

NeurIPS 2023 Workshop on Tackling Climate Change with Machine Learning

Antarctic Bed Topography Super-Resolution via Transfer Learning

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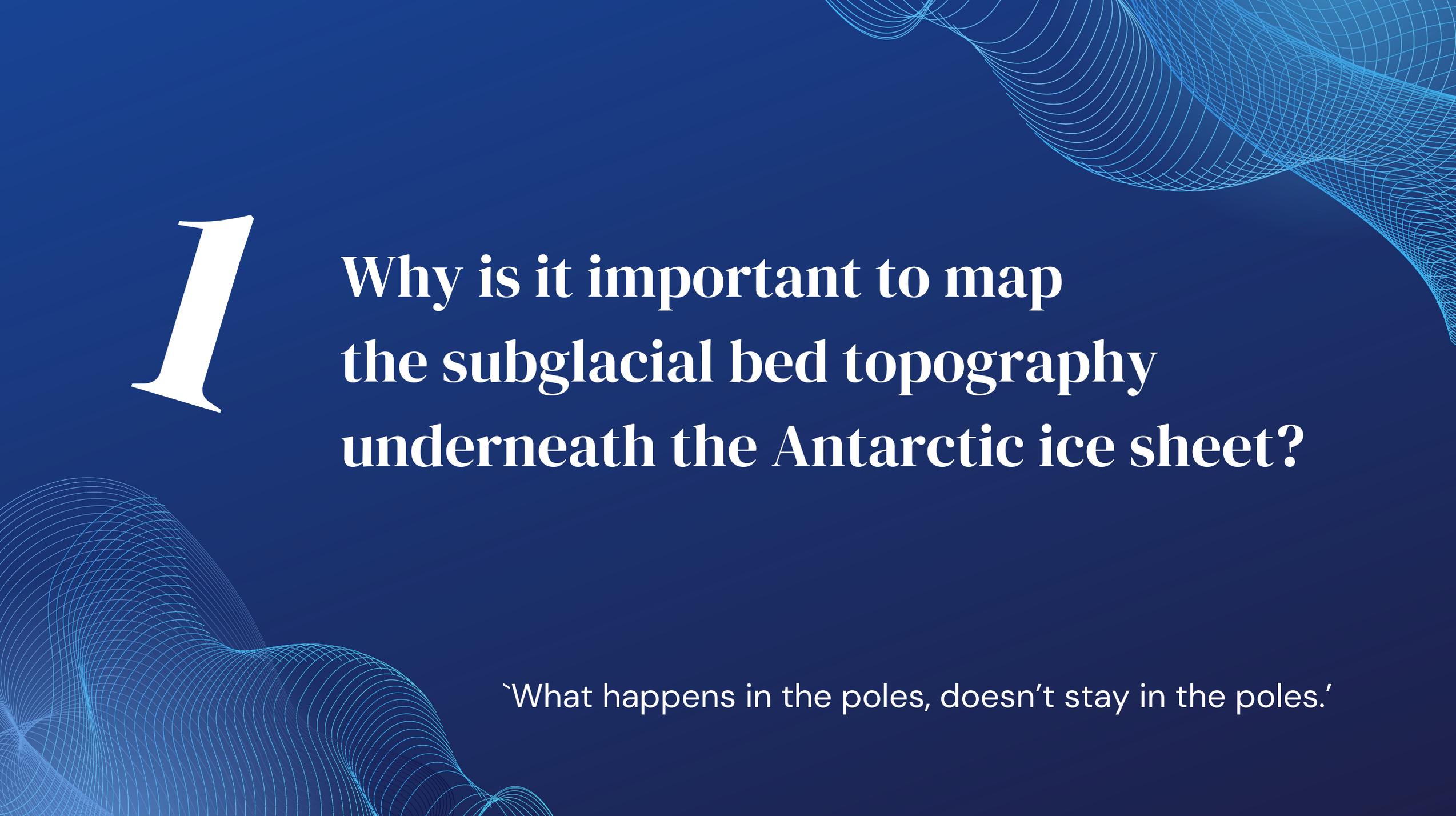


THE UNIVERSITY OF
SYDNEY



DARE

ARC Training Centre in
Data Analytics for Resources & Environments



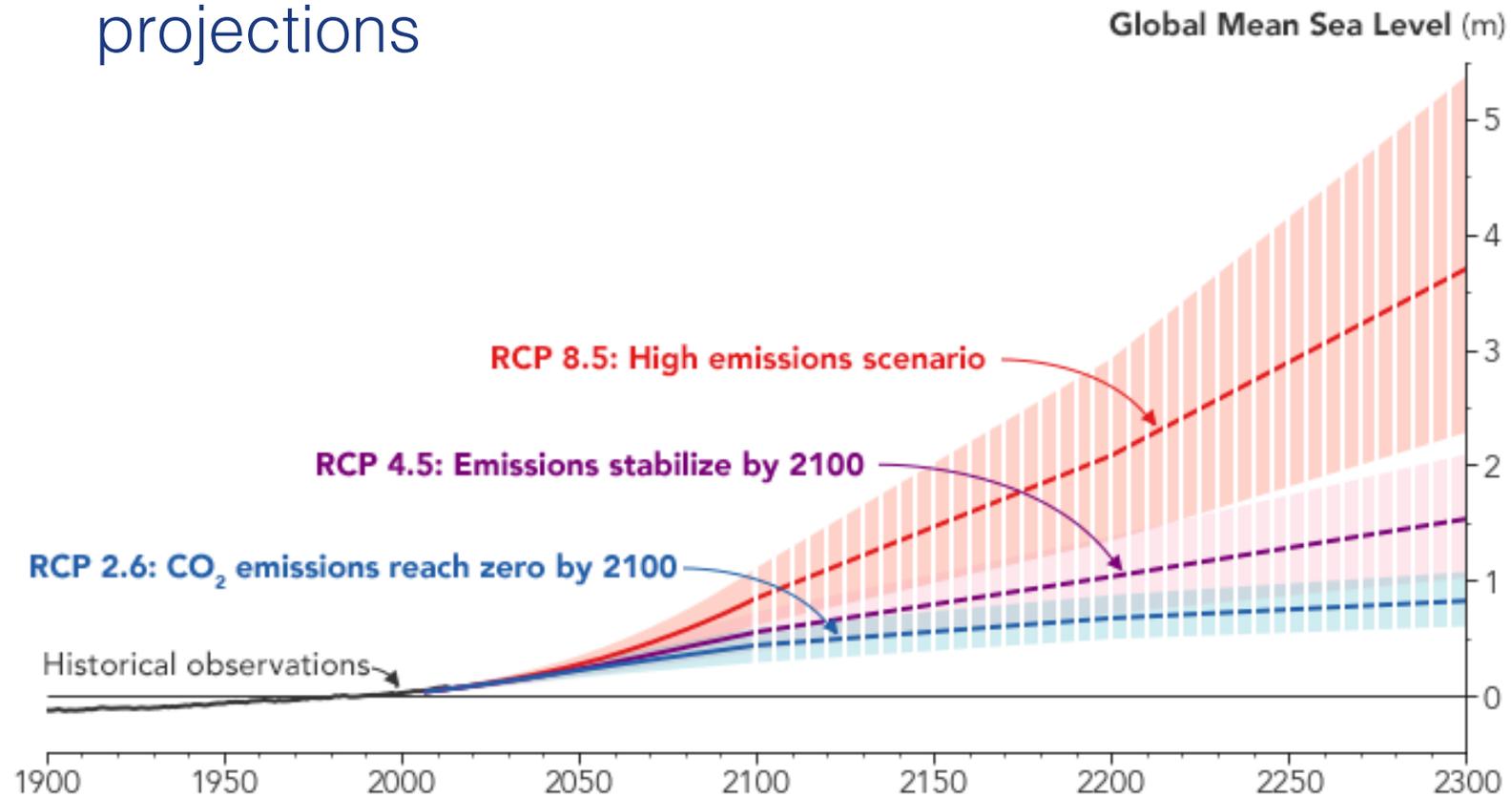
1

**Why is it important to map
the subglacial bed topography
underneath the Antarctic ice sheet?**

‘What happens in the poles, doesn’t stay in the poles.’

Motivation

- Uncertainty in sea level rise projections



Source: NASA Earth Observatory



Source: created by DALL·E

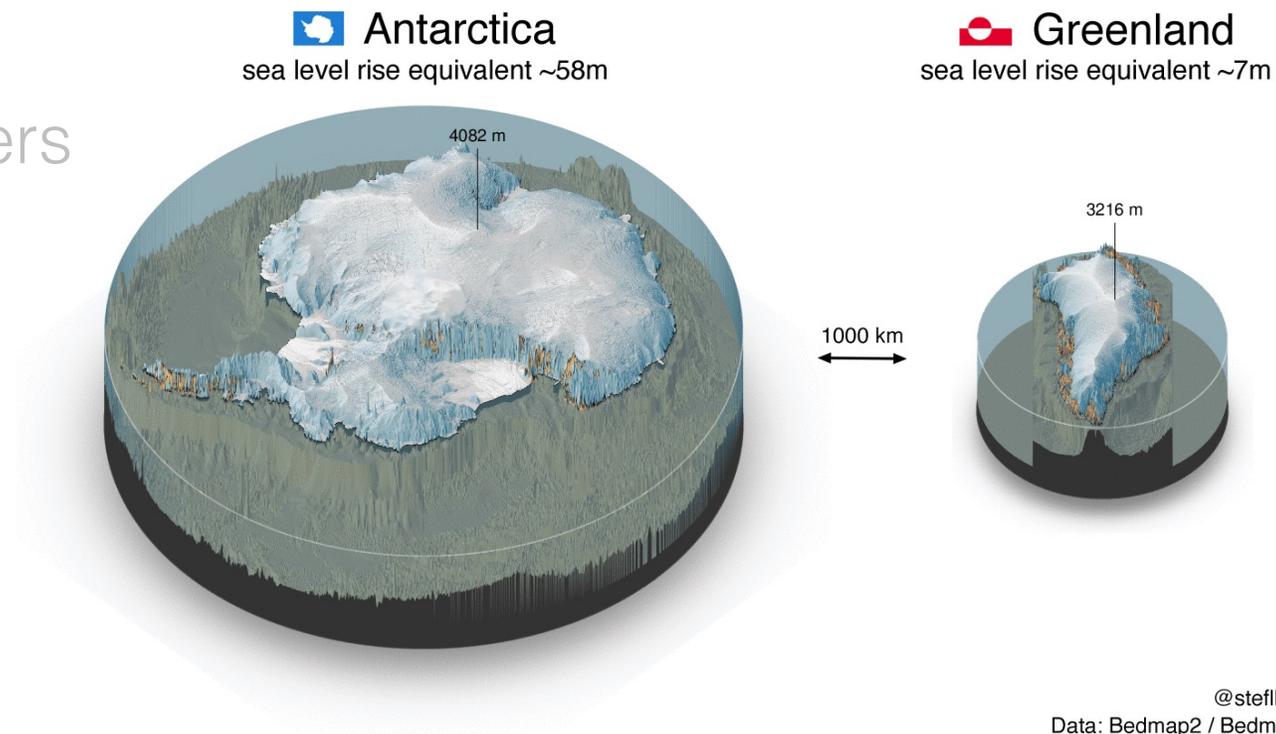
Motivation

- Uncertainty in sea level rise projections
- Antarctic ice sheet: 57.9 meters sea level equivalent



Motivation

- Uncertainty in sea level rise projections
- Antarctic ice sheet: 57.9 meters sea level equivalent
- Source of uncertainty: Digital Elevation Models of Antarctica



@steflhermitte
Data: Bedmap2 / Bedmachine3

Mapping challenges

- Antarctica: vast, remote, with extreme climate conditions

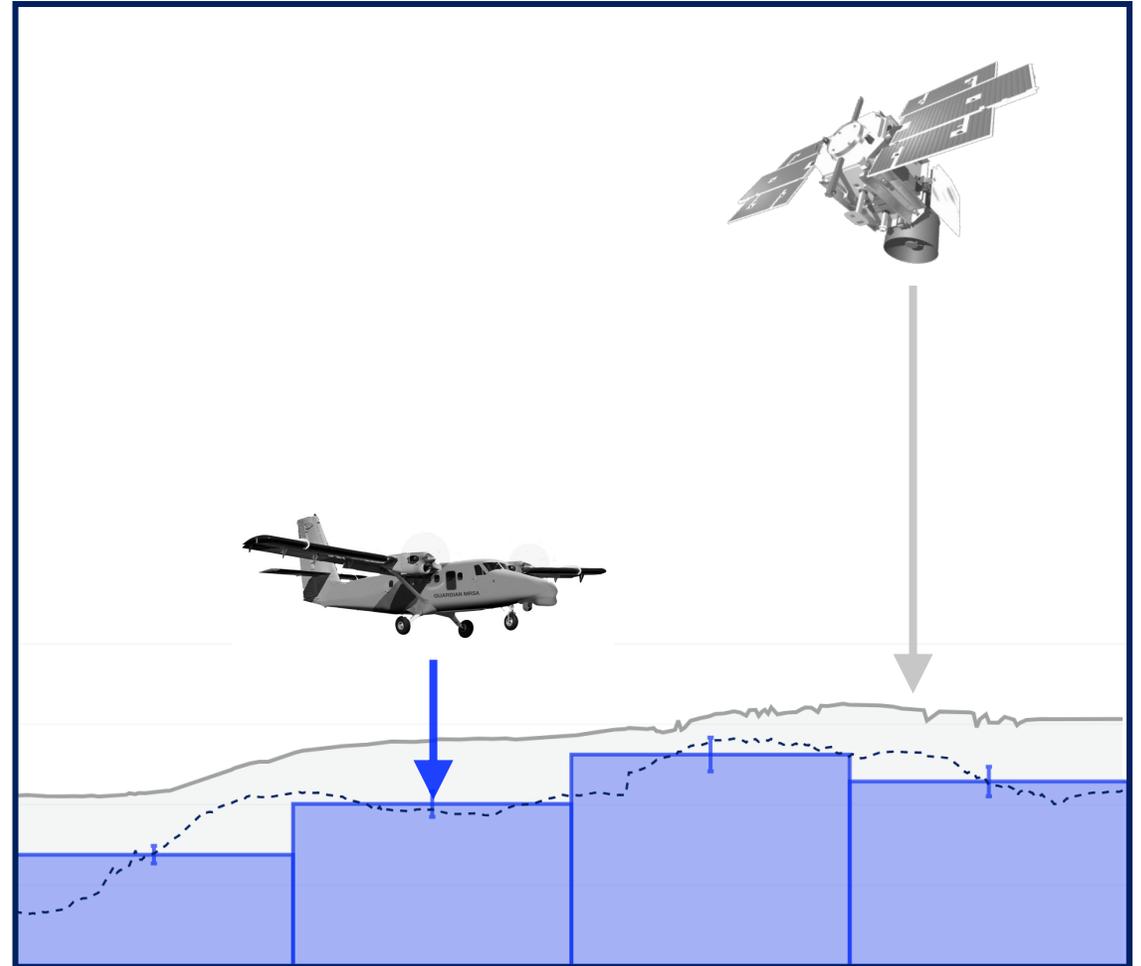


Source: NASA Scientific Visualisation Studio

Mapping challenges

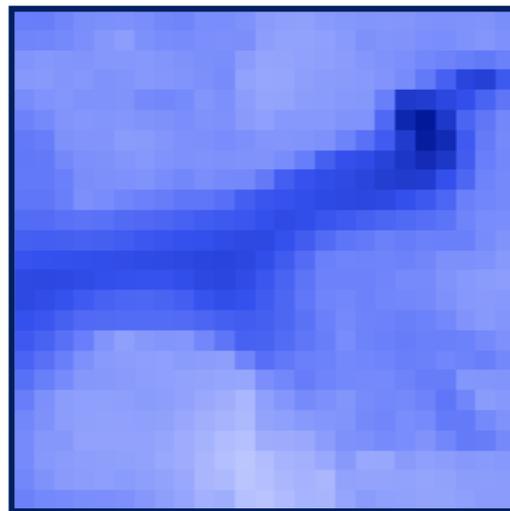
- Antarctica: vast, remote, with extreme climate conditions
- Aircrafts with ice-penetrating radars can map the bed

ice surface elevation s ■
ice thickness t ■
bed elevation b (grid) ■
true bed elevation --

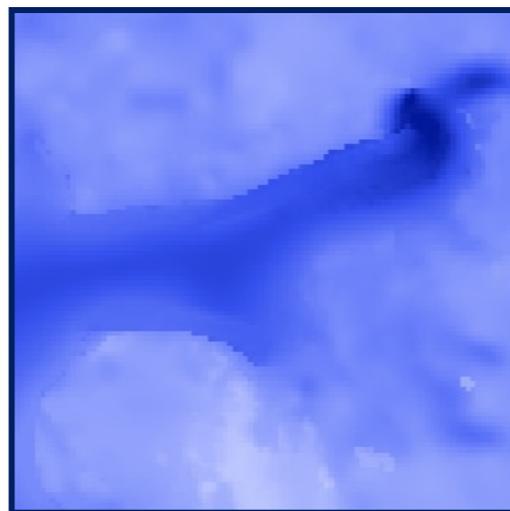


Mapping challenges

- Antarctica: vast, remote, with extreme climate conditions
- Aircrafts with ice-penetrating radars can map the bed
- **Super-resolution:** Increase the resolution of existing bed topography grids/images



low-resolution
(lr)



high-resolution
(hr)



2

FROST

Fusion Regression for

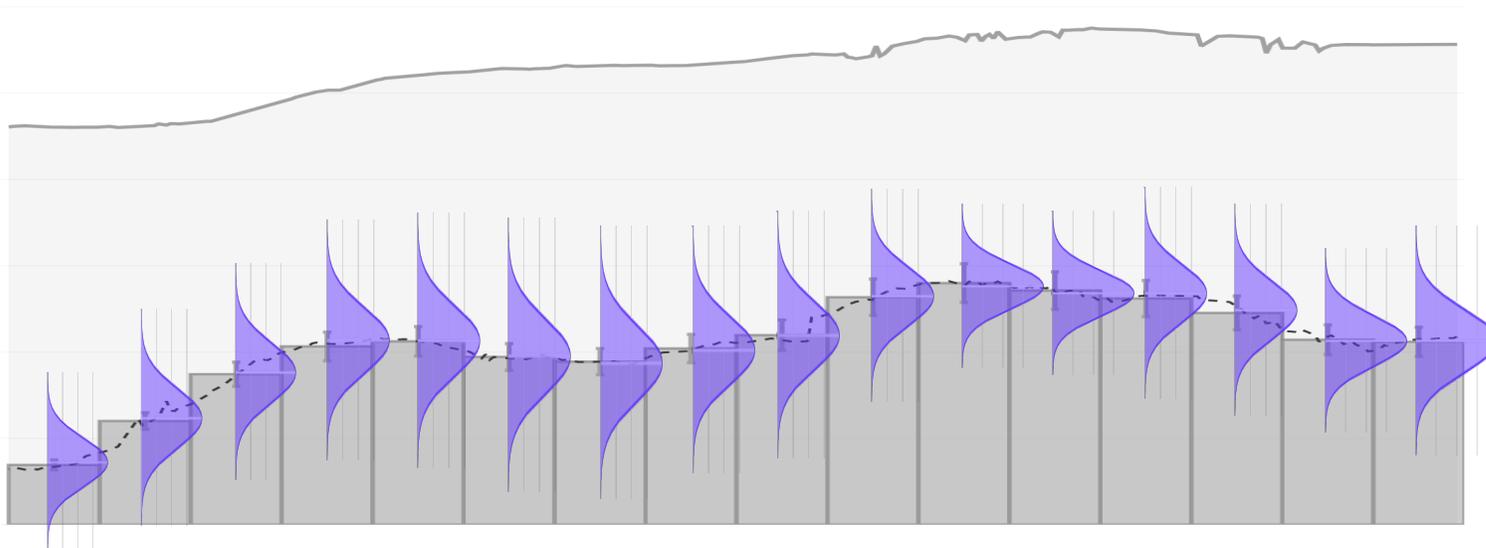
Optimal Subglacial Topography

Introducing FROST

- Gaussian Process (GP) framework (adopted from Reid et al. 2013)

$$\text{bed}_{hr} \mid \text{bed}_{lr}, \text{surface}_{hr} \sim N(\mu, \Sigma)$$

$$\mu^* = \hat{b}(P_{hr}) = k(P_{hr}, P_{lr})[k(P_{lr}, P_{lr}) + \sigma_n^2 \mathbf{I}]^{-1}(b(P_{lr}) - \mu_b) + \mu_b$$

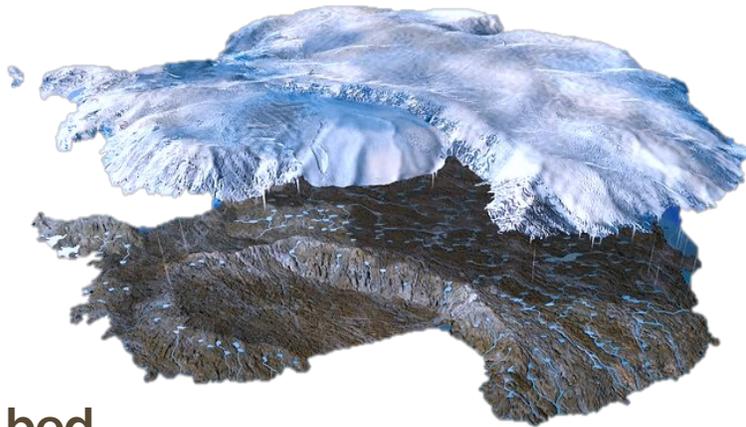


predictive
distribution

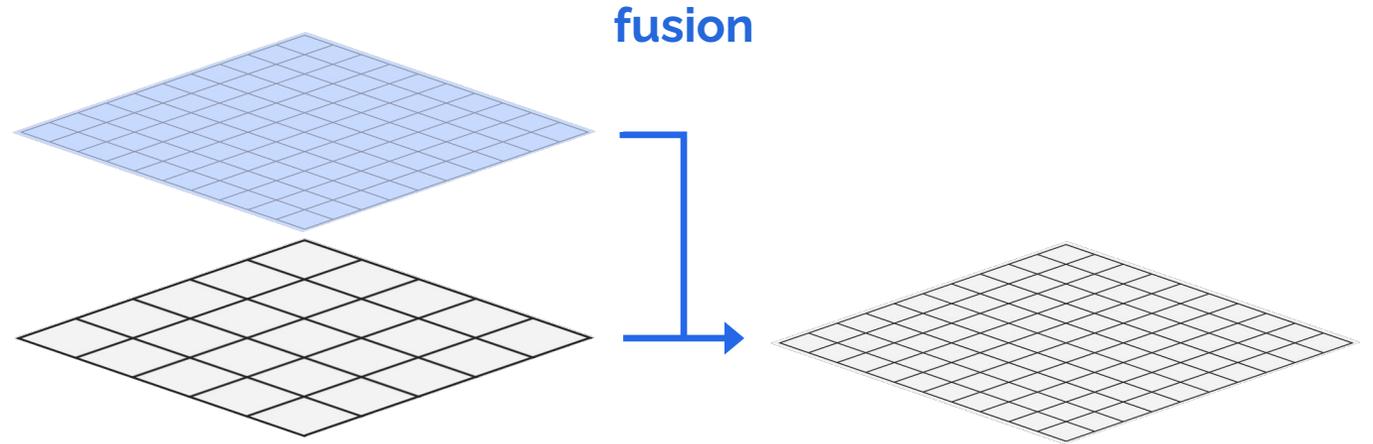
Introducing FROST

- Gaussian Process (GP) framework
- Inter-modal covariance transfer

surface



bed



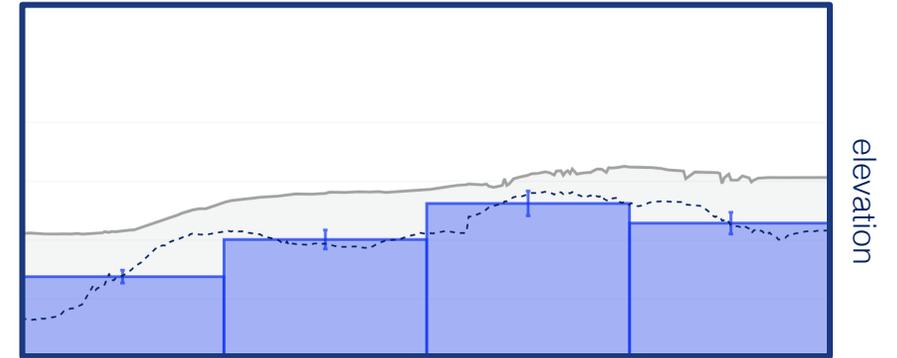
Introducing FROST

- Gaussian Process (GP) framework
- Inter-modal covariance transfer
- Flexibility in upscaling factor

e.g. $\times 2$, $\times 3$, $\times 4$, $\times 5$ or $\times 6$

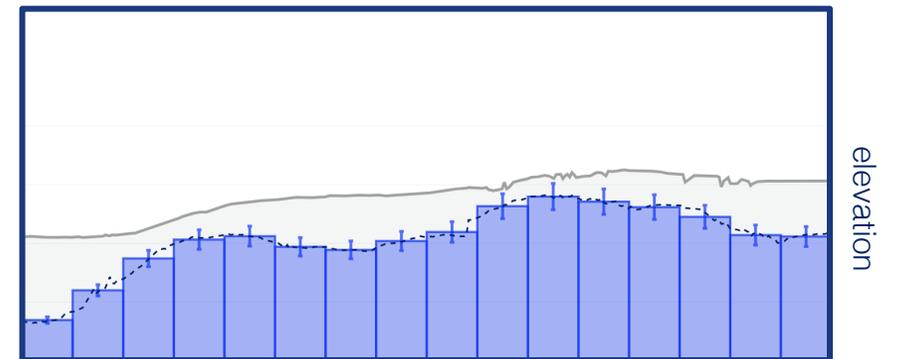
ice surface elevation s ■
ice thickness t ■
bed elevation b (grid) ■
true bed elevation --

low-resolution (lr)



↓ e.g. $\times 4$

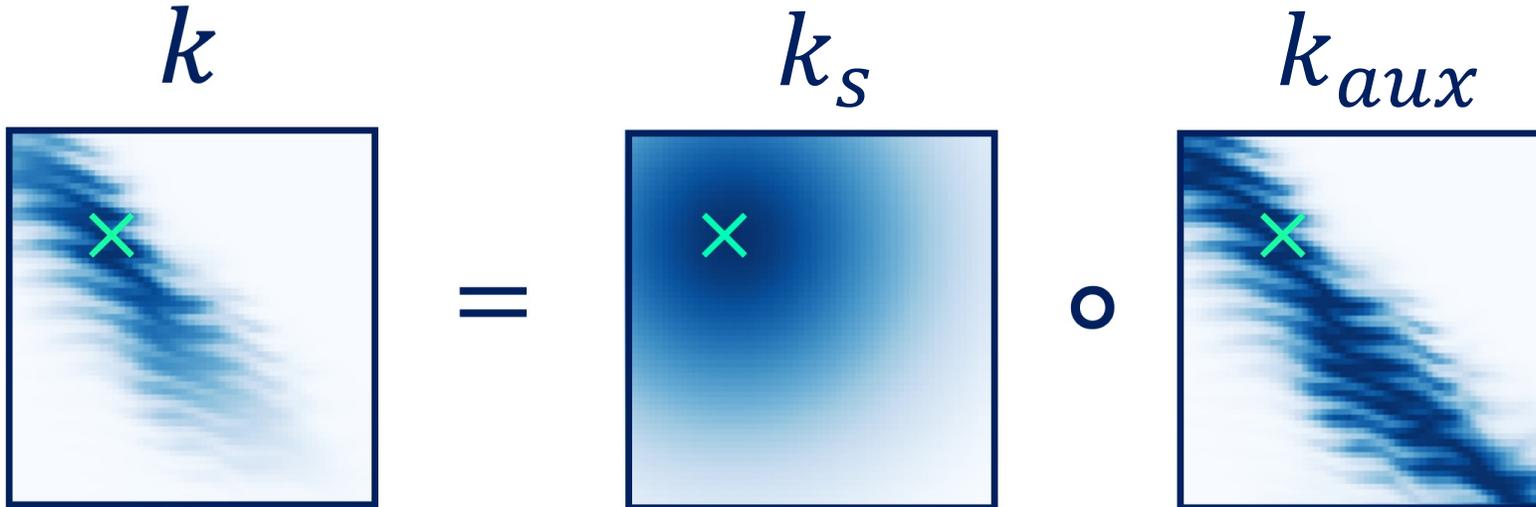
high-resolution (hr)



x-coordinate of transect

Covariance transfer

$$k(P_{hr}, P_{hr}') = k_s(P_{hr}, P_{hr}') \circ k_{aux}(s(P_{hr}), s(P_{hr}'))$$



- Local filter
- Sparsity

- Non-stationarity

3

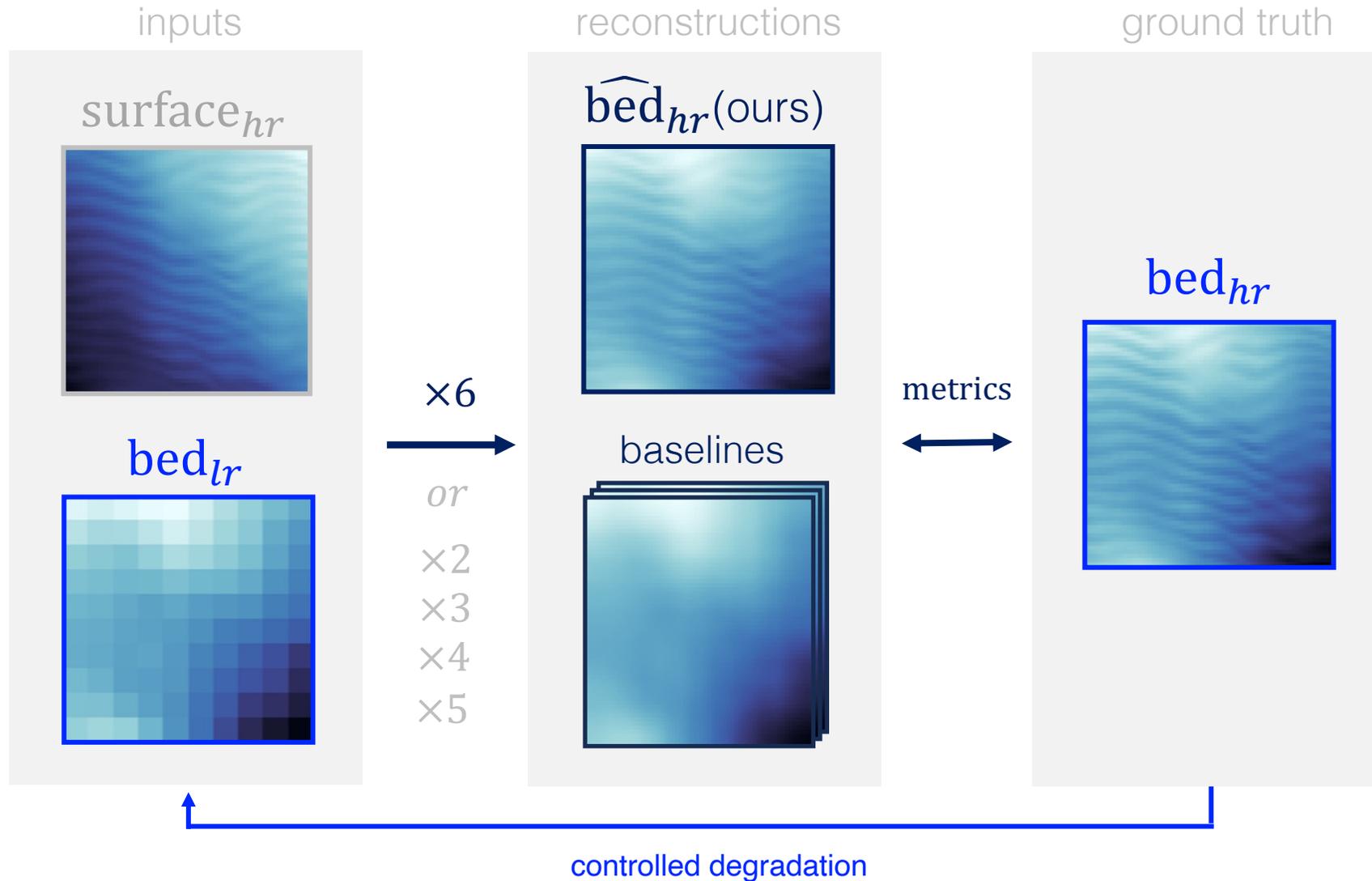
Experiments & Results

Bed topography image reconstruction

domain with 400 images



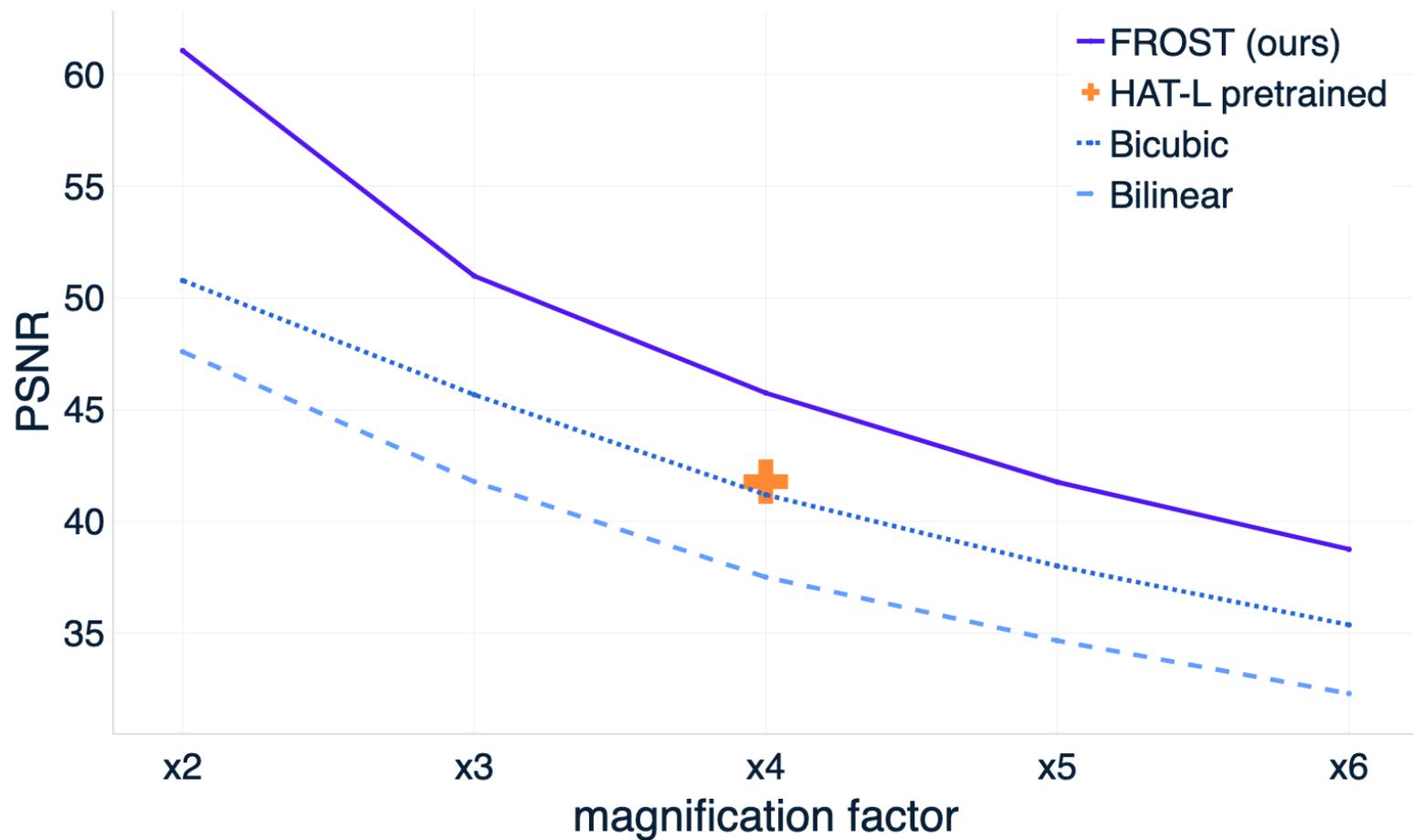
Image reconstruction experiments



MEaSURE
BedMachine
Antarctica v3
Morlighem et al.
2020

Results

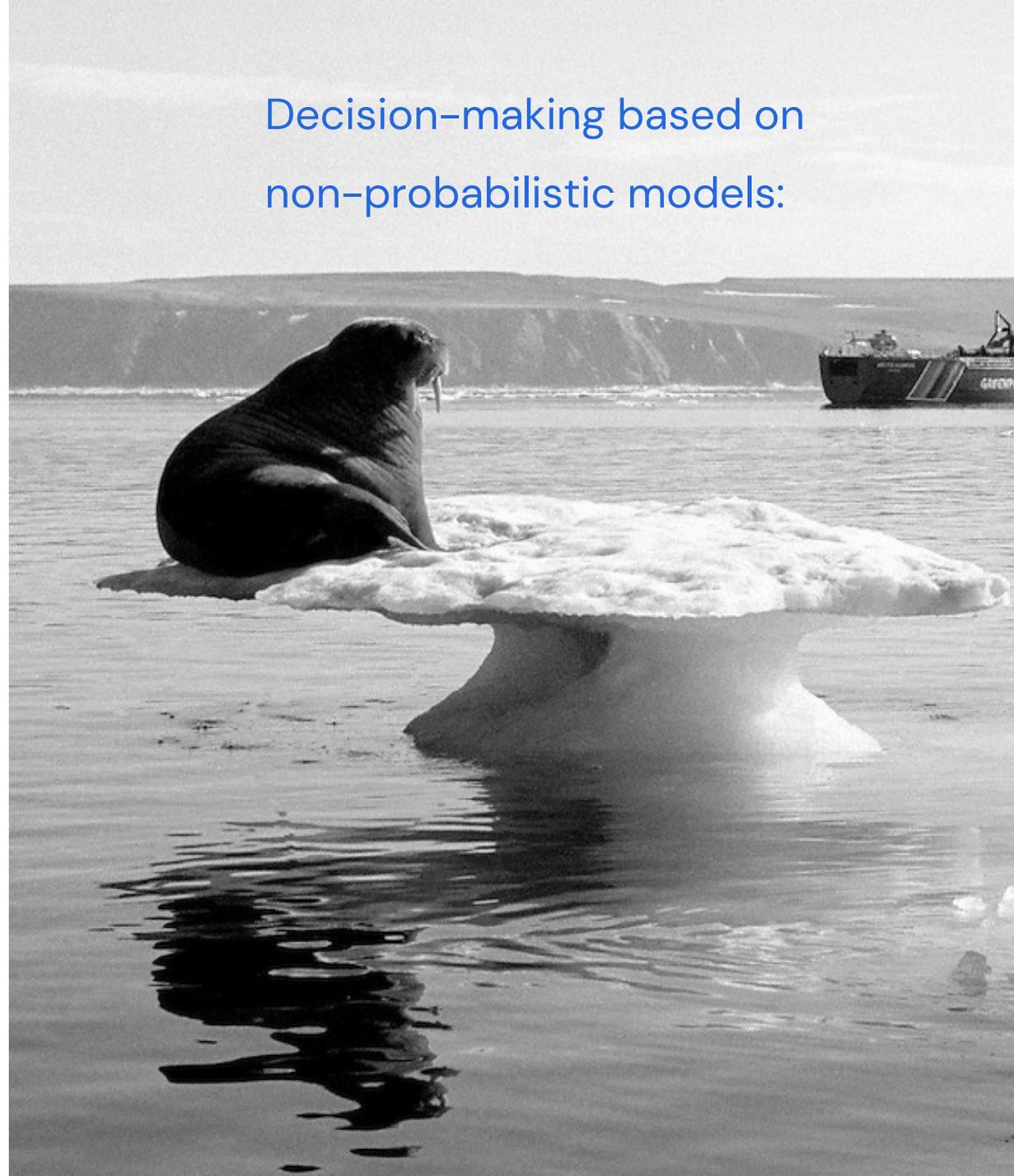
Peak Signal-to-Noise Ratio (PSNR), higher is better ↑



In conclusion

- **FROST does not require** gridded bed topography **training data** at target resolution.
- **FROST leverages** ubiquitous, high-quality **ice surface data**.
- **FROST quantifies uncertainty:**
 - input for down-stream modelling
 - inform fieldwork and data acquisition strategies

Decision-making based on non-probabilistic models:



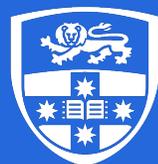
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