Timing of infrastructure failure from permafrost degradation - some modeling insights

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PermaRisk

AWI Innovation Funds Project
IP10200006

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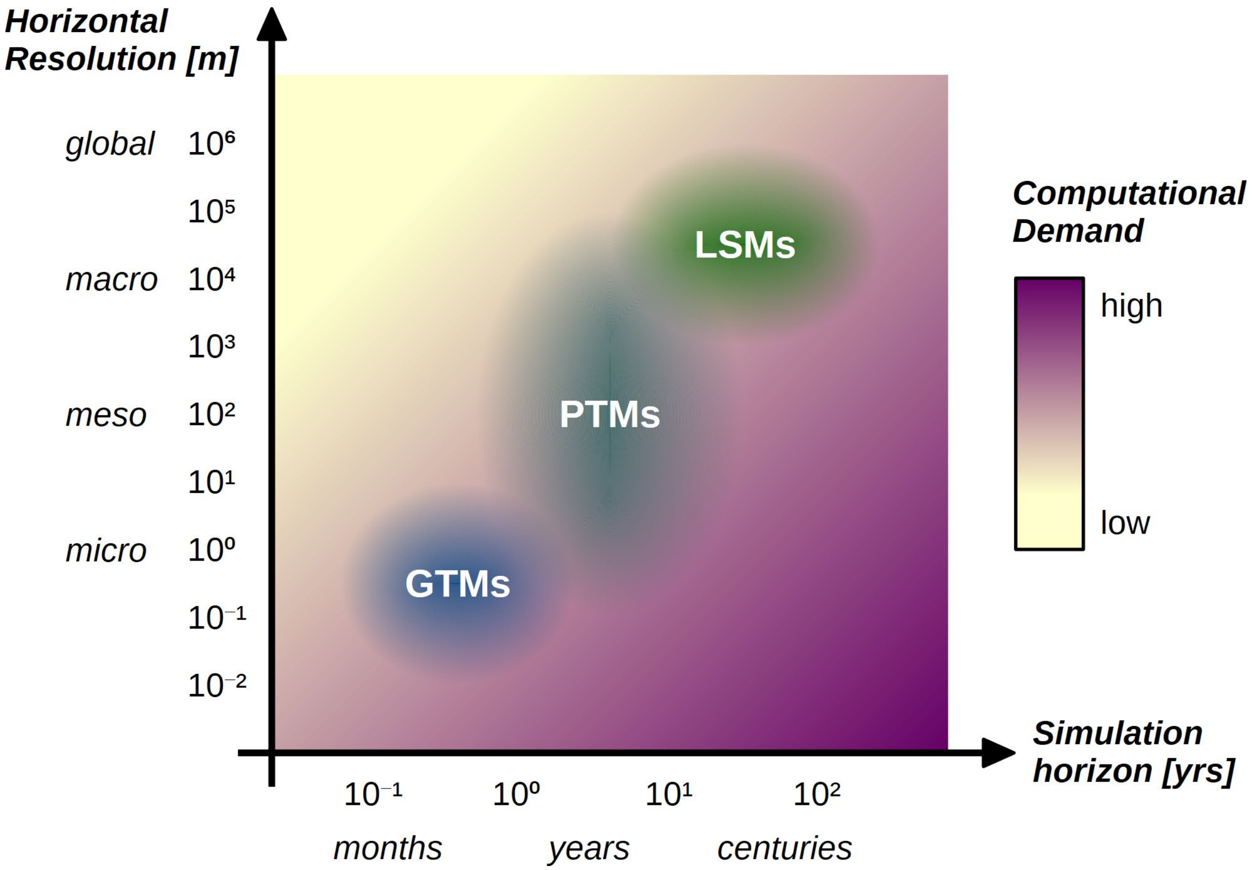
Modelling challenge: closing the gap in spatial and temporal scales

- **GTMs** (Geotechnical Models)
Designed to represent small scales, focus on short timescales (up to a few years)

- **LSMs** (Land Surface Models)
Designed for large scales (hor. Resolution ~100km) and long timescales (climate relevant)

- **PTMs** (Process-based Tiling Models)
    - **scalability** to a specific modelling problem
    - **computational efficiency** allows long-term simulations to investigate climate change impacts



- We used CryoGrid3 – a laterally coupled 1D heat conduction model (extended for linear infrastructure) (Github, Zenodo)

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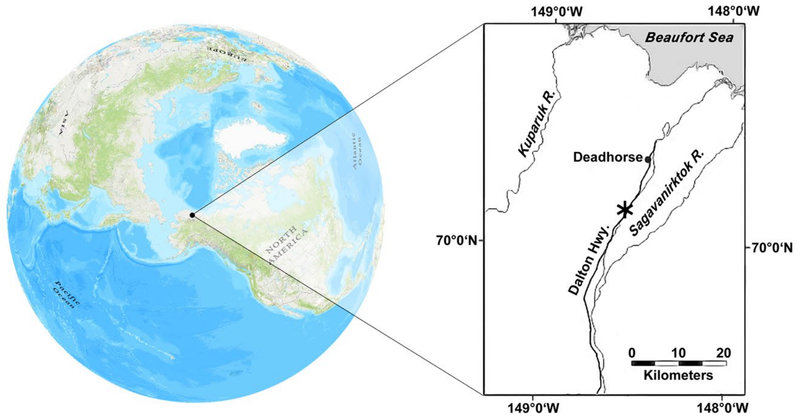
Modelling of a gravel road on cold continuous permafrost



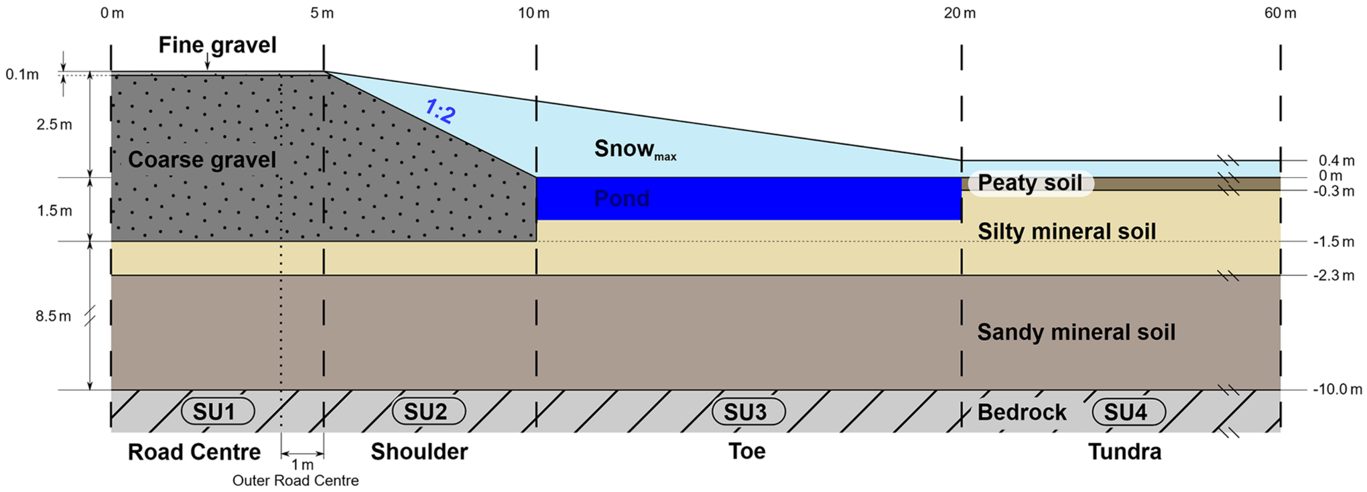
Map source: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), © OpenStreetMap contributors 2020. Distributed under a Creative Commons BY-SA License.

Dalton highway (near Deadhorse, Alaska)

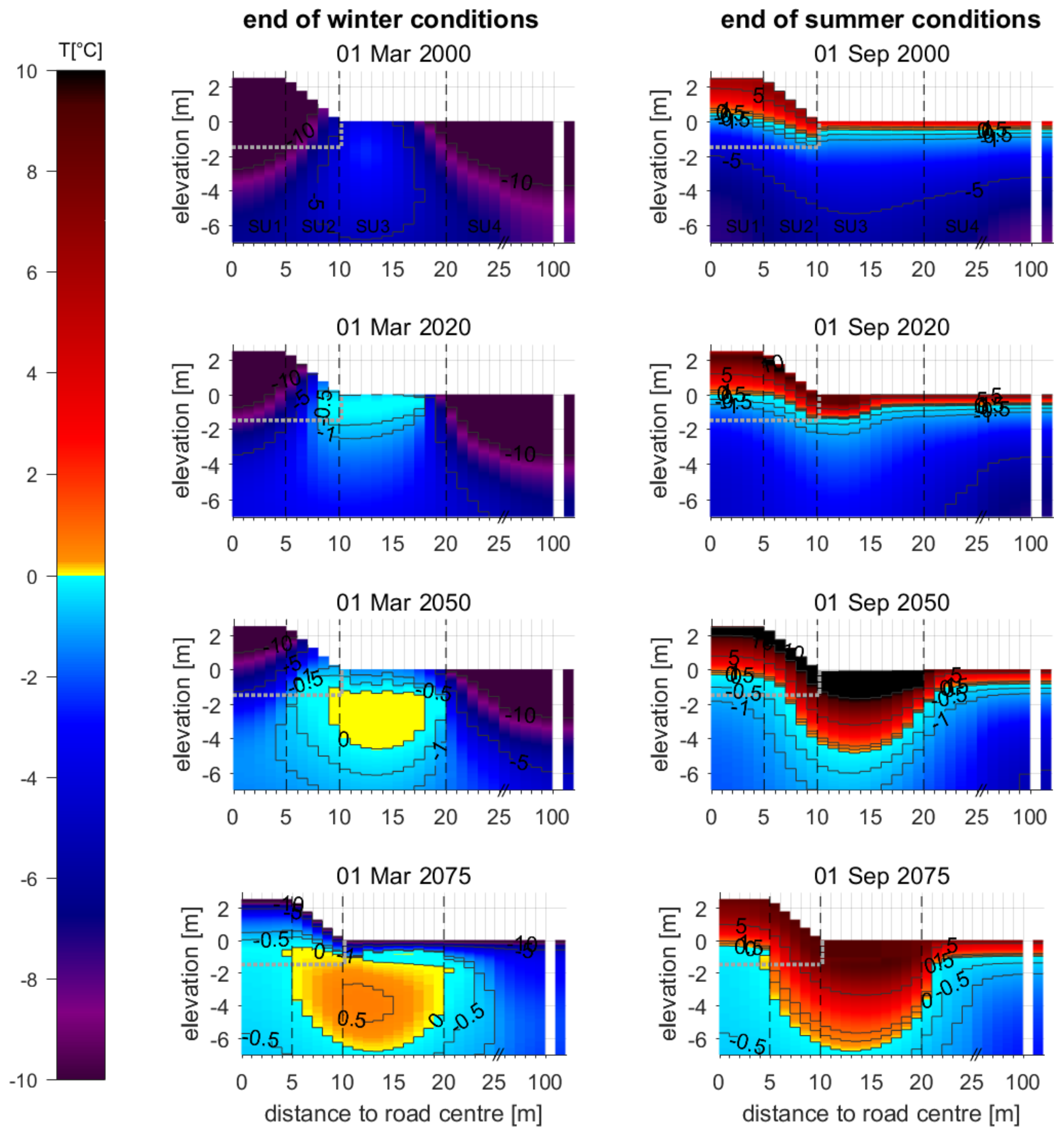
T. Schneider von Deimling, H. Lee, T Ingeman-Nielsen, S.Westermann, V.Romanovsky, S. Lamoureux, D.Walker, S.Chadburn, L.Cai, E.Trochim, J.Nitzbon, S.Jacobi, M.Langer. **Consequences of permafrost degradation for Arctic infrastructure - bridging the model gap between regional and engineering scales**. The Cryosphere, 2021

Model setup

- Description of road centre, shoulder, toe, and tundra
- We applied the model to historical climate conditions and to a scenario of intensive future warming (RCP8.5)
- We tested different horizontal resolutions



Modeling results:
simulated ground temperatures



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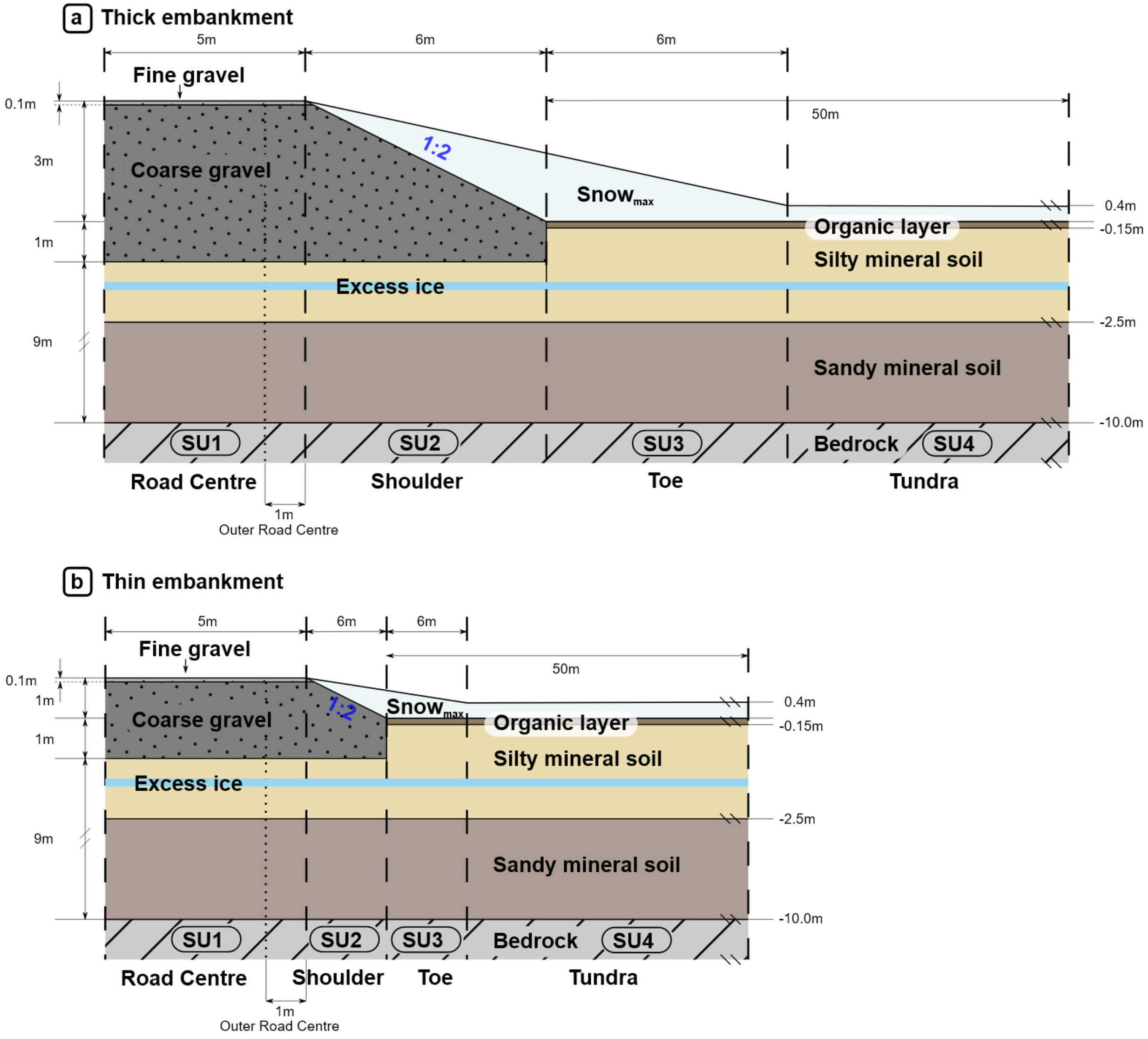
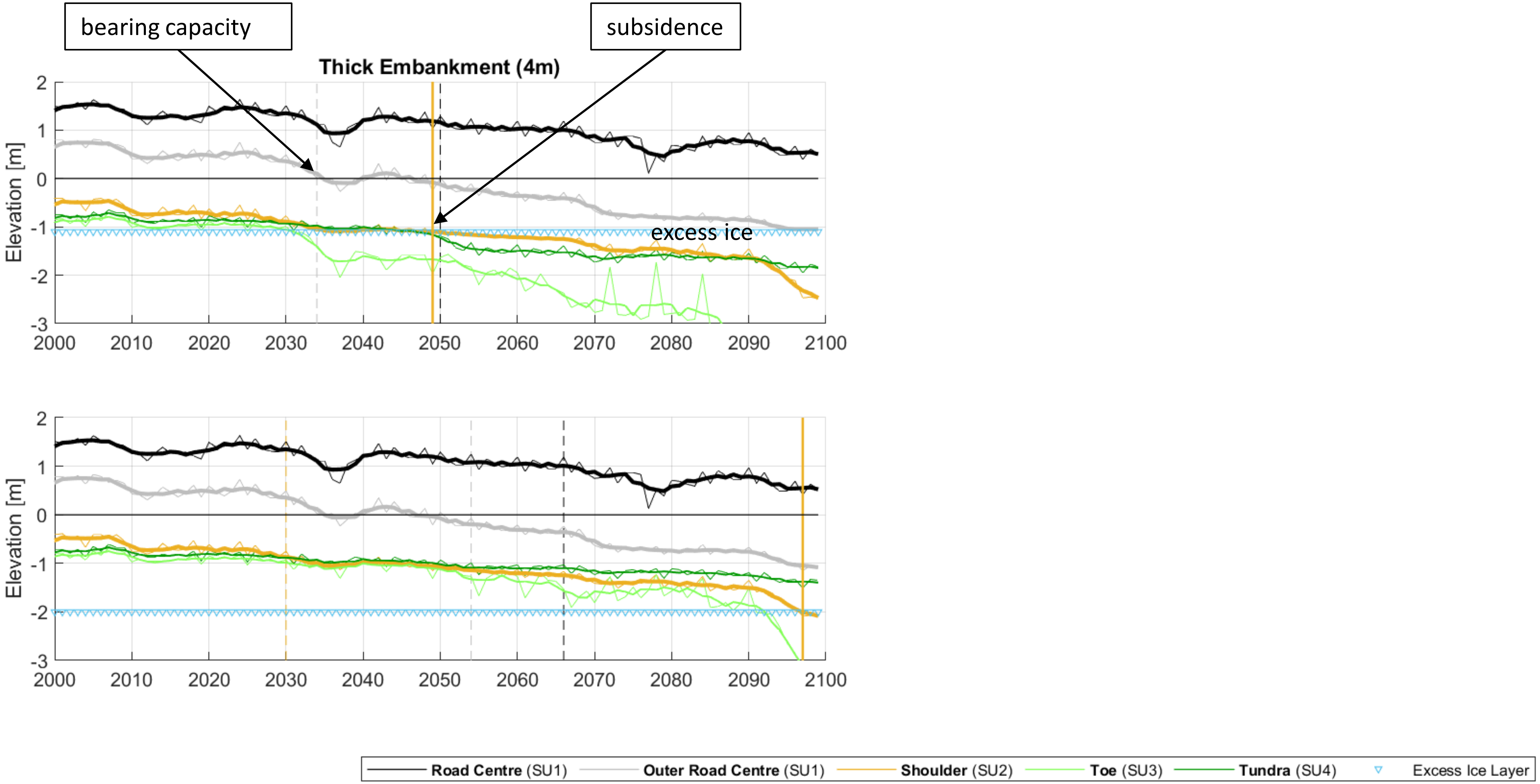
Uncertainty in the timing of future infrastructure failure (model setting)

Analyzing the sensitivity to

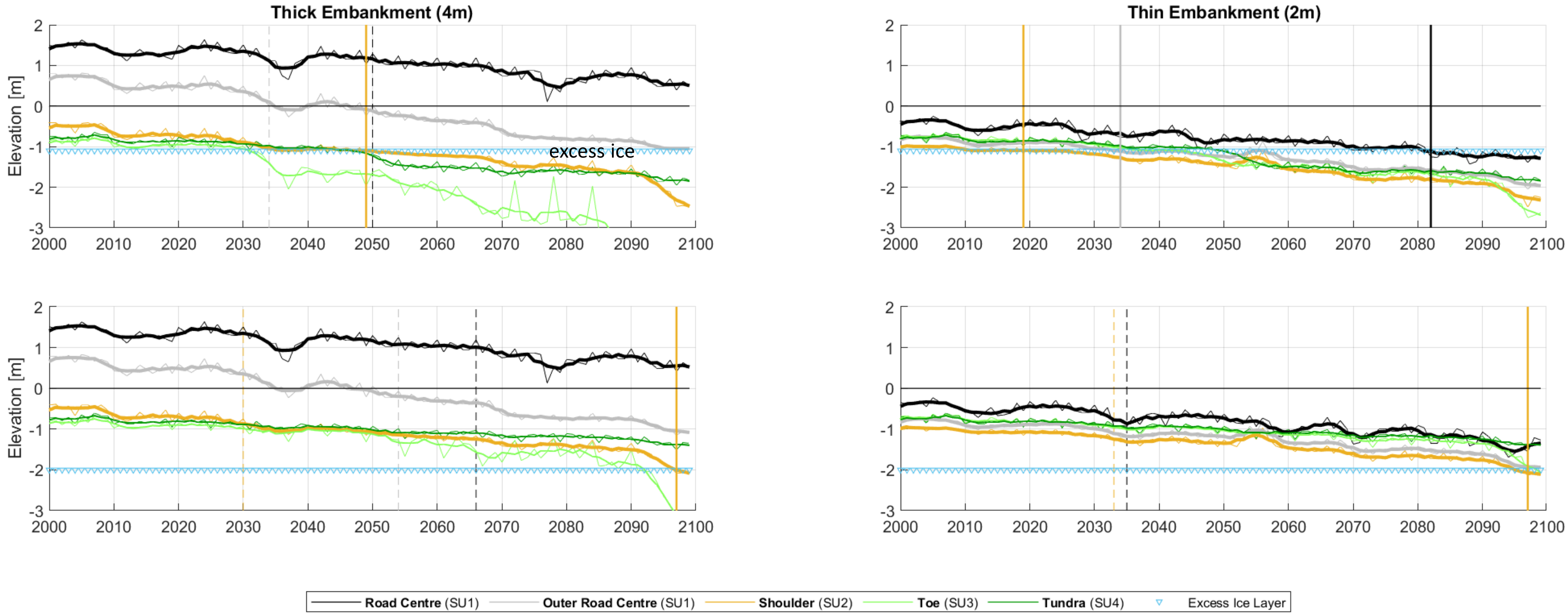
- **Depth of excess ice**
- **Embankment thickness**



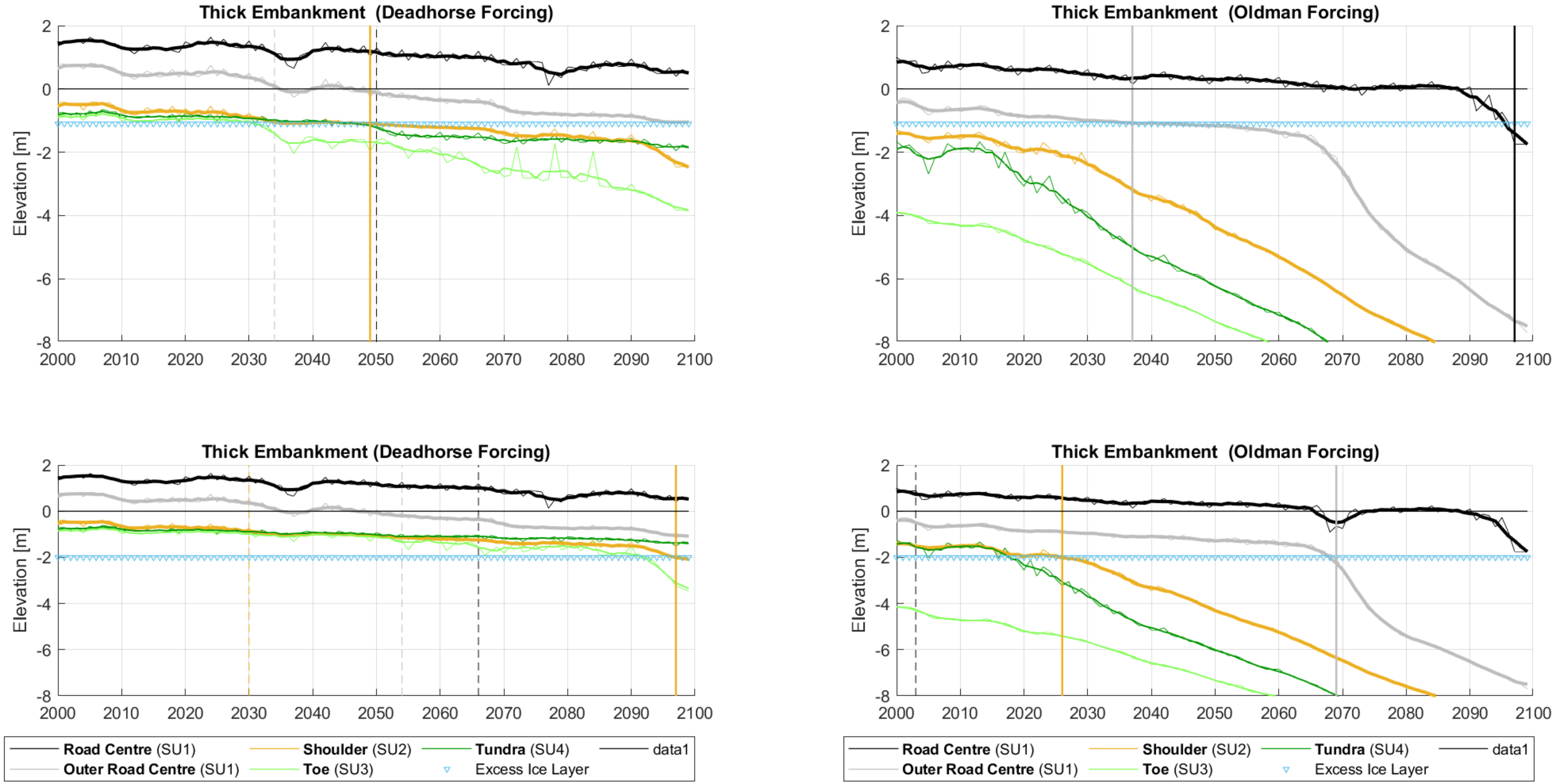
Uncertainty in the timing of future infrastructure failure



Uncertainty in the timing of future infrastructure failure



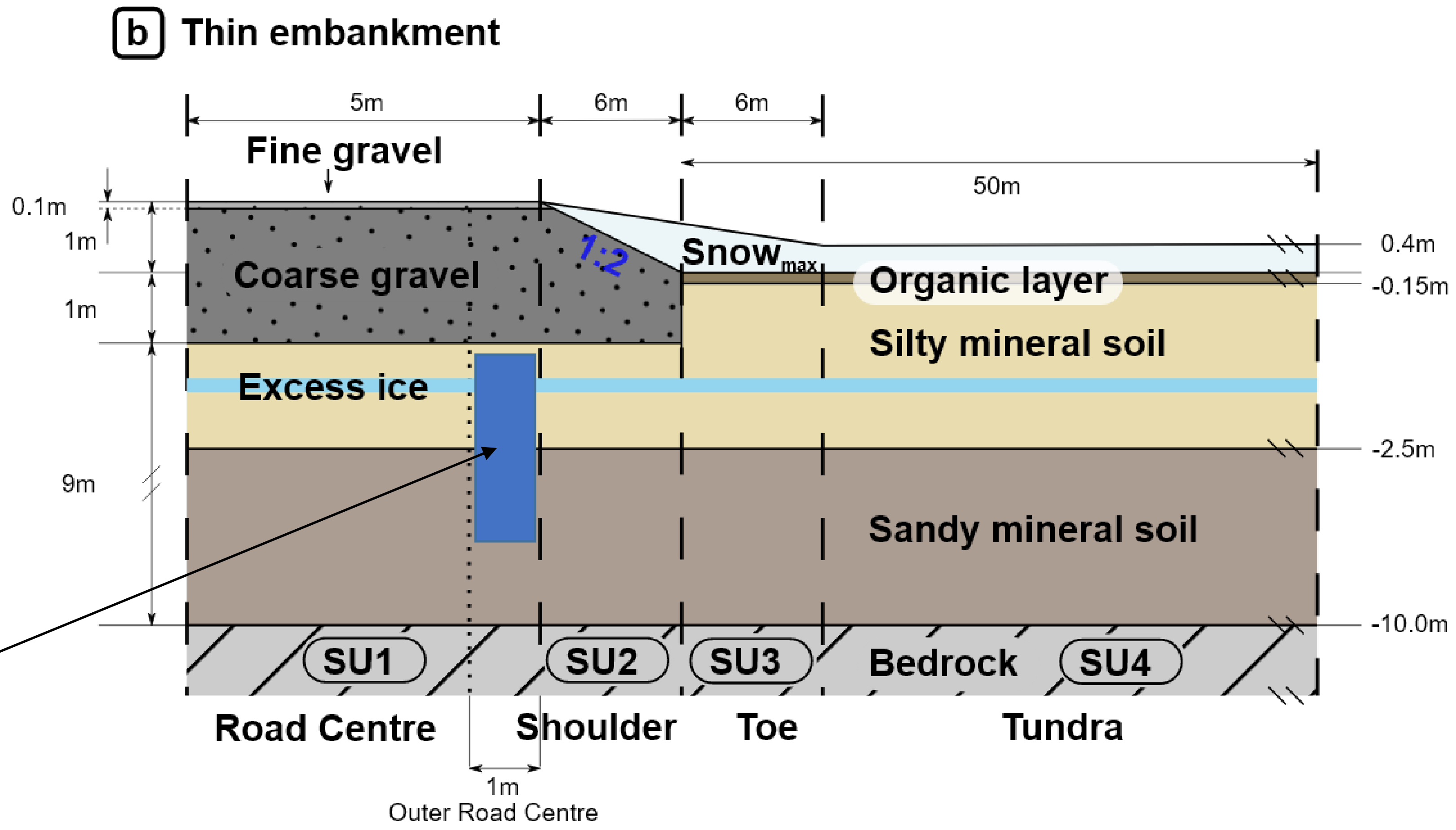
Considering infrastructure subject to a warmer present day climate



Slowing of infrastructure failure through passive cooling

Analyzing the sensitivity to

- **Depth of excess ice**
- **Embankment thickness**

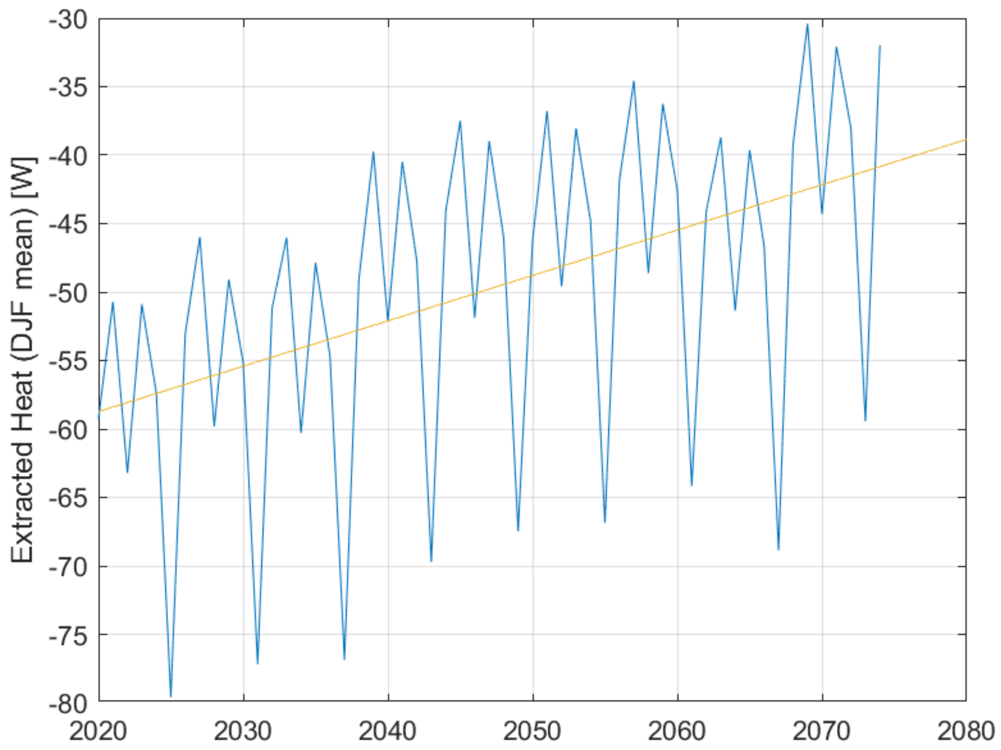


Heat extraction if $(T_{Ground}-T_{Air}) > 0.5K$

Slowing of infrastructure failure through passive cooling

Start of heat extraction

Climate-warming affected reduction in thermosyphon efficacy (passive cooling)



- Reduction in heat extraction by 18% (compared to 2020) by 2050

- Reduction in heat extraction by 33% by 2075

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Key Points

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- Small-scale infrastructure-permafrost interaction together with long-term climate change impacts can be described by models (possible with low horizontal model resolution)
    - Risk of model-based underestimates of the time of infrastructure failure when neglegting infrastructure-permafrost interaction

- Infrastructure sites on cold and continous permafrost can suffer from stability issues already under today‘s climate conditions
  (bearing capacity loss can occur many decades before infrastructure failure from ground subsidence)

- Uncertainty in estimating the timing of future failure is very large
  (a key uncertainty is the depth of excess ice in the ground which can translate into estimates for failure differing by many decades)

- Climate change poses increasing challenges for Arctic infrastructure due to
  - rising numbers of sites affected by permafrost warming or degradation
  - decreasing efficacy of passive cooling techniques

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