# Session 15: Arctic Navigation - Practical Application of Sea Ice Information in Current and Future Maritime Operations

## 2024 European Polar Science Week

3–6 September 2024 | The Black Diamond | Copenhagen, Denmark

Universität Bremen

Center for Industrial Mathematics (ZeTeM)

**Department 03**

Mathematics / Computer Science

# Calculation of optimal shipping routes through polar waters based on AI supported evaluation of earth observation data and weather forecasts

B. Schmitz[1], C. Eis[1], M. Bathmann[2,3], C. Büskens[1]

[1] University Bremen, Center for Industrial Mathmatics (ZeTeM), Germany
[2] German Aeorospace Center (DLR), Remote Sensing Technology Institute (IMF), Germany
[3] University Bremen, Institute of Environmental Physics (IUP), Germany

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Copenhagen, 06.09.2024

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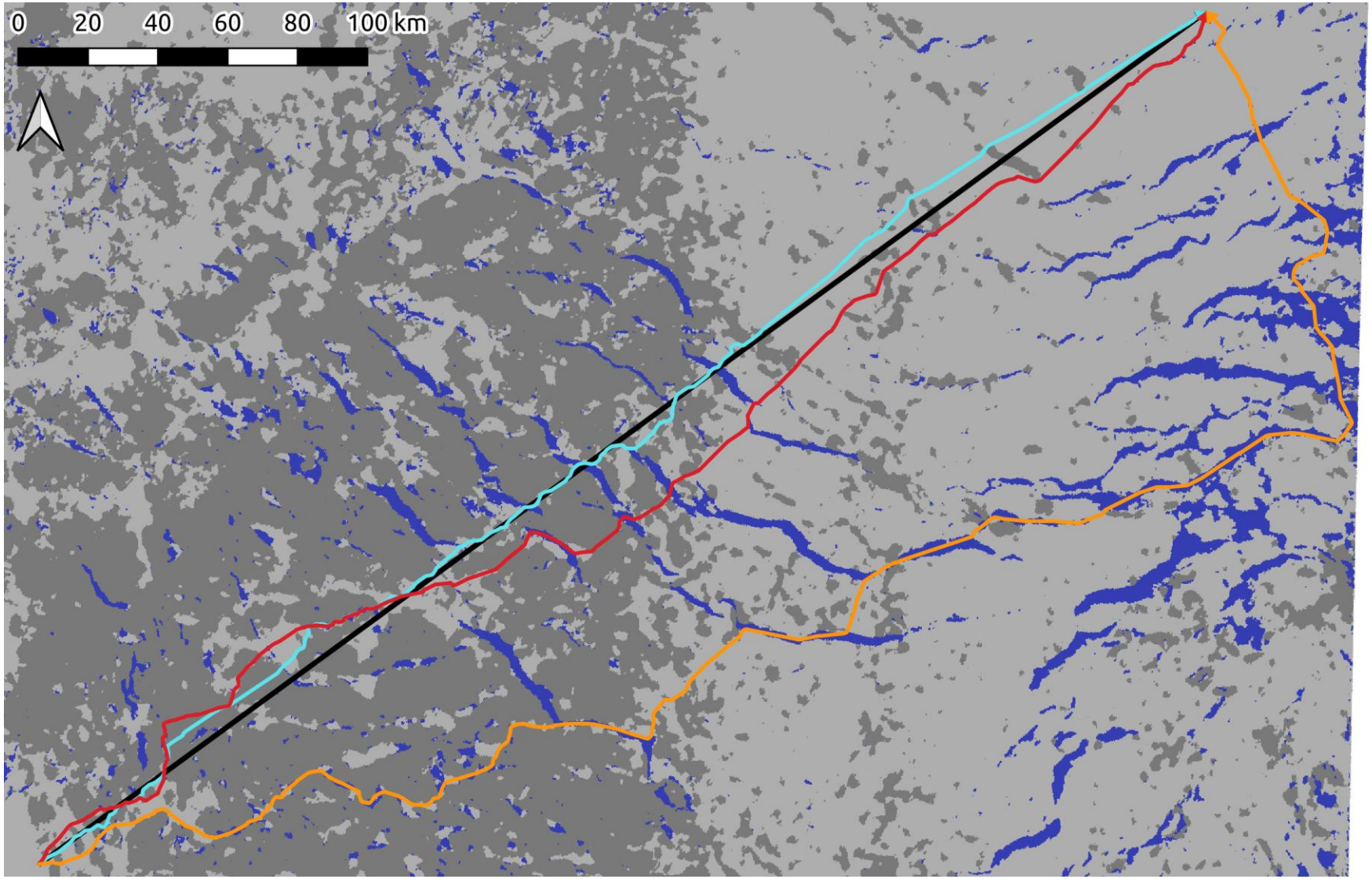


Surface type
- Multiyear ice
- Other ice
- Water

Route suggestions
- Line of sight
- Optical observation (2 km)
- Ice radar (7.4 km)
- Optimal (full information)

**41 h**

**- 42 %** **- 29 %** **- 22 %**

Contains modified Copernicus Sentinel 1 data (2023), processed by ESA.
Classified by the German Aerospace Center (DLR): Murashkin and Frost (2021).

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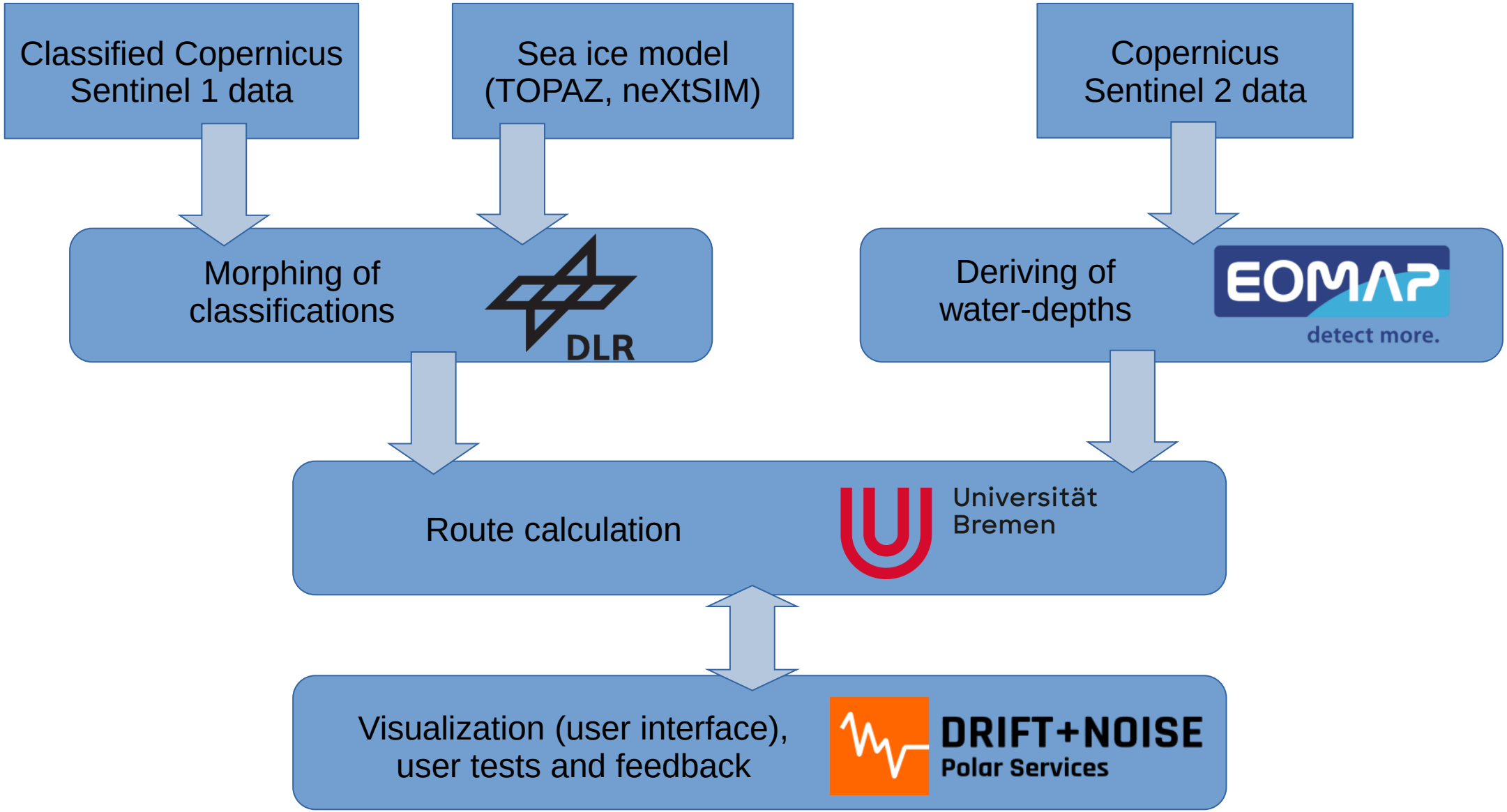

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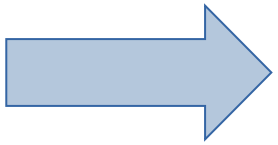

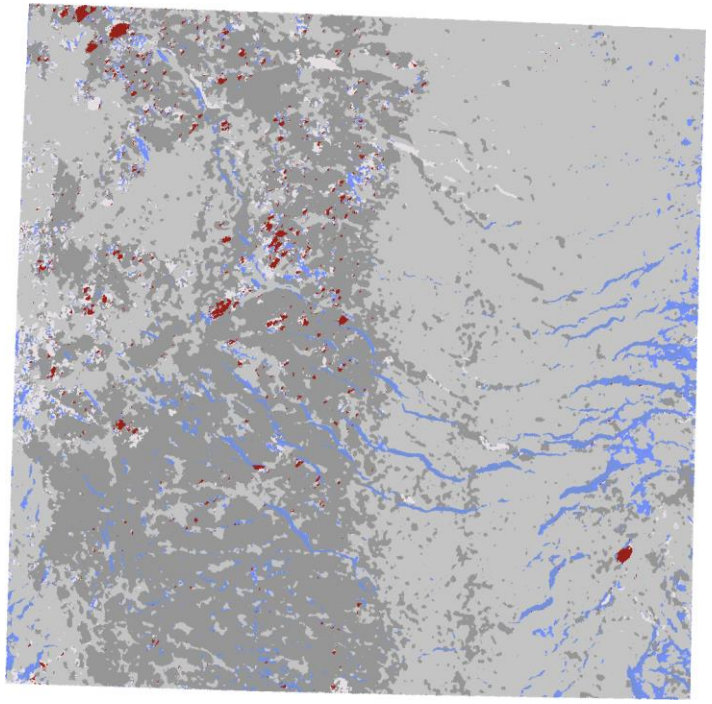

Input data generated from S1 radar data: 160 m resolution, 6 classes. Data provided via the Eisklass2 project (2020–2023).

Left: Copernicus Sentinel data 2023:
S1A_EW_GRDM_1SDH_20230117T212054_20230117T212154_046829_059D73_6422
Right: Contains modified Copernicus Sentinel 1 data (2023), processed by ESA.
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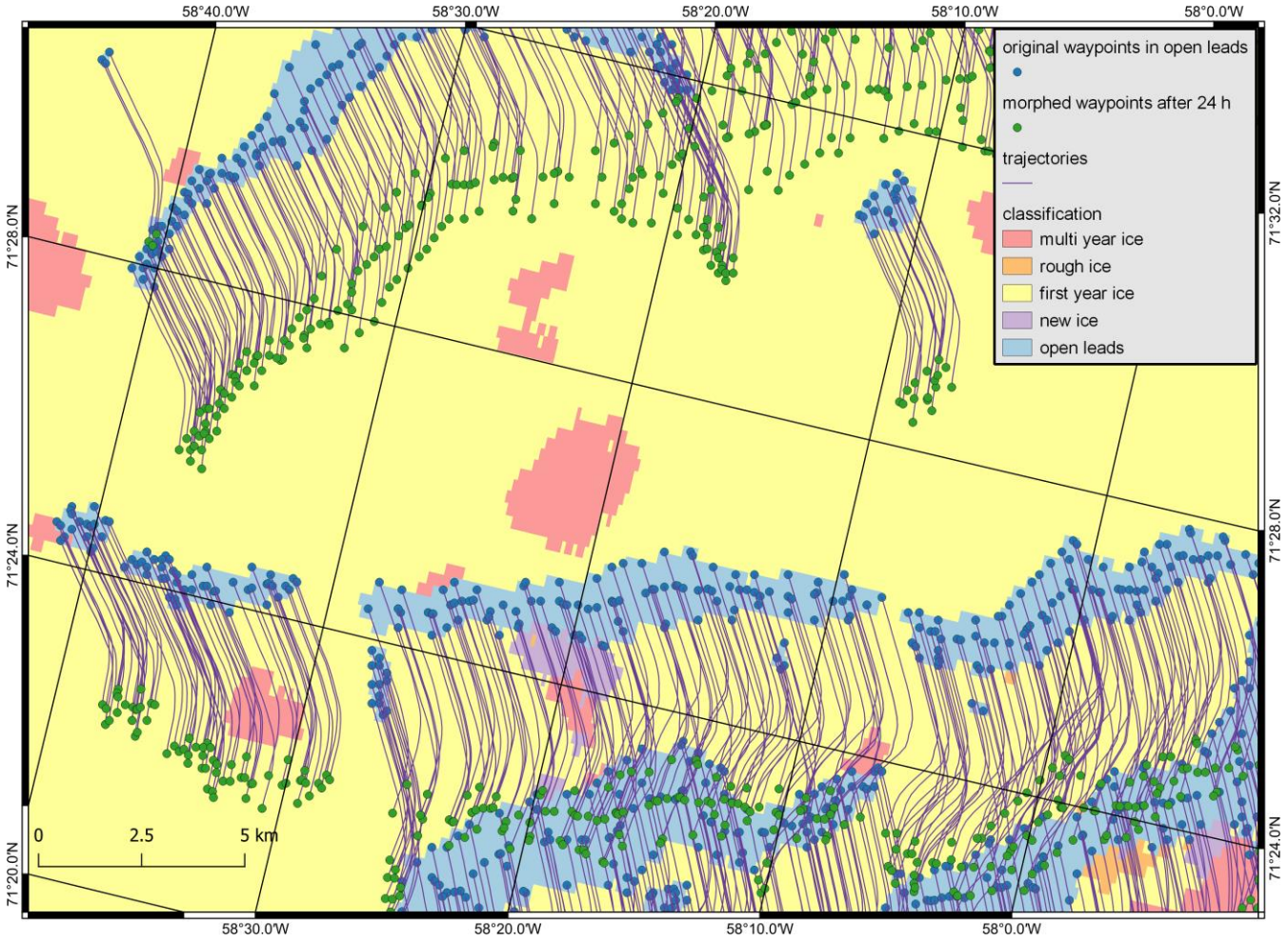
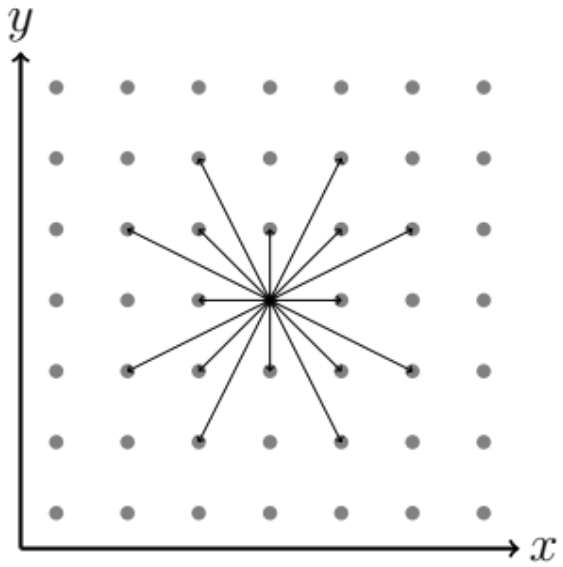
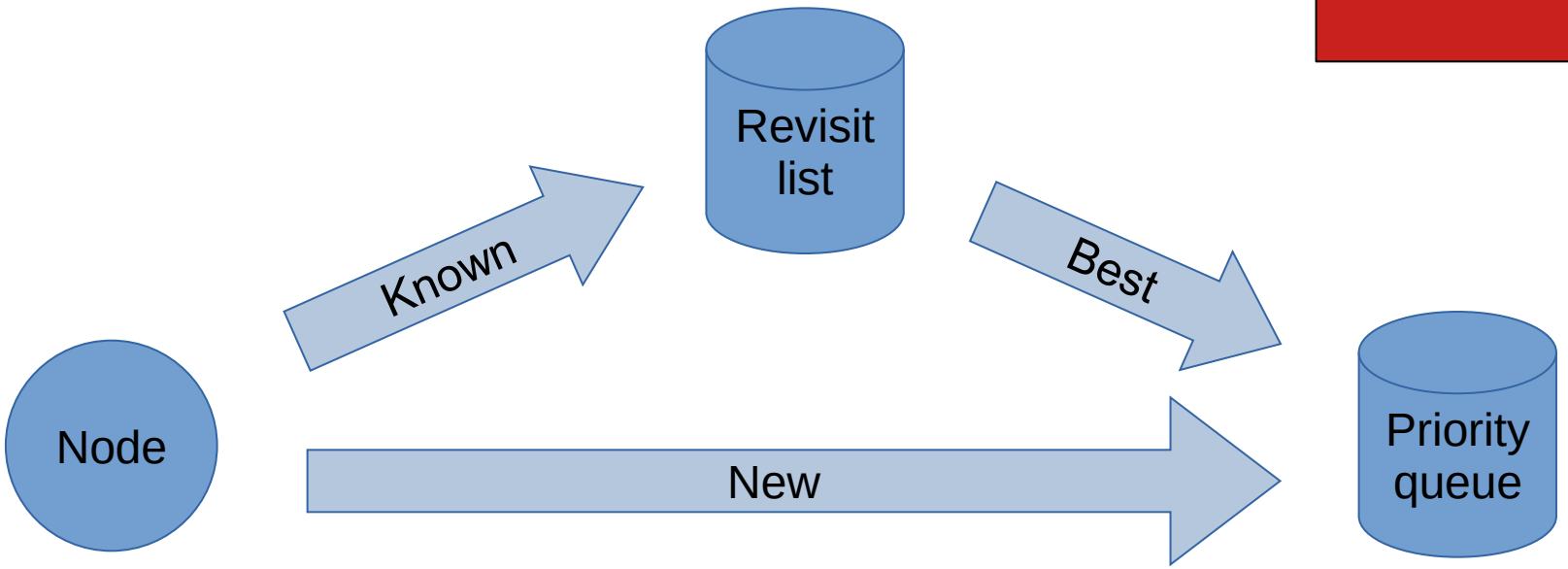
- Spatial and temporal interpolation of input model (TOPAZ, neXtSIM)
- Particle tracking
- Output: Slices containing forecasted ice conditions, hourly resolution.
- Validation against SAR based ice drift vector fields showed that there are restrictions when using forecasts at navigation scale.




Bathmann, M., Murashkin, D., Schmitz, B., Frost, A., Wiehle, S., Ludwig, V. and Spreen, G.: Sea Ice Data for Shipping Routes, AGU23, San Francisco, CA, USA, available at: https://agu23.ipostersessions.com/Default.aspx?s=68-A7-19-9C-B9-09-67-22-C3-6A-B3-C9-2E-0B-CE-E0.

Static routing




- Create graph representation of the problem
- Objective function: f(s) = g(s) + ε h(s)
- Weighted A*: Prioritize nodes close to the target
- Anytime Repairing A*: Prevent repeated evaluation

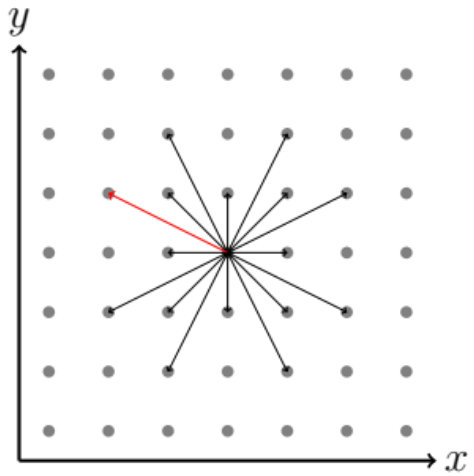
Likhachev M, Gordon GJ and Thrun S (2003) ARA*: Anytime A* with Provable Bounds on Sub-Optimality.
In S. Thrun, L. Saul and B. Schölkopf (eds.), Advances in Neural Information Processing Systems, volume 16, MIT Press.

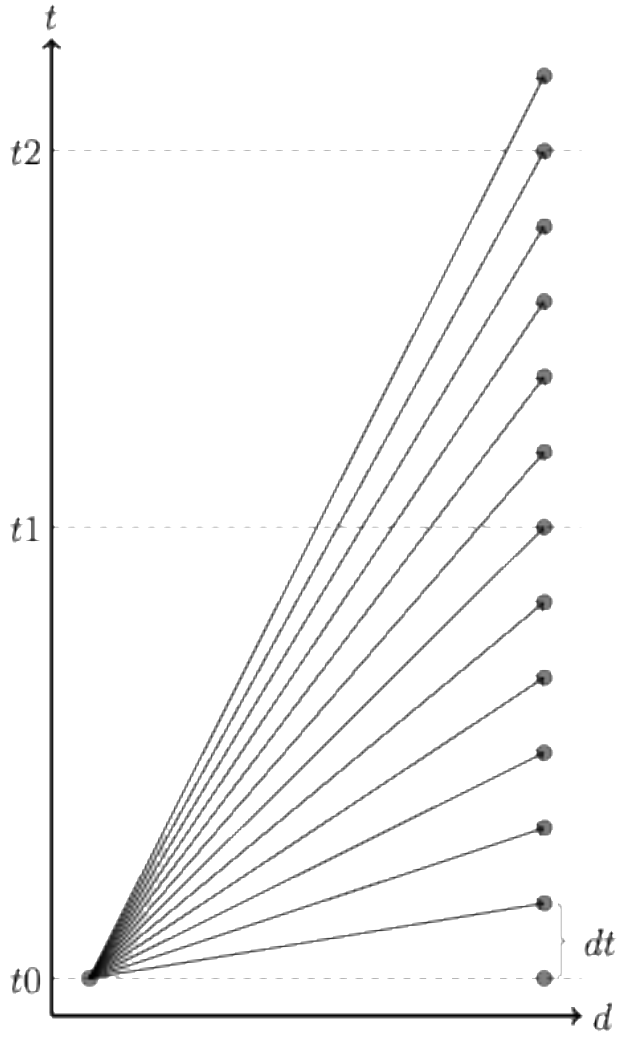
## Dynamic routing

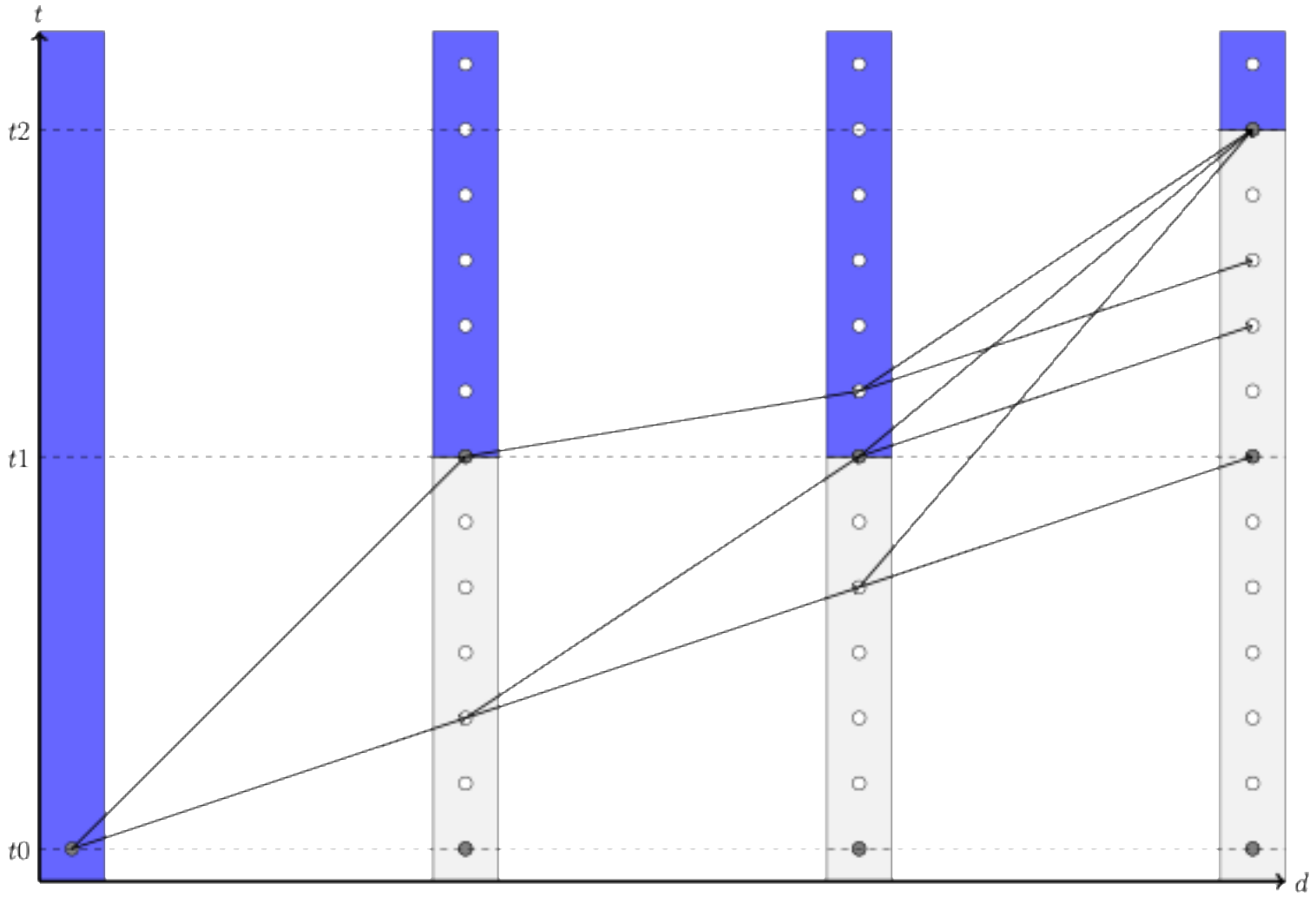
Enable algorithm to visit a location at different times, considering ice conditions at the time of visiting.

Goal: Algorithm makes use of dynamic ice condition

Problem: Too many nodes and edges






Reduce number of edges by using available information as much as possible:

- It is known when the ice condition will change, so for “minimal time” we only need nodes at that times!
- Apply turn restrictions
- Apply velocity restrictions
- …

For reducing fuel consumption / emissions: Reward speed reduction, small accelerations.

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Velocity [m/s]

2.4 - 2.5

7.5 - 7.9

Ship position

Multi Year Ice

Open water

Other ice

Initial ice condition

0 10 20 km

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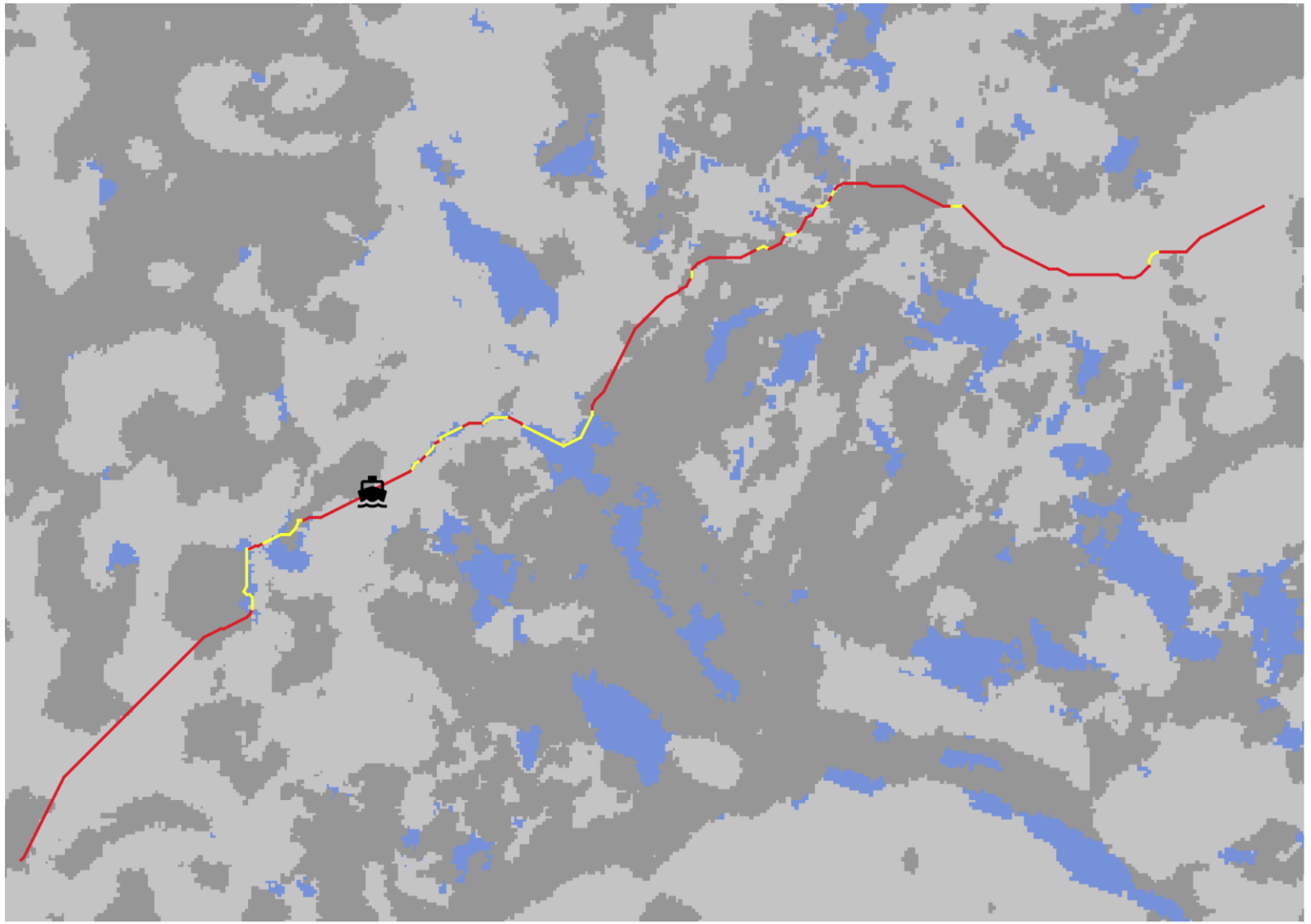


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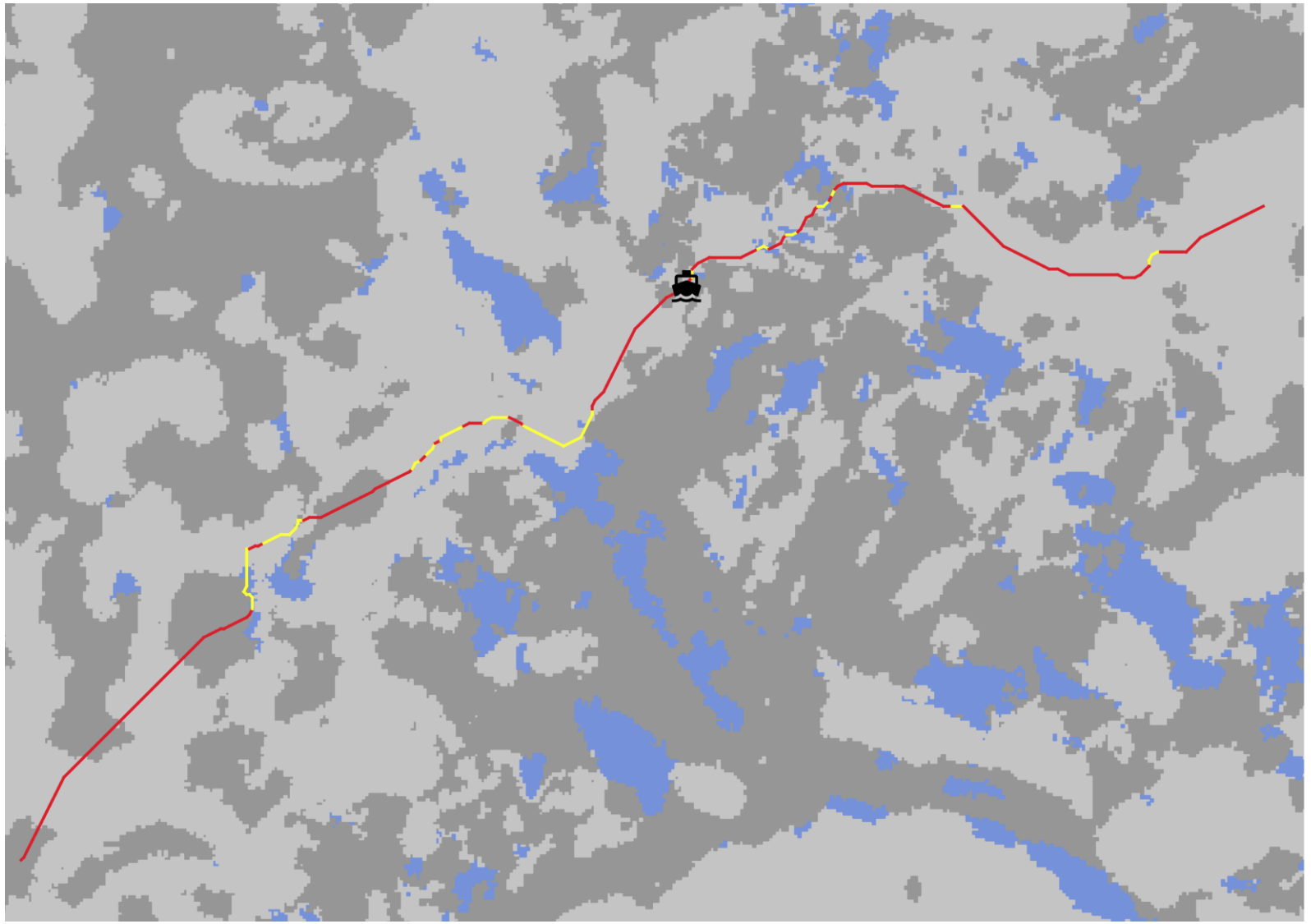


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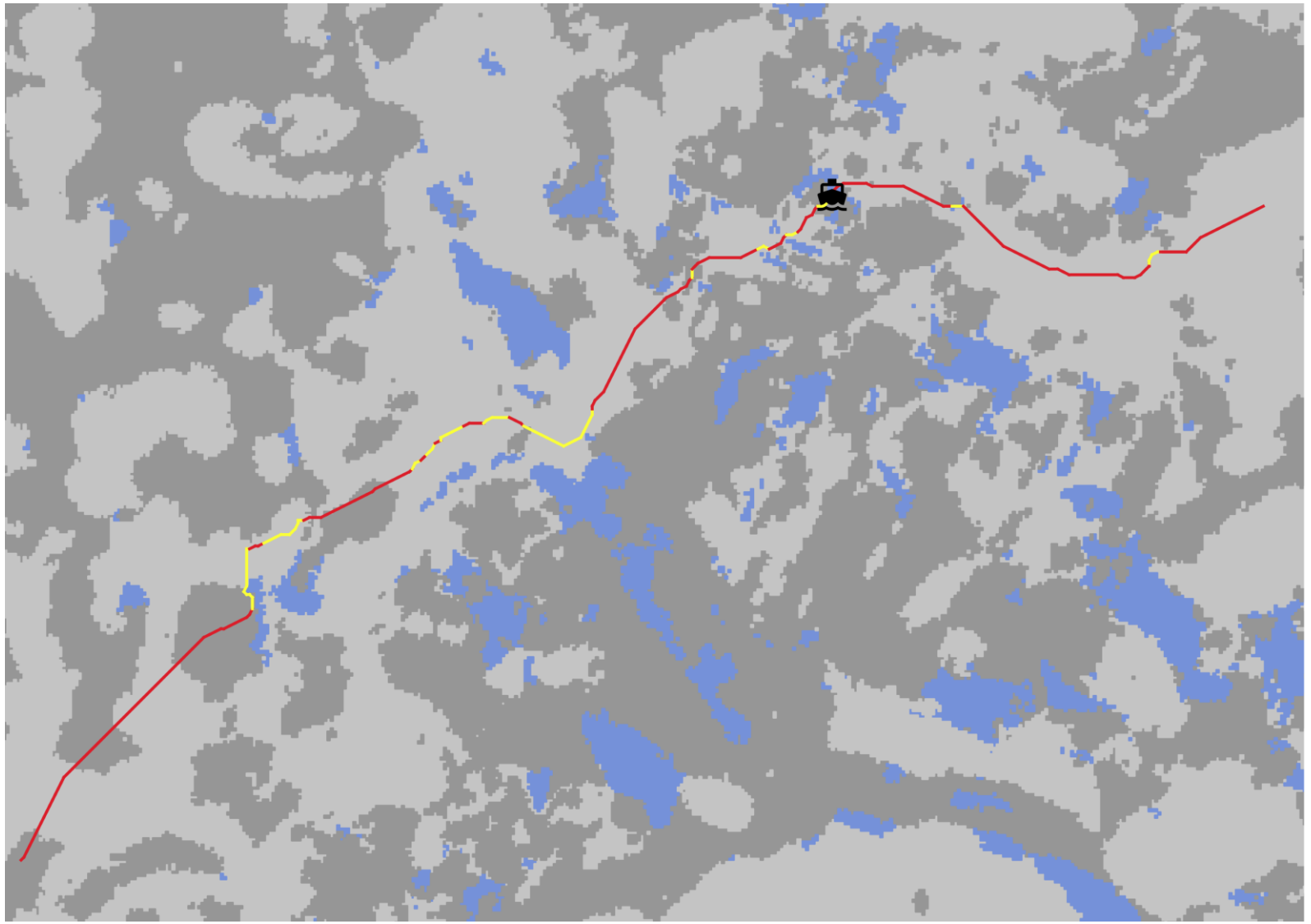


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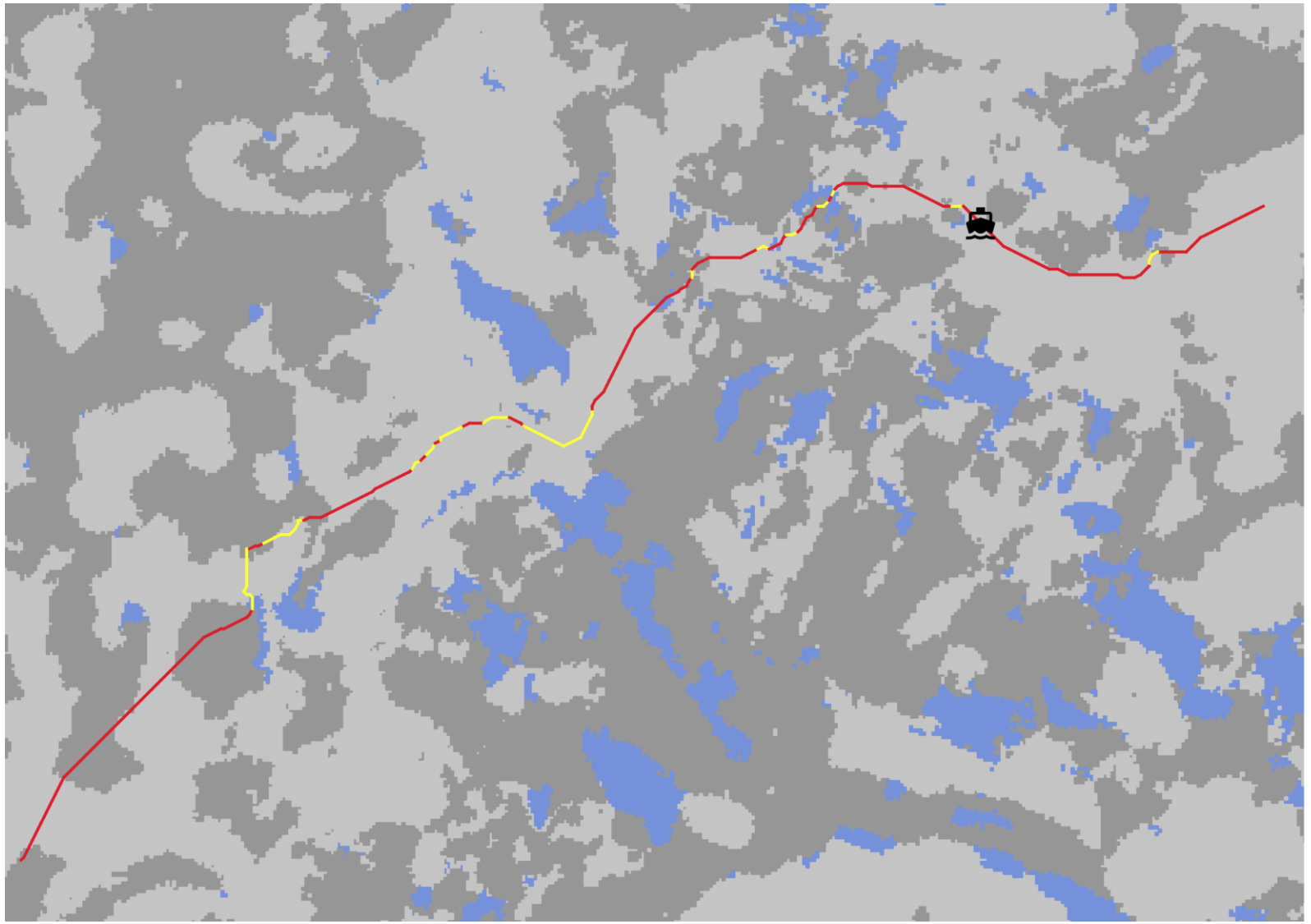


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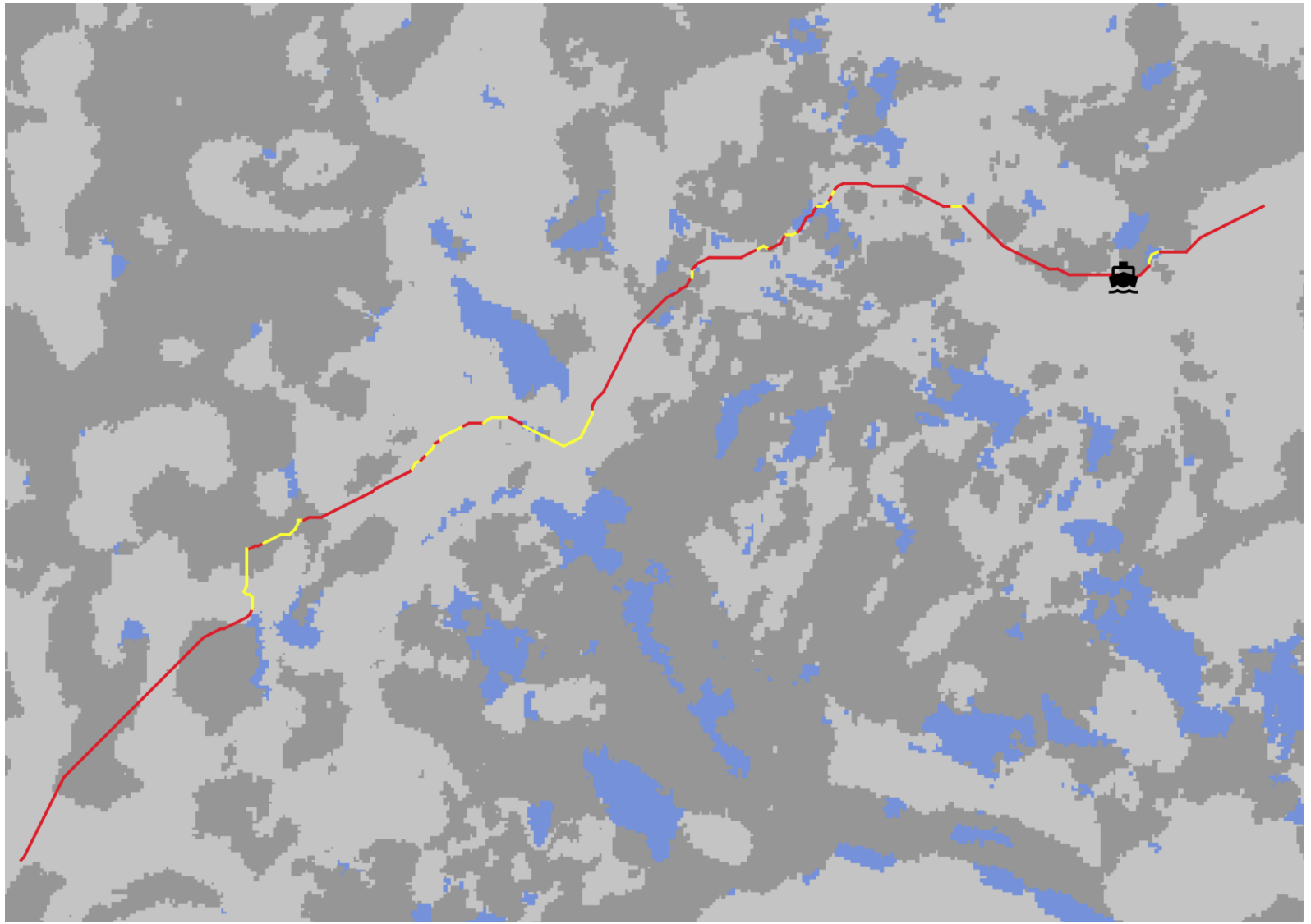


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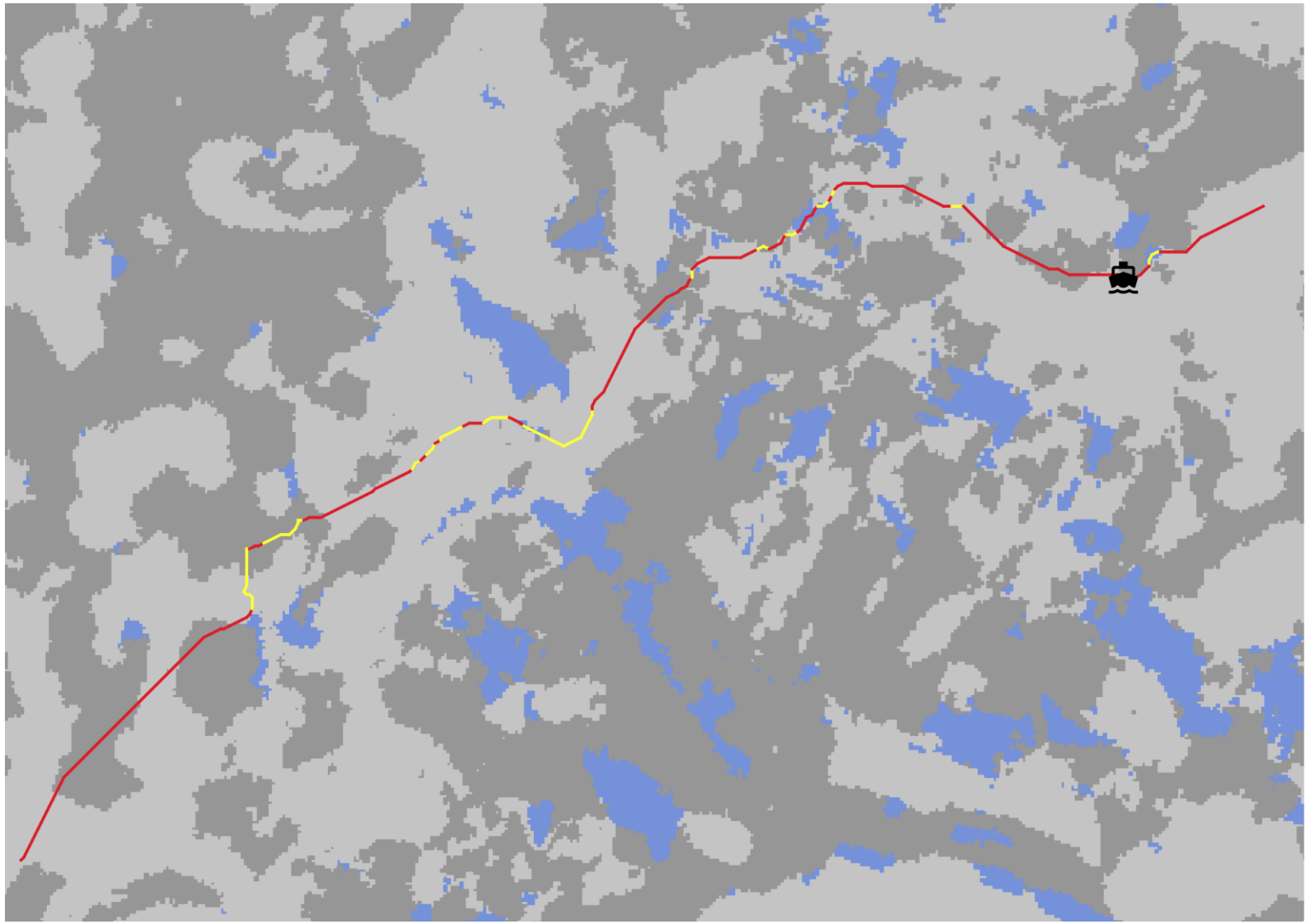


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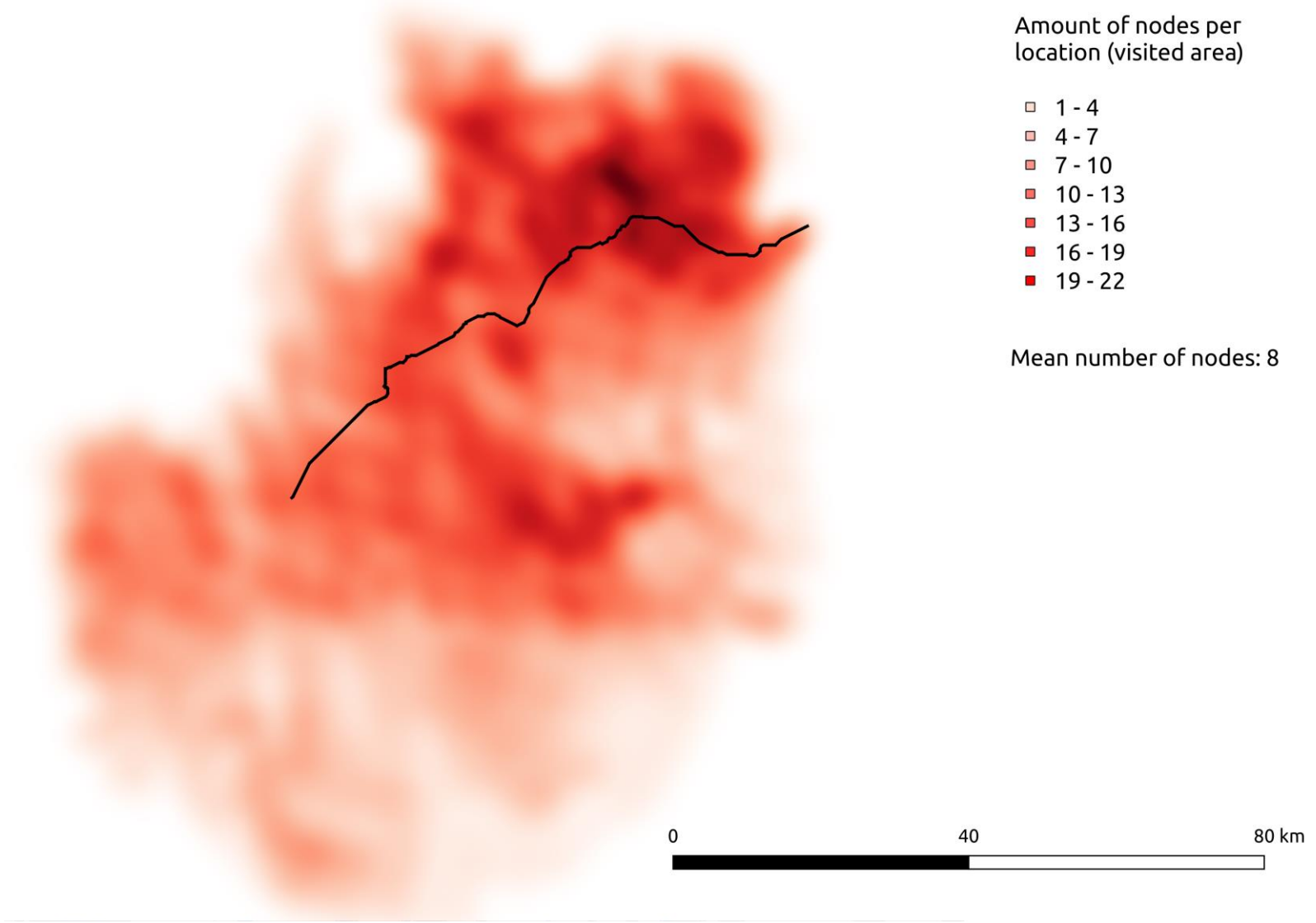

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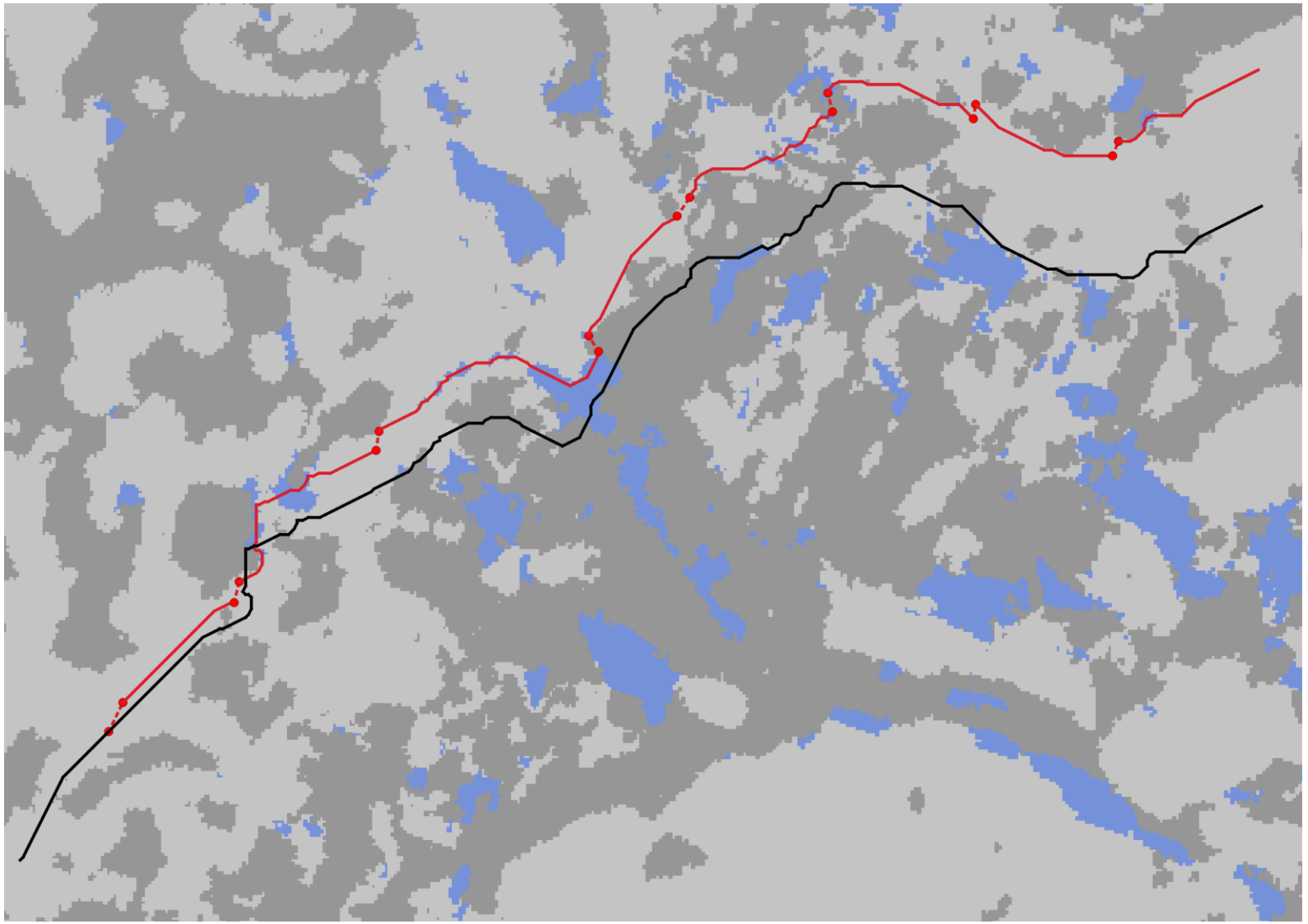

Route suggestion

Route suggestion, projected to initial ice condition

Segment affected by ice condition update

Multi Year Ice

Open water

Other ice

0 10 20 km

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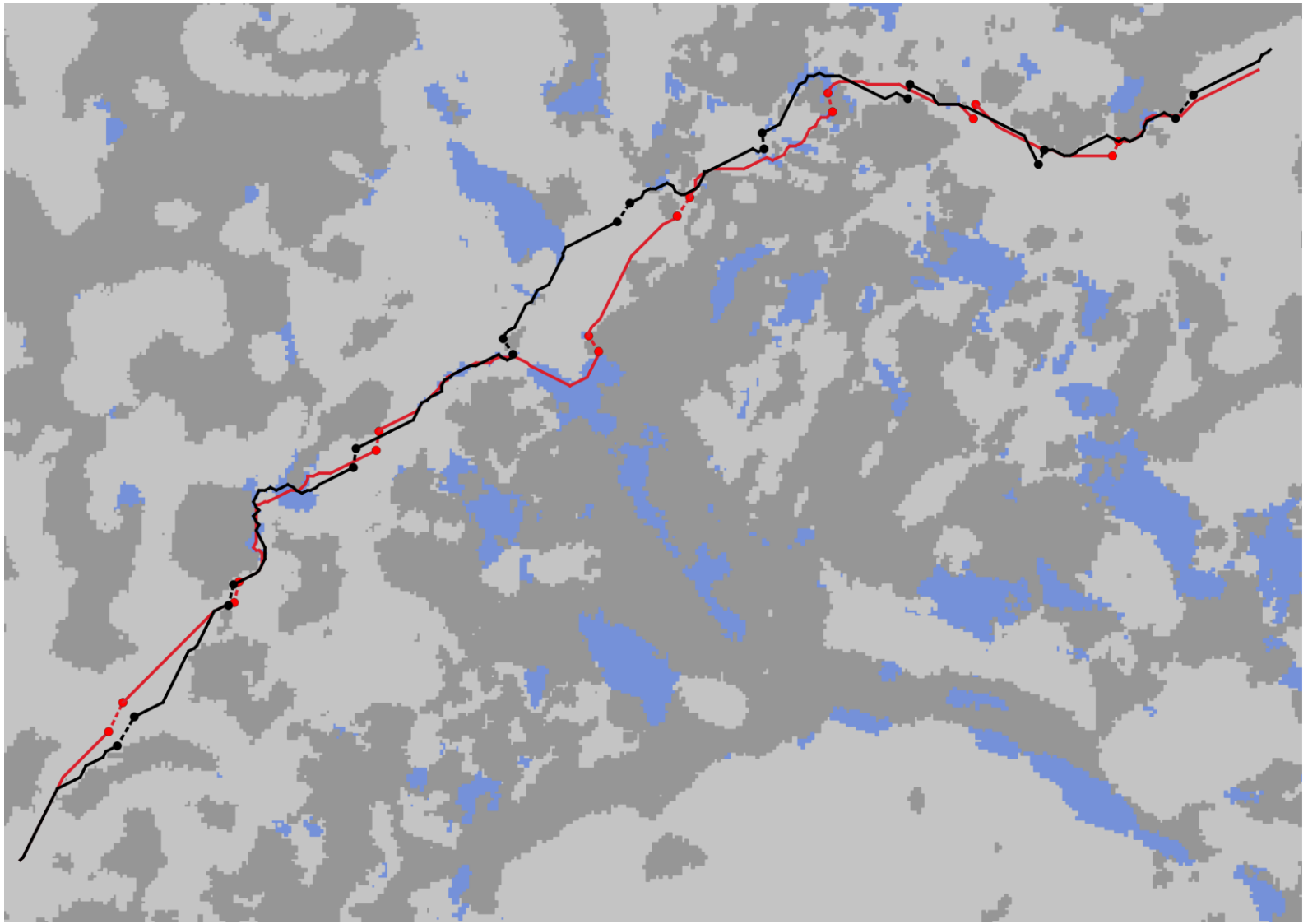

Solution #1
Travel time: 9h 34 min

Segment affected by ice condition update

Route suggestion, projected to initial ice condition

Solution #238 (final result)
Travel time: 8h 59 min

Segment affected by ice condition update

Route suggestion, projected to initial ice condition

Multi Year Ice

Open water

Other ice

0 10 20 km

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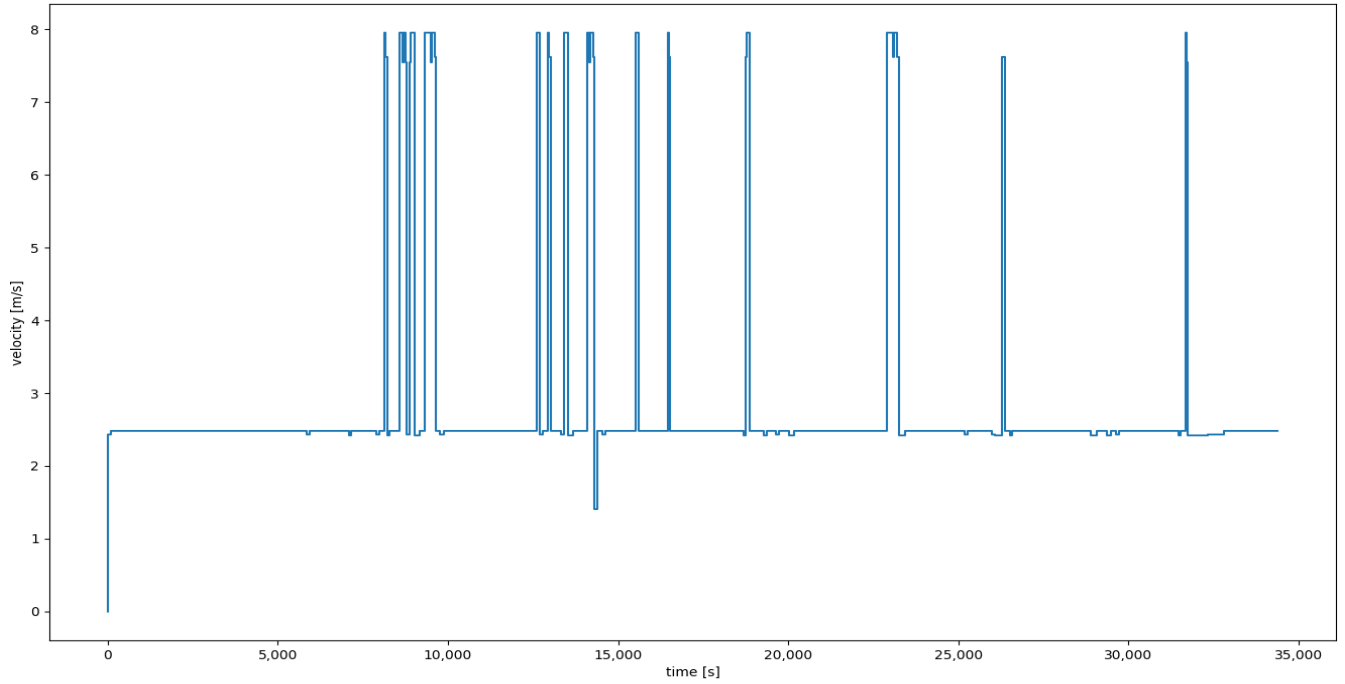

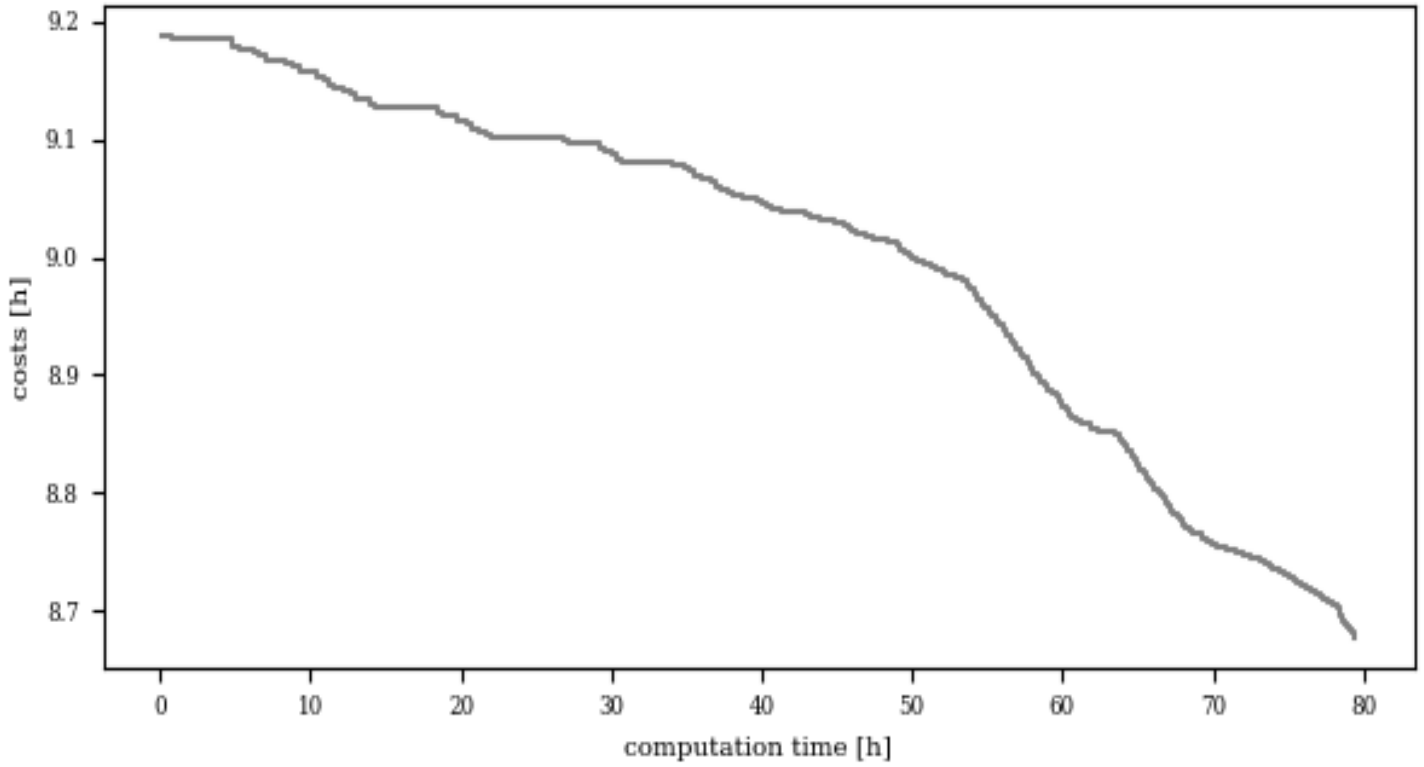
9.2
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costs [h]
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computation time [h]