Efficient generative flows unlock physical consistent surrogates

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Original title: Efficient generative deep learning for large-scale sea-ice modelling

Motivation

Generative model can produce photorealistic images and videos.

Surrogate modelling can improve geophysical modelling strategies (faster, adjoint „for free“, possible learning from data)

How to scale generative flows for surrogate modelling? What is the advantage of those surrogates?

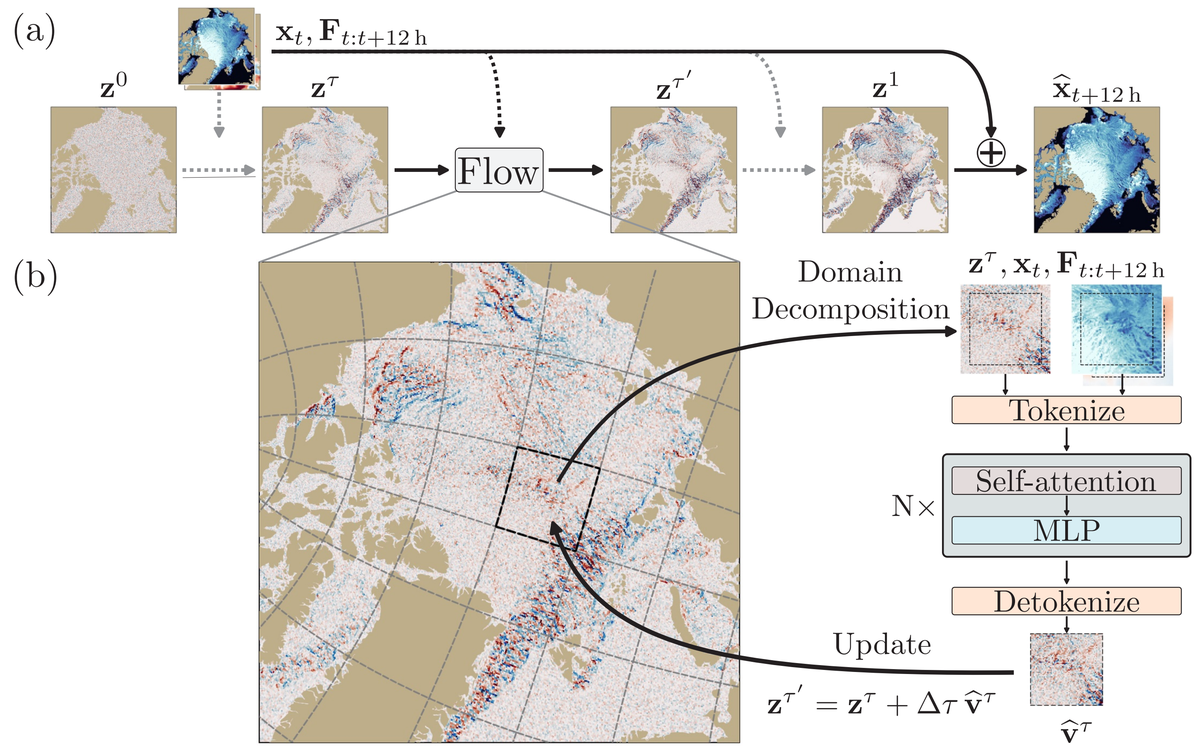
Data from sea-ice simulations

Model: neXtSIM coupled to ocean model (Boutin et al., 2023)

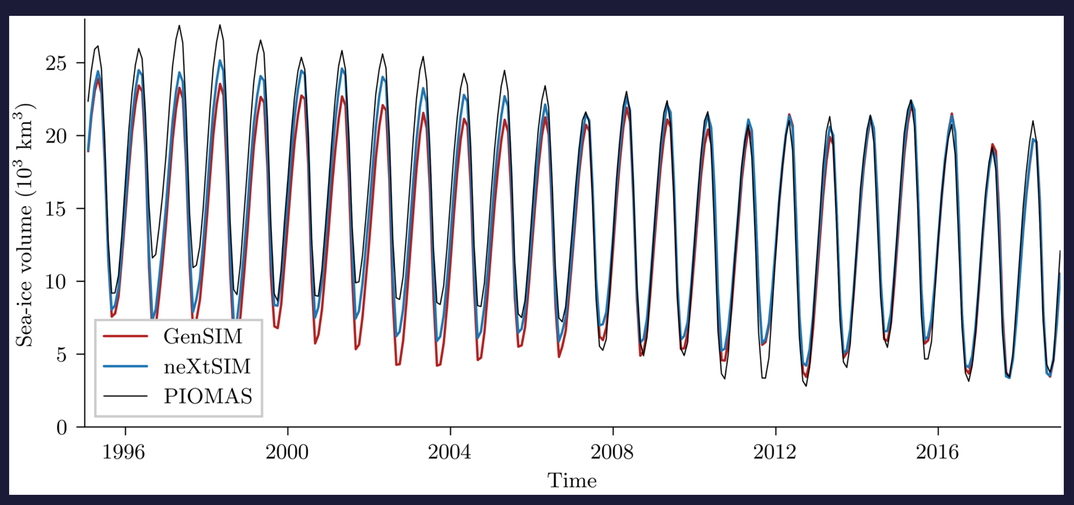
Setup: Arctic-wide at a 1/4 ° resolution (≈ 12 km), six-hourly output

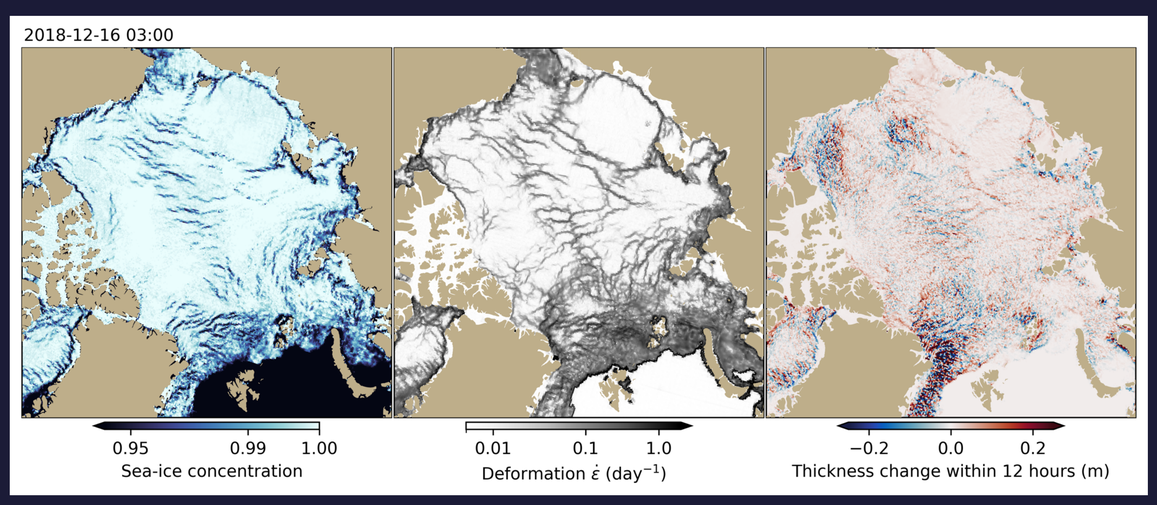
Training setup: Multiscale training with patching, 12 hour lead time
1995-2014 training with data augmentation; 2016-2018 testing

Generative flow with domain decomposition

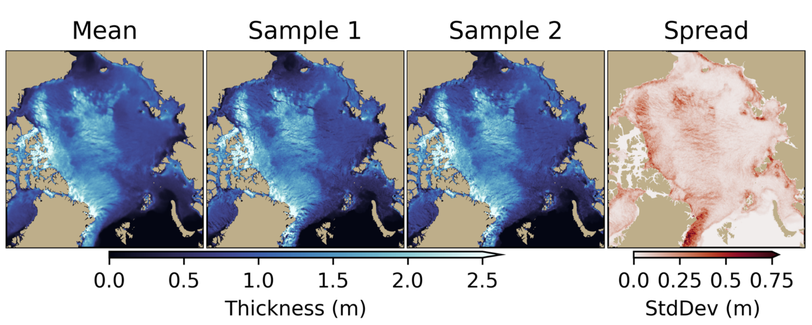


Produces stable and realistic long-term simulations

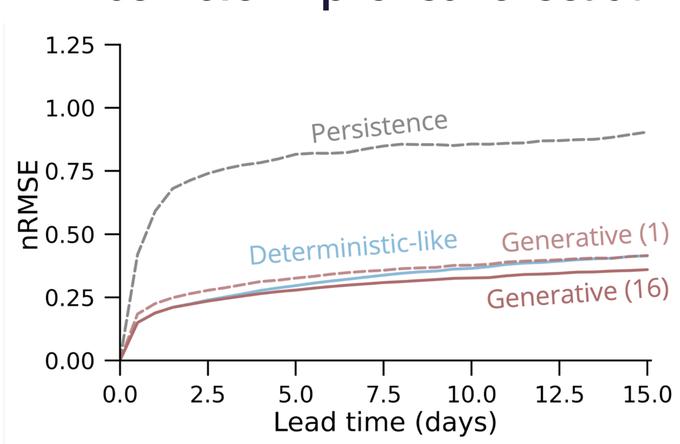




Enables ensemble forecasts



Ensemble improves forecast



Conclusions

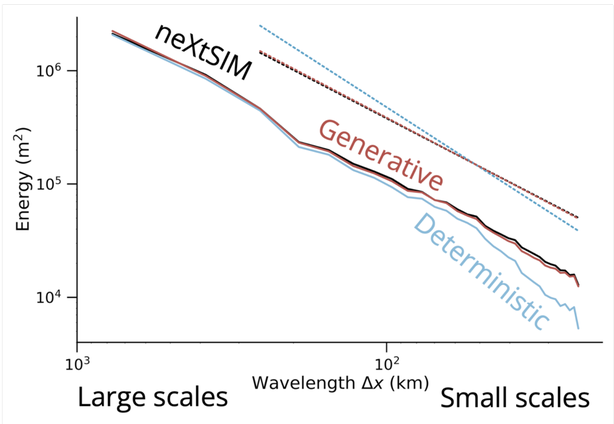
Efficient approach with generative flow and domain decomposition + localization

When properly trained for forecasting, generative flows stable for long simulations

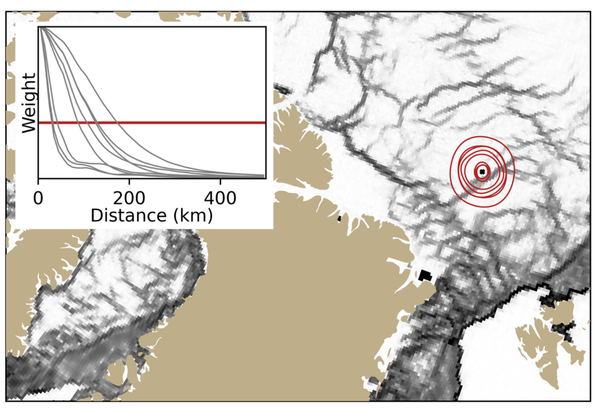
Generative flows do the right things for the right reasons leading to physical consistency

Working on efficient large-scale models, application to extremes, proving the stability, and uncovering what the models learn

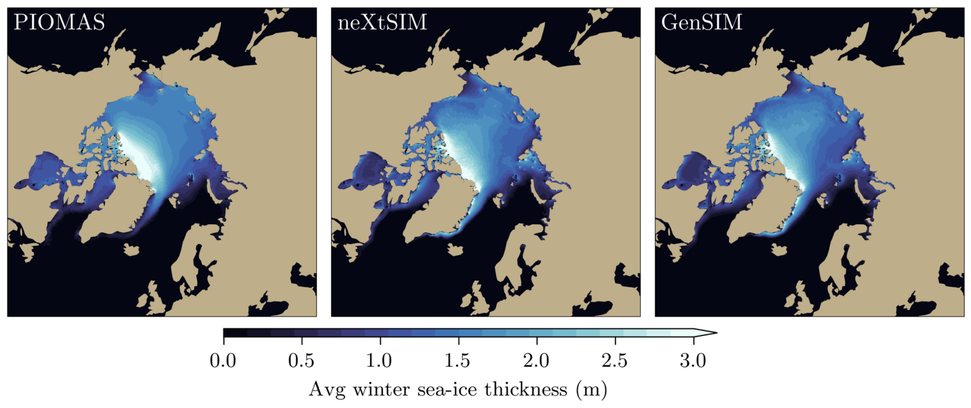
Solves issues of smoothing



Learned localization



Similar statistics as geophysical model



Finn et al. (2025), *Efficient Arctic-wide sea-ice modelling with generative flows*, to be submitted to *Nature Geophysics*

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