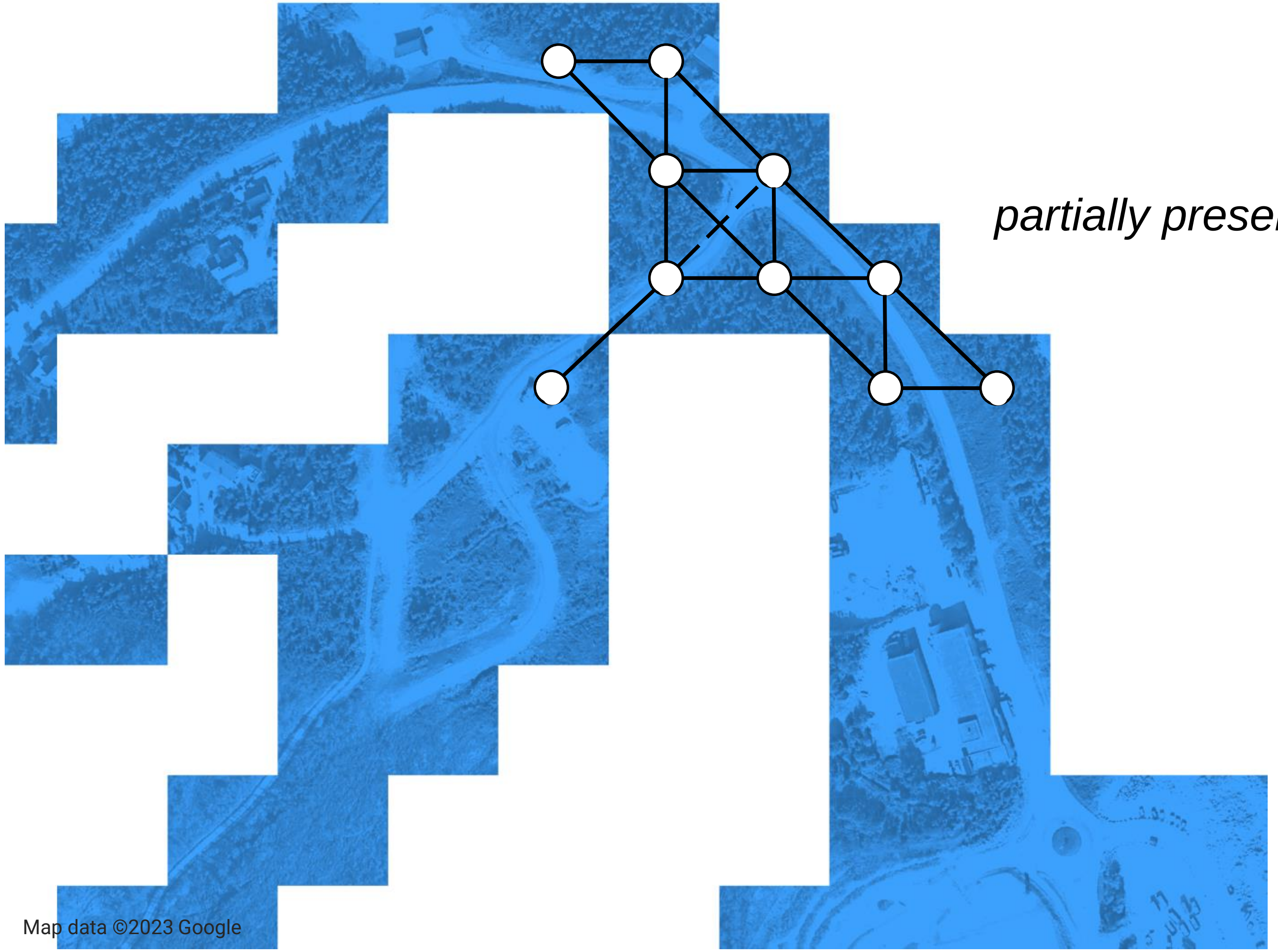
370 residents
367 residents
8,913 residents
41,434 residents
18,063 residents
280 residents
Road network
with formal settlements
and population data
0
3
6 km
Map data ©2023 Google, Norwegian Mapping Authority
<= 0.00
0.00 - 0.20
0.20 - 0.30
0.30 - 0.40
0.40 - 0.50
0.50 - 0.60
0.60 - 0.70
0.70 - 0.80
0.80 - 0.90
> 0.90



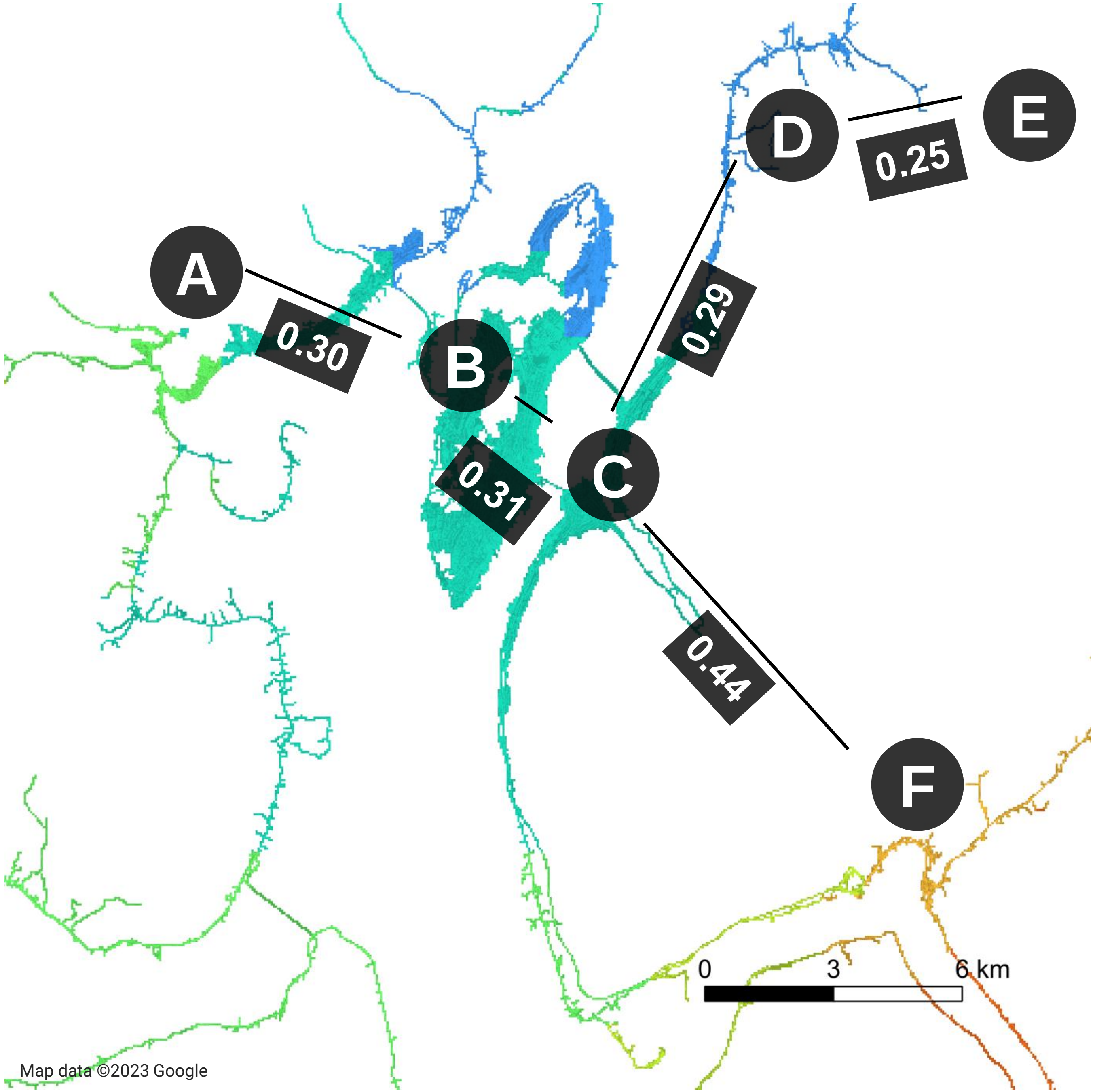
from 1km to 50m (20x finer)

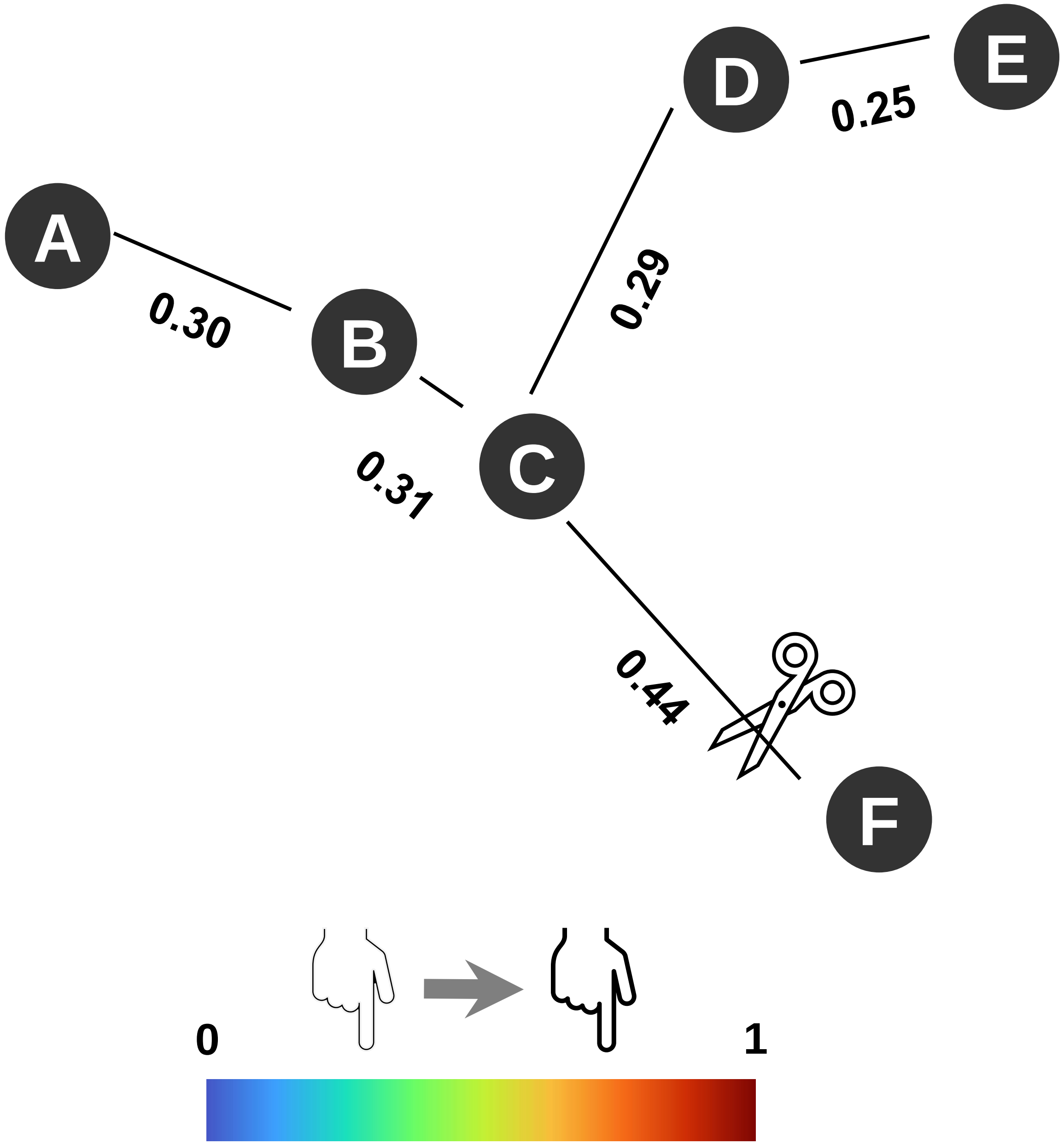
simplicial networks

shortest path



partially presented


A
B
C
D
E
F
0.30
0.31
0.29
0.25
0.44
0
3
6 km
Map data ©2023 Google



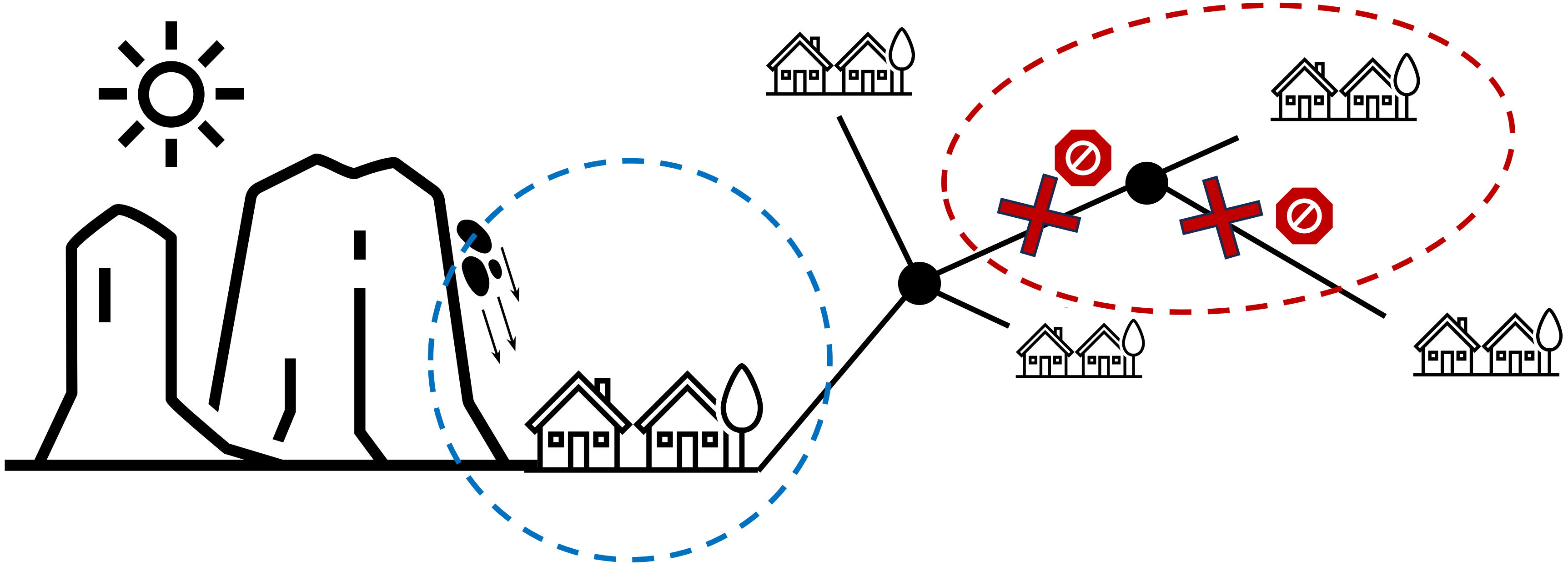
Iteratively increase the cutoff susceptibility threshold [0,1] to “cut” the edge (i.e., road)

Perform spectral graph clustering using the Laplacian transformation

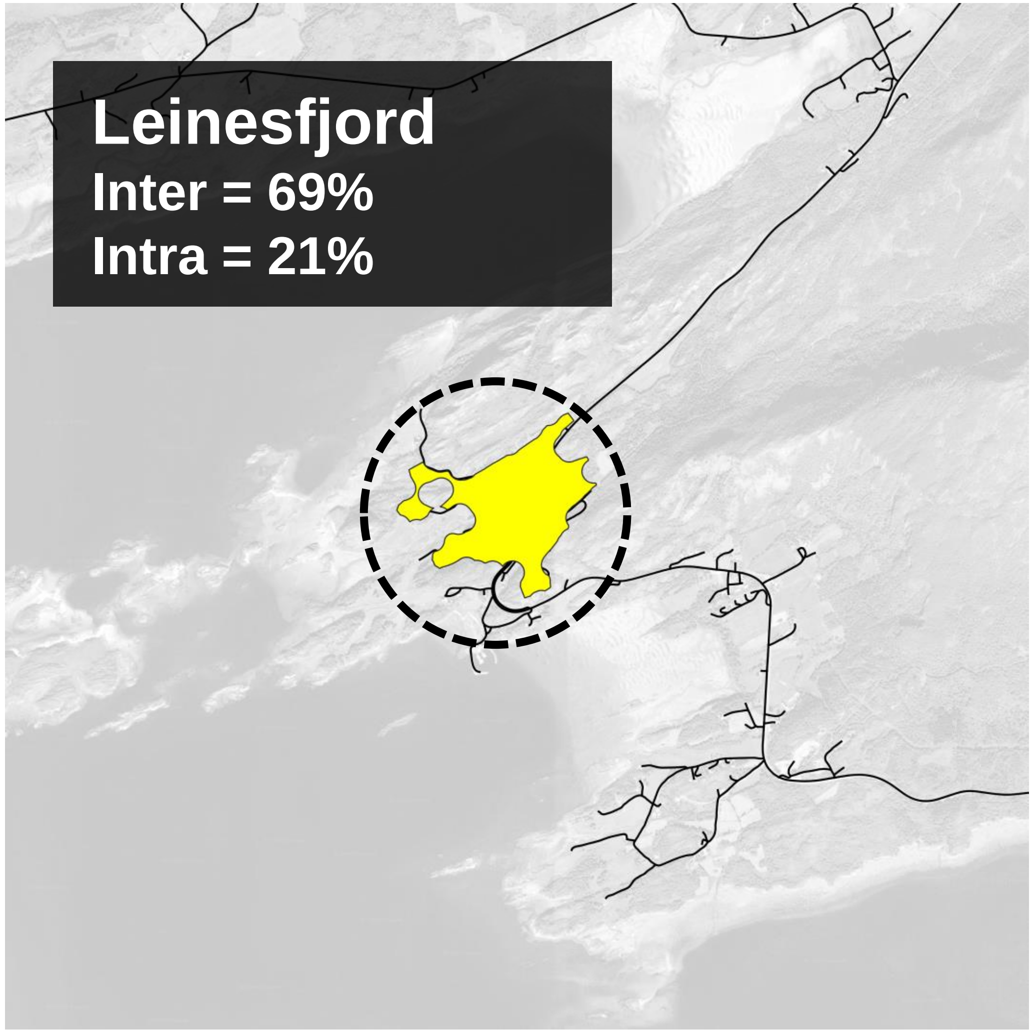
Extract the lowest cutoff value that results in the isolation of a settlement from the graph

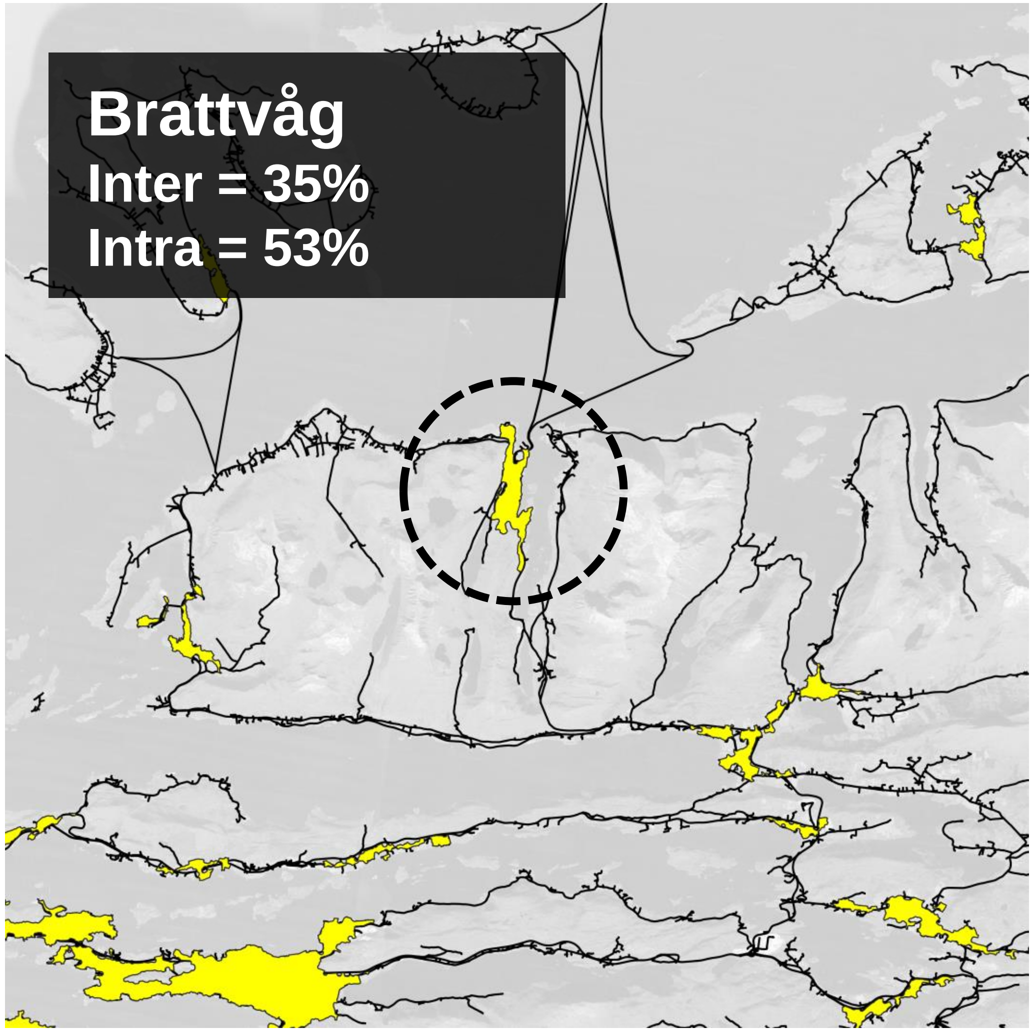
lowest cutoff value

Minimum Triggering Exposure Probability of Mass-Movement-Susceptible Roads for **Inter-Settlement** Isolation



Intra-Settlement Exposure Probability of Being a Mass-Movement-Susceptible Area





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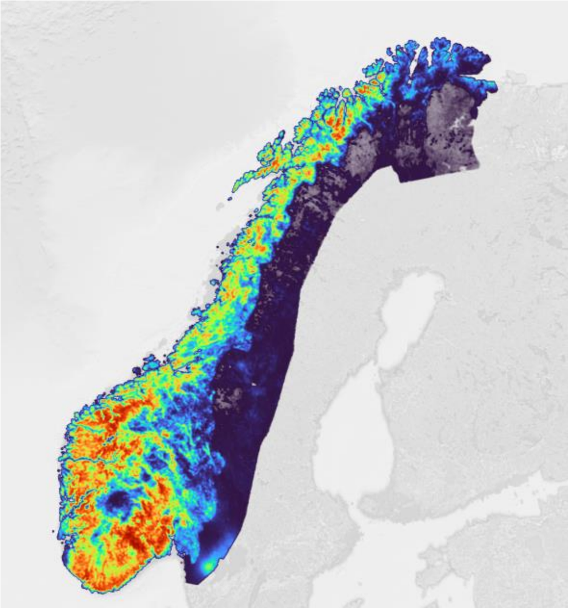

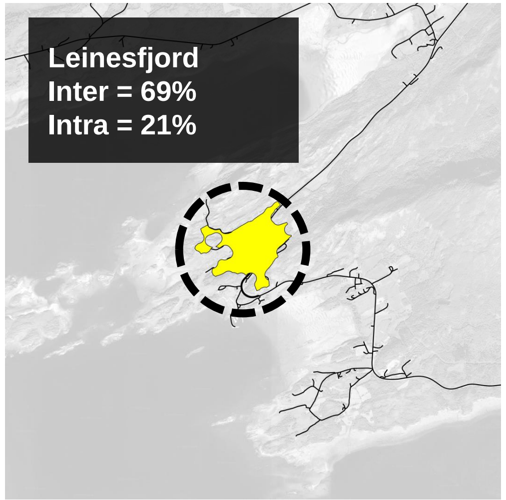

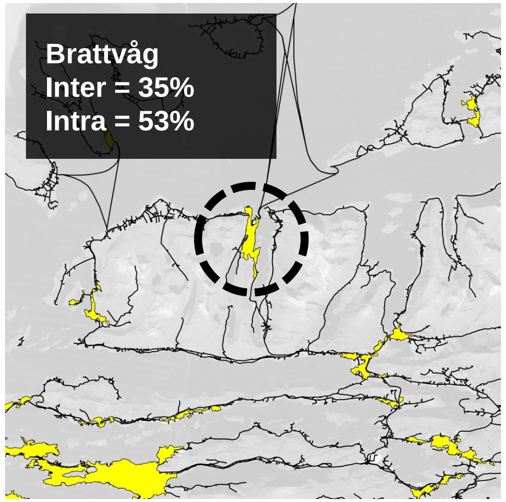

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Table A.5: 190 settlements or villages in Oslo-Viken.

Village	Intra	Inter	Population
Askgrenda	82.73%	82.30%	522
Askim	21.03%	20.73%	14651
Aulifeltet	25.02%	25.33%	2,875
Aursmoen	15.40%	15.92%	3493
Berger	57.26%	58.43%	1110
Bjertnestunet	9.50%	9.65%	415