Data-driven sea-ice modelling with generative deep learning

Tobias Sebastian Finn

Charlotte Durand, Alban Farchi, Marc Bocquet,
Pierre Rampal, Alberto Carrassi, Julien Brajard and others

This research was funded by Schmidt Sciences - a philanthropic initiative that seeks to improve societal outcomes through the development of emerging science and technologies


Imagen

How to emulate what an ocean/sea-ice model is doing?

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1. Faster version of the model

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3. Possibility to improve the model by observations

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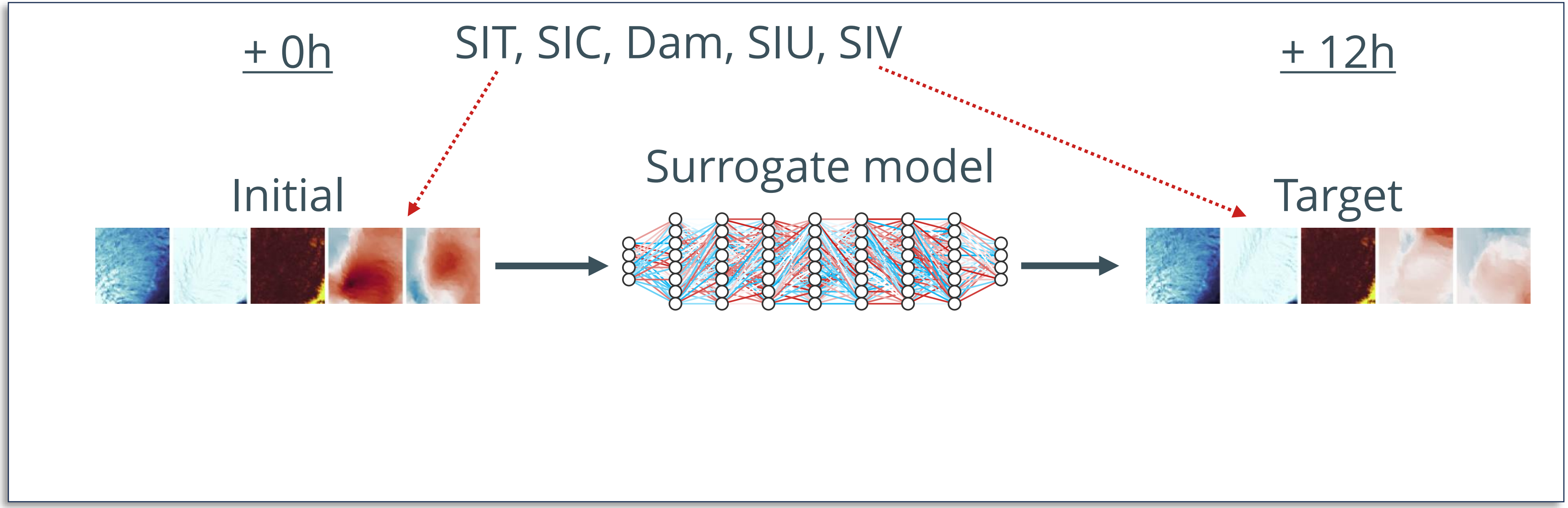
<u>Our solution</u>: Generative diffusion model

We need data, a lot of data …



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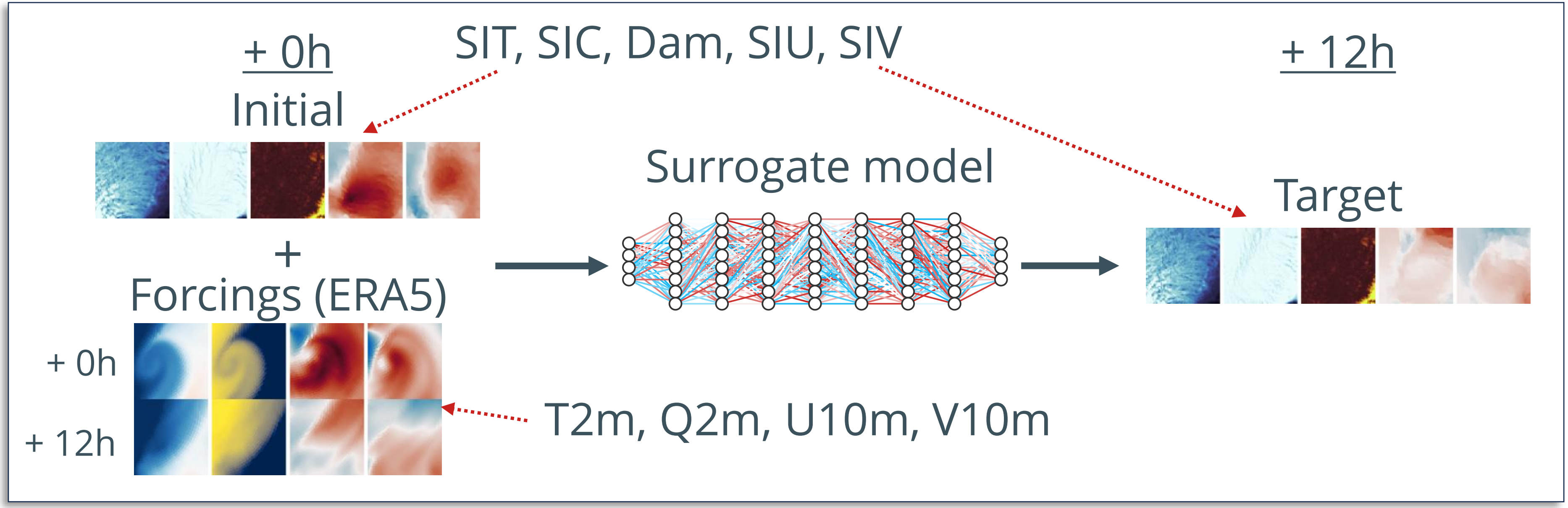

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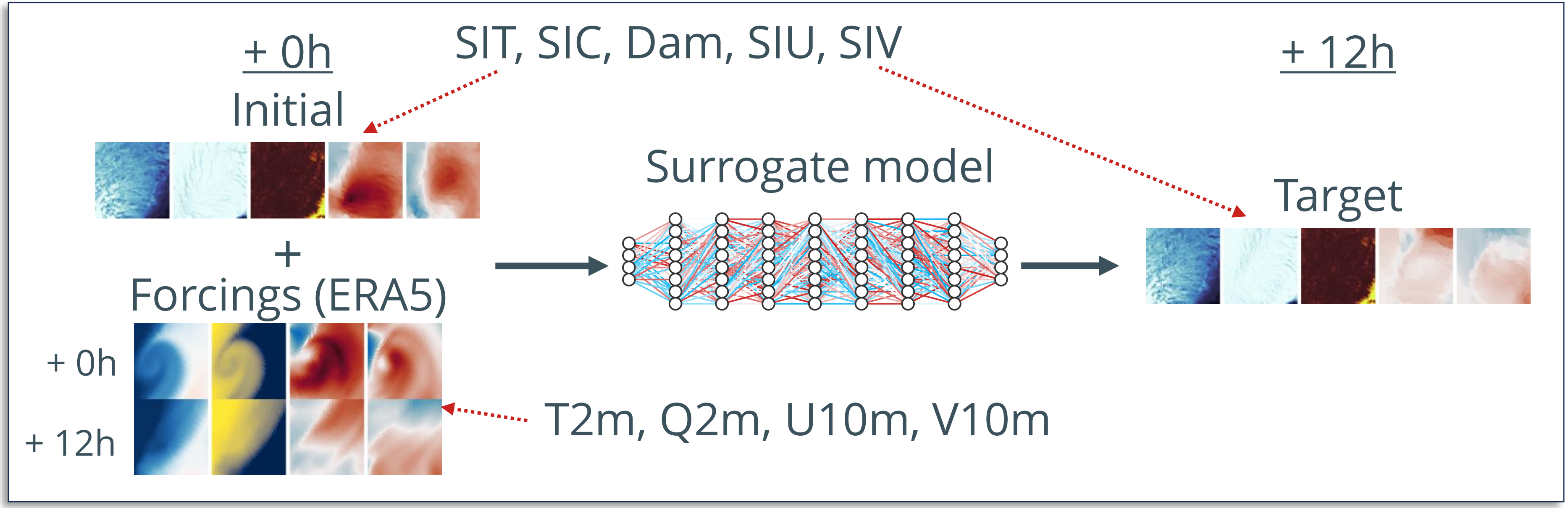
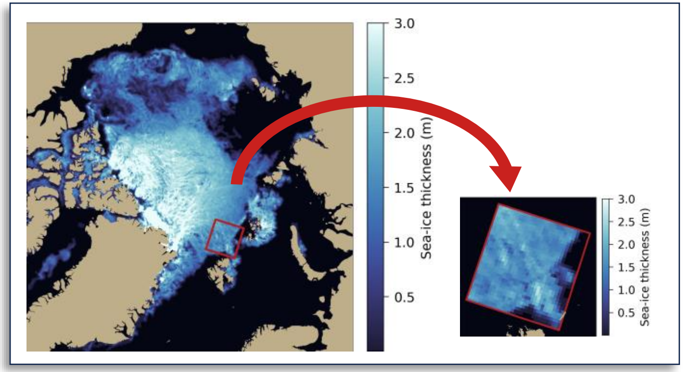


Regional setup



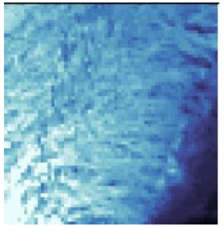
Lagrangian neXtSIM
+ ¼° NEMO (Boutin et al., 2023)

1995-2014: Training

2016-2018: Testing

Train the neural network as generative model

Training

Target 

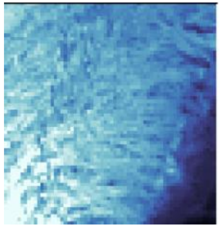
$\sim\mathcal{N}(\mathbf{0}, \boldsymbol{I})$

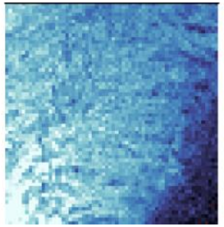
Train the neural network as generative model

Training

+ noise

Target





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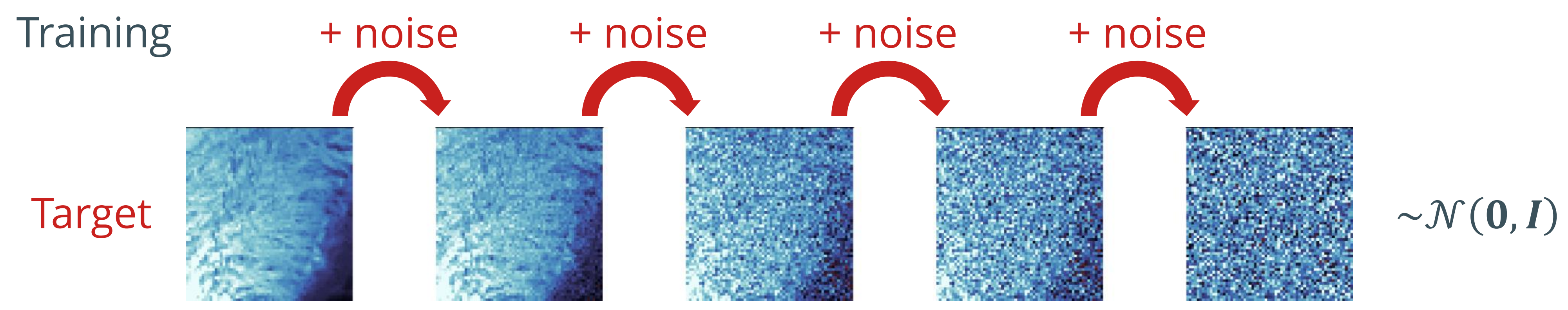

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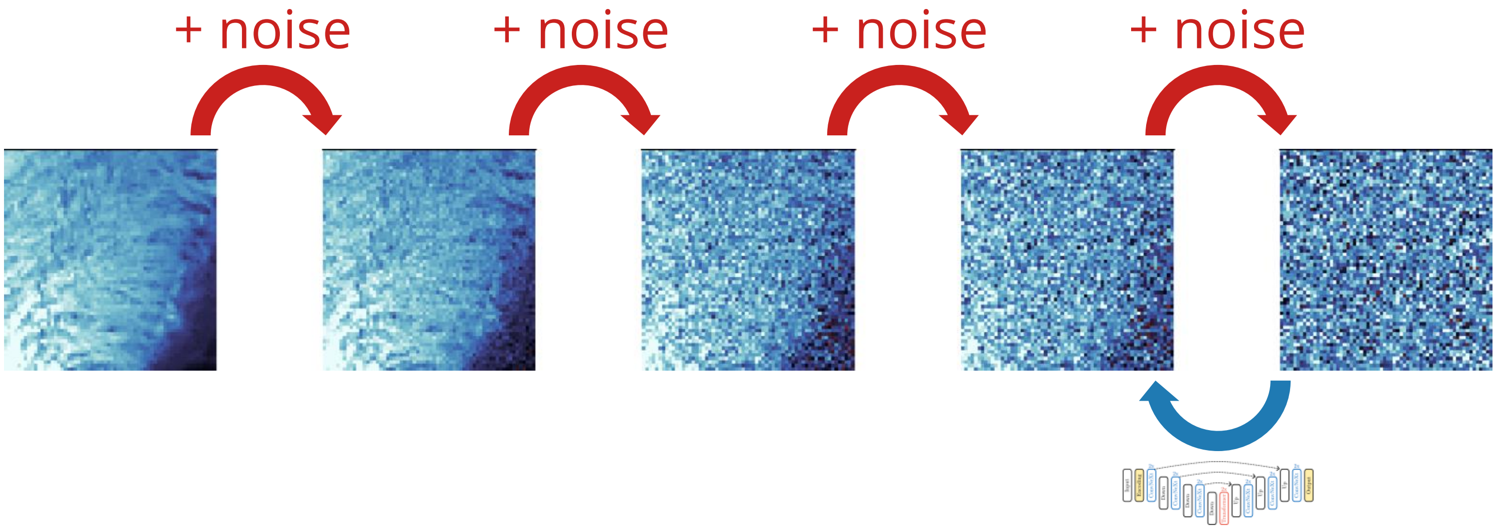

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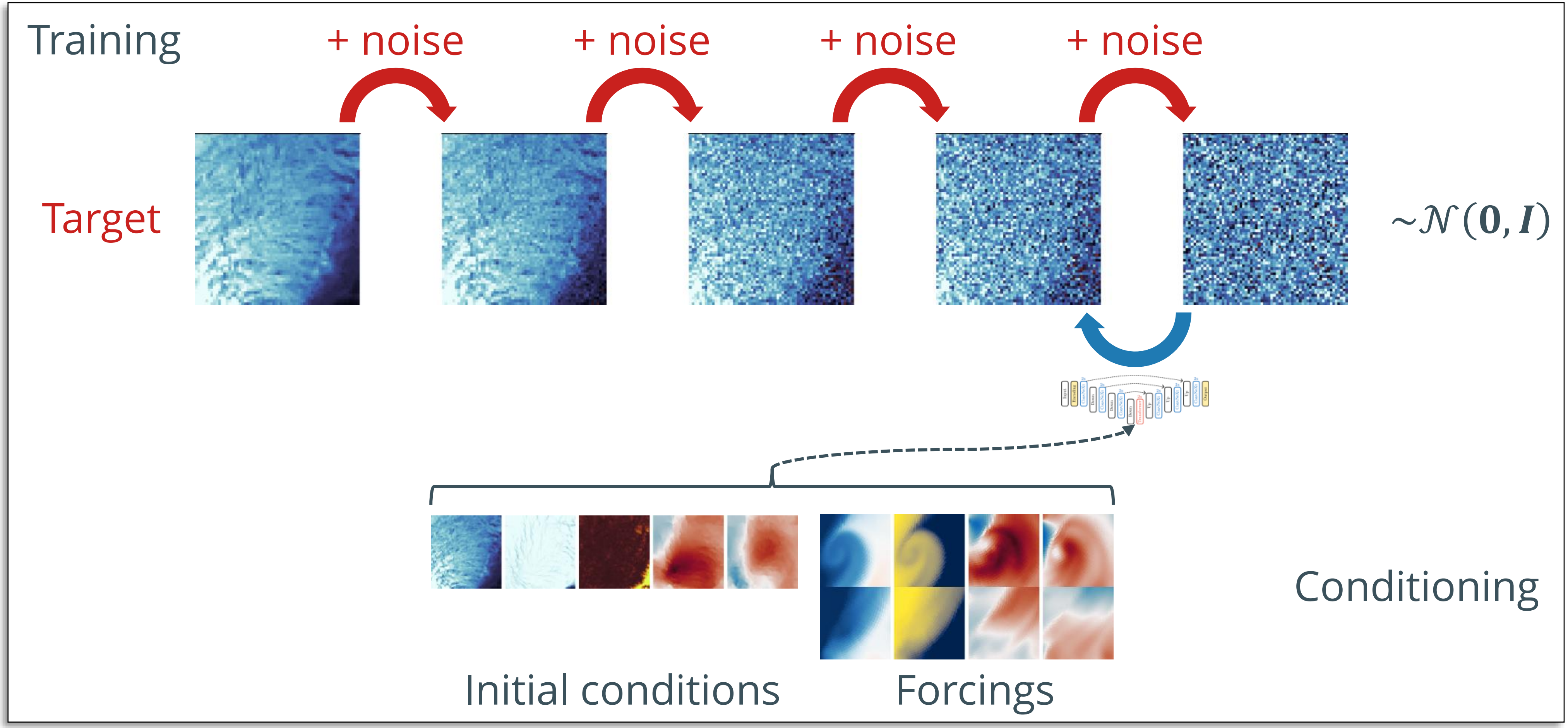

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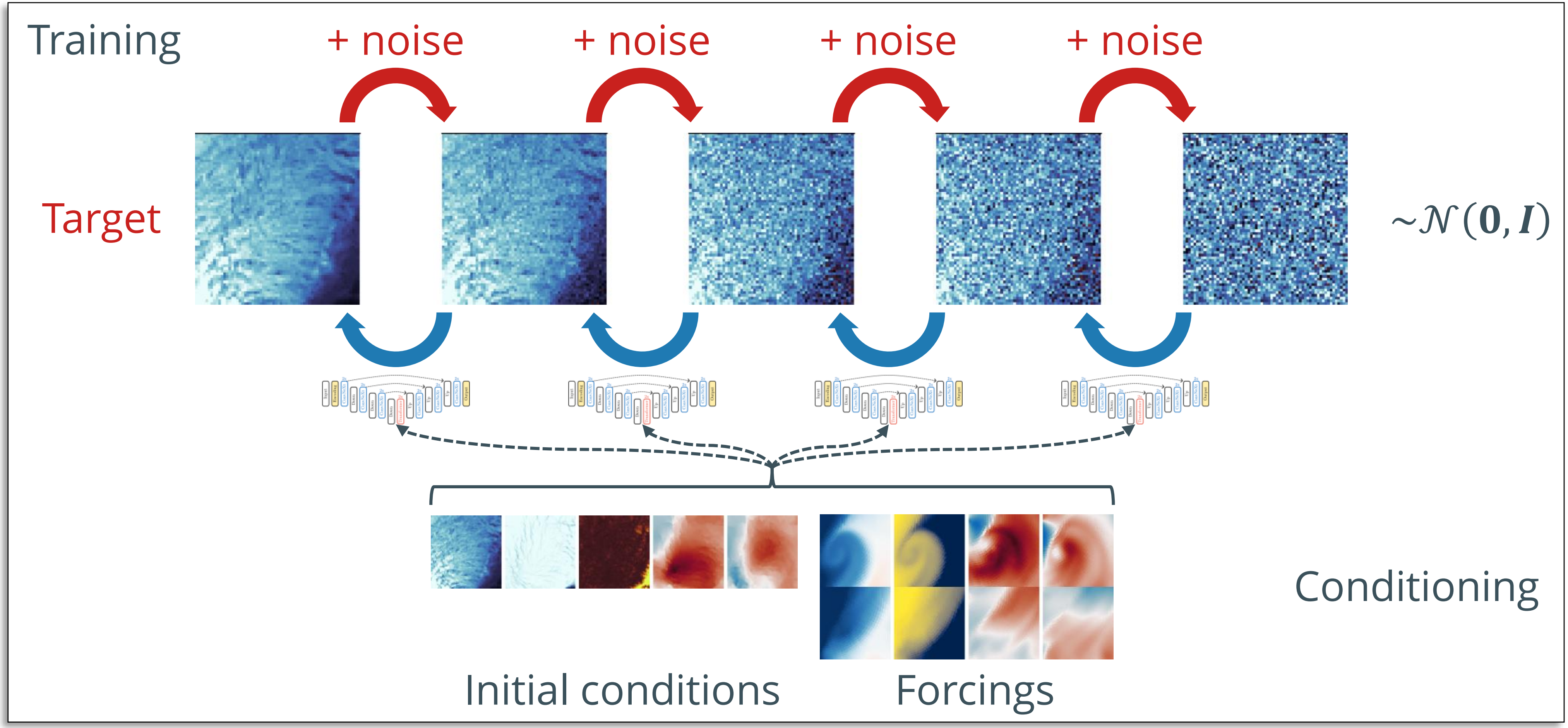
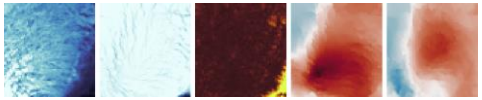


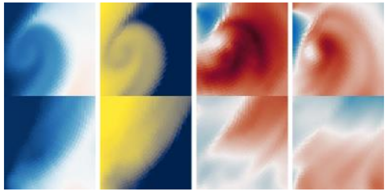
Train the neural network as generative model

Forecast

?



Initial conditions



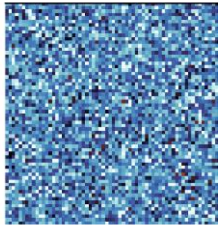
Forcings

Conditioning

Train the neural network as generative model

Stochastic

Forecast



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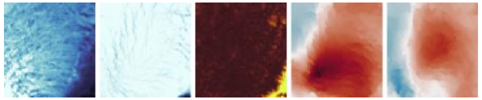

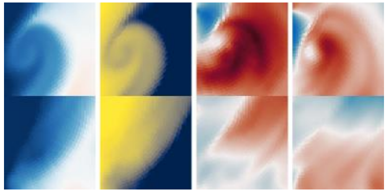

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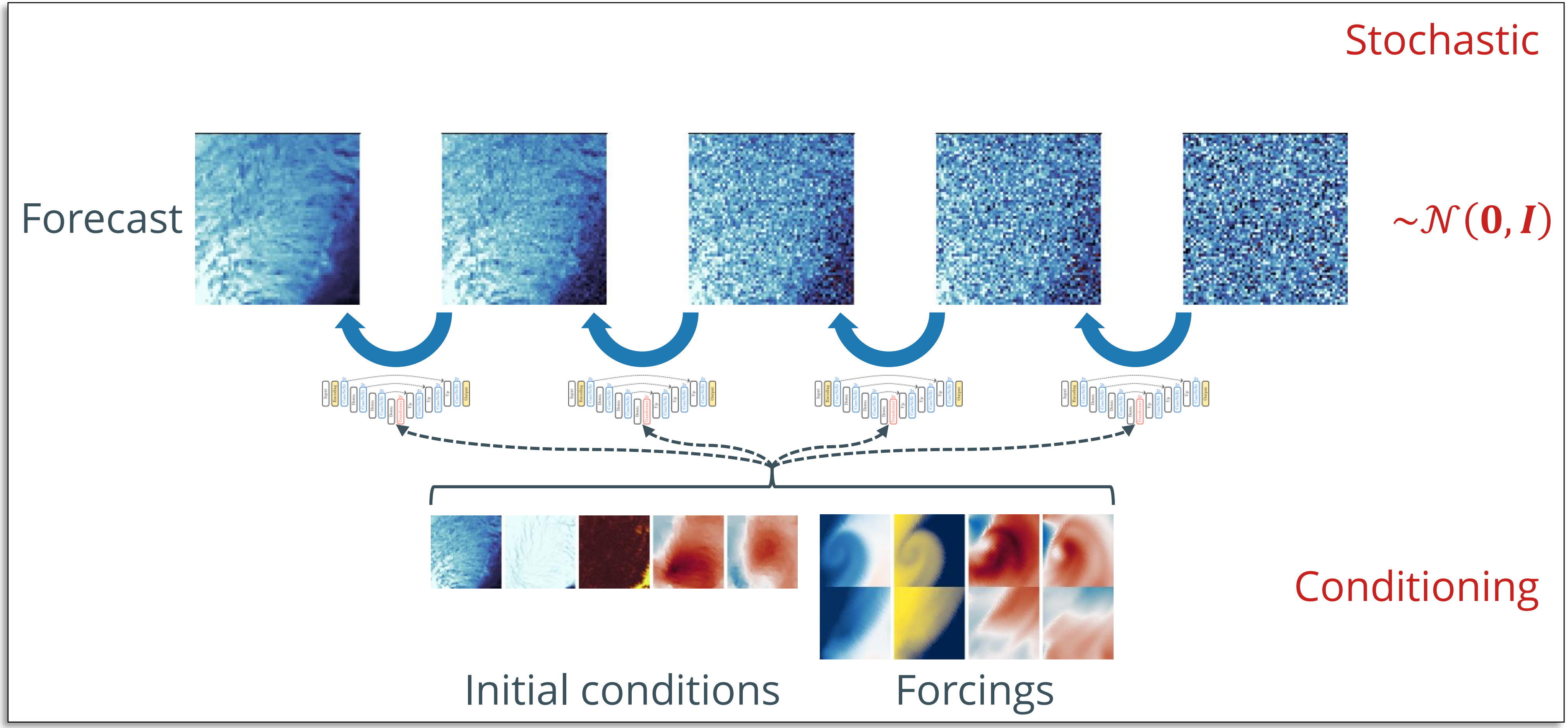
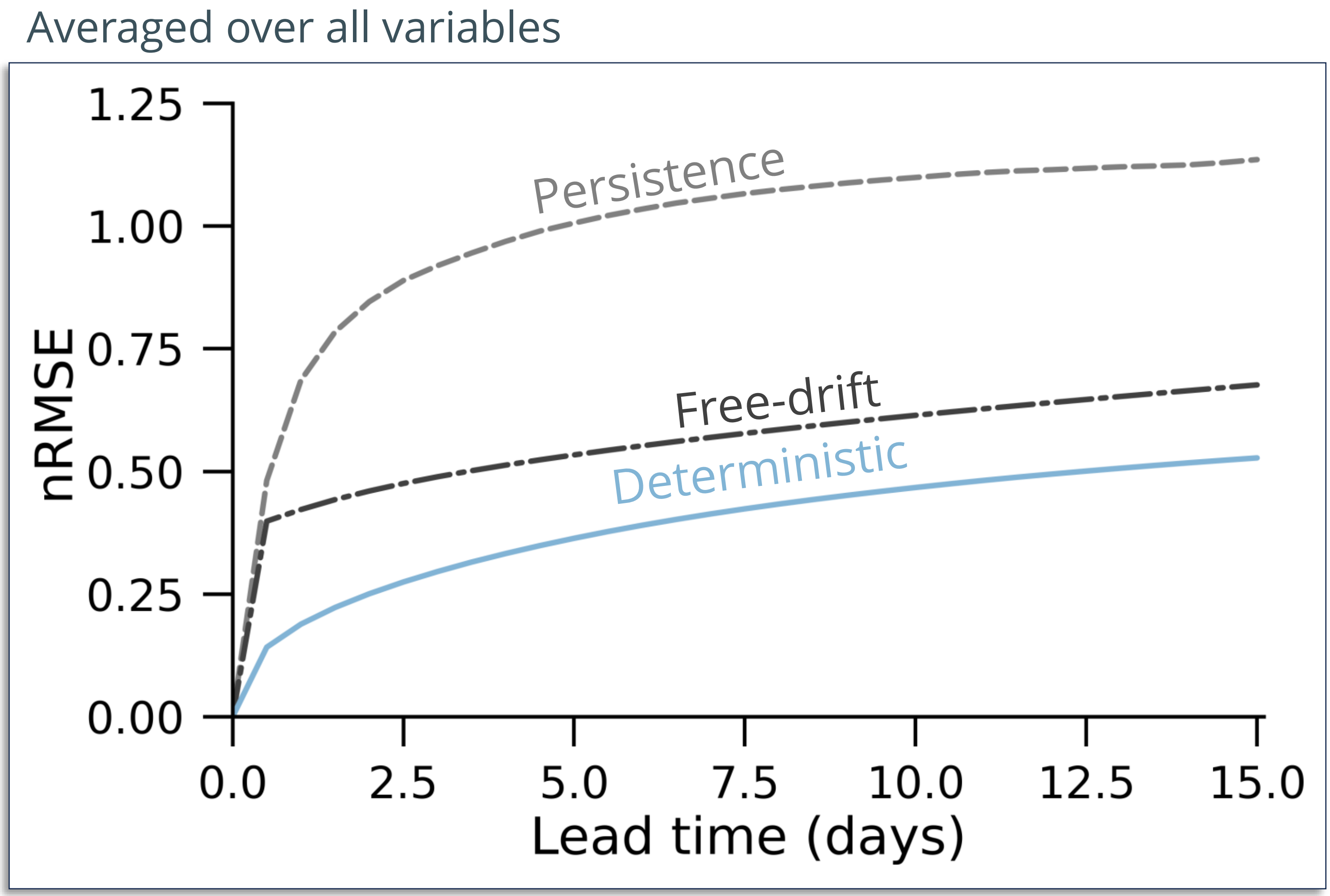
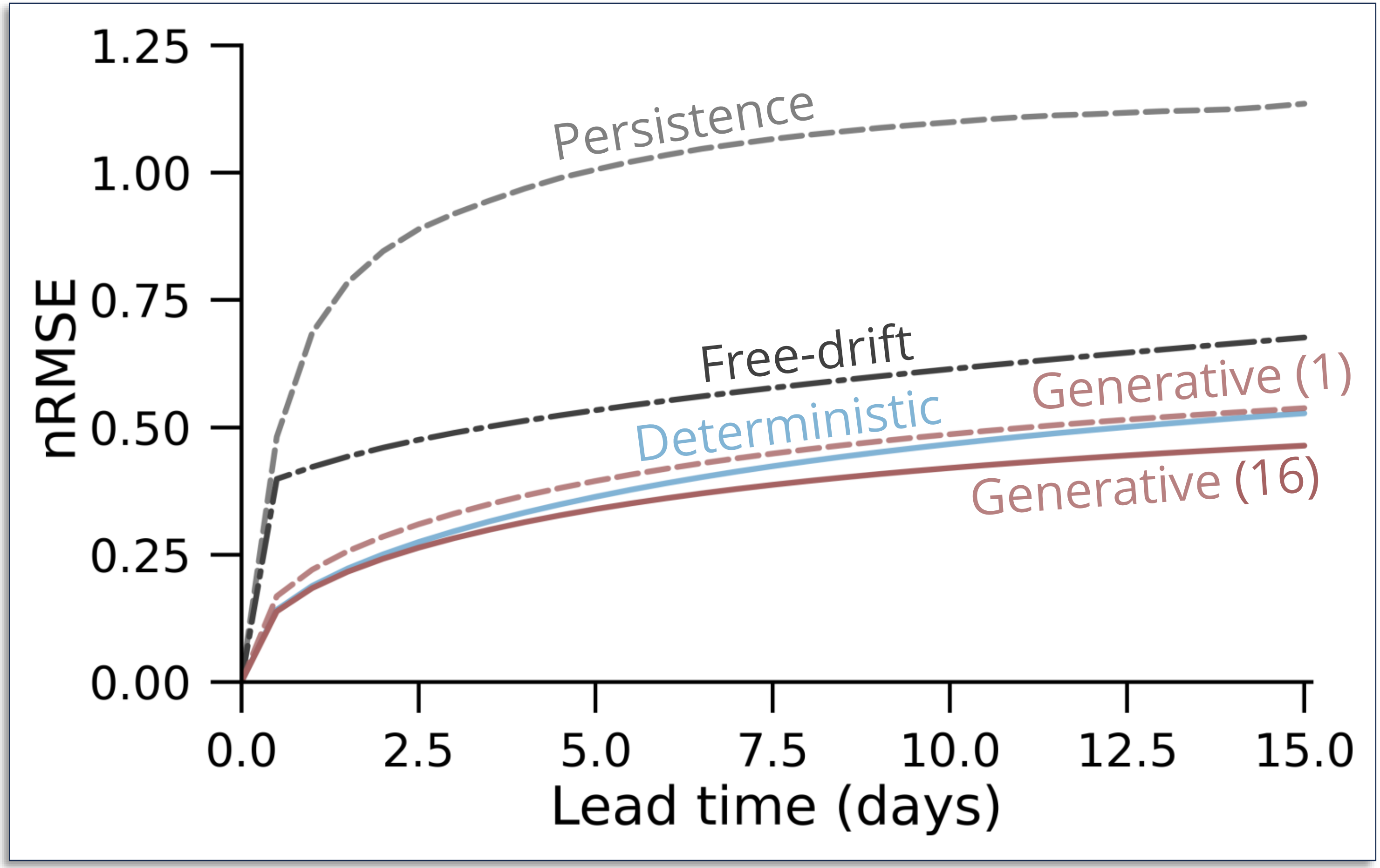


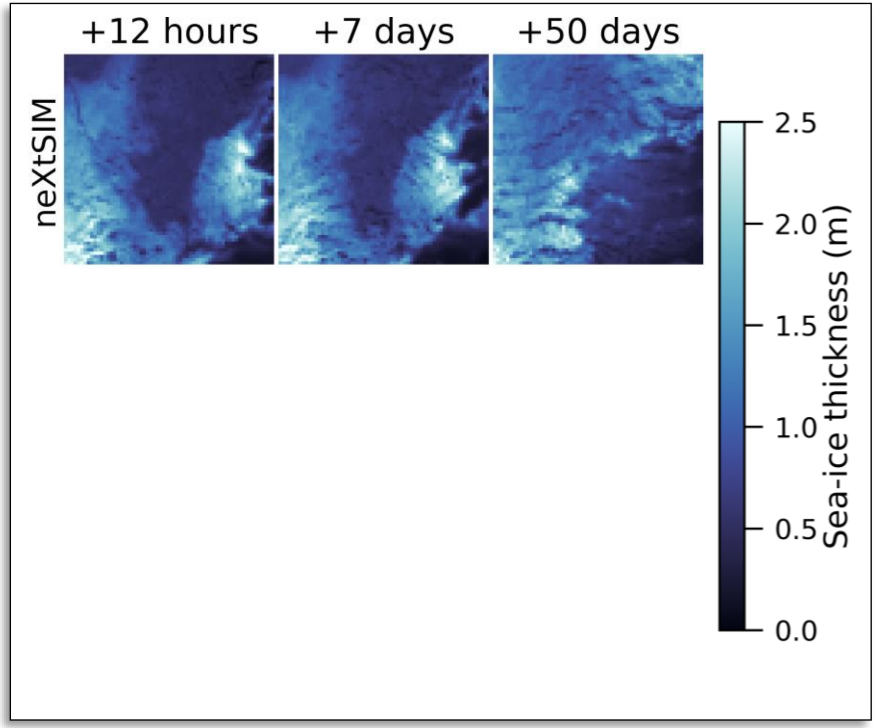
Neural network baseline works ...



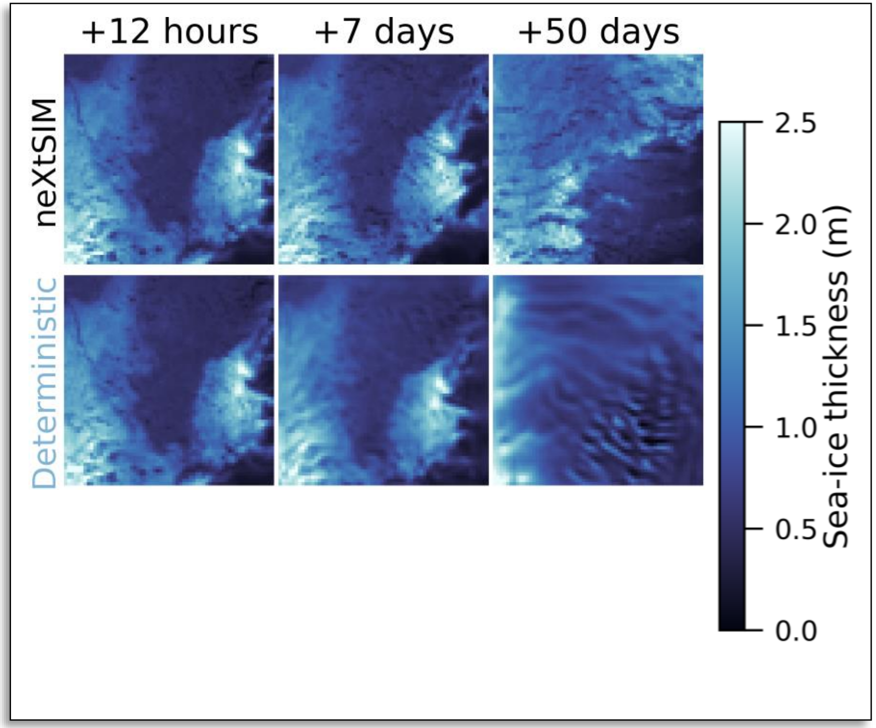
… but ensemble with generative performs best

Averaged over all variables





+12 hours
+7 days
+50 days
neXtSIM
2.5
2.0
1.5
1.0
0.5
0.0
Sea-ice thickness (m)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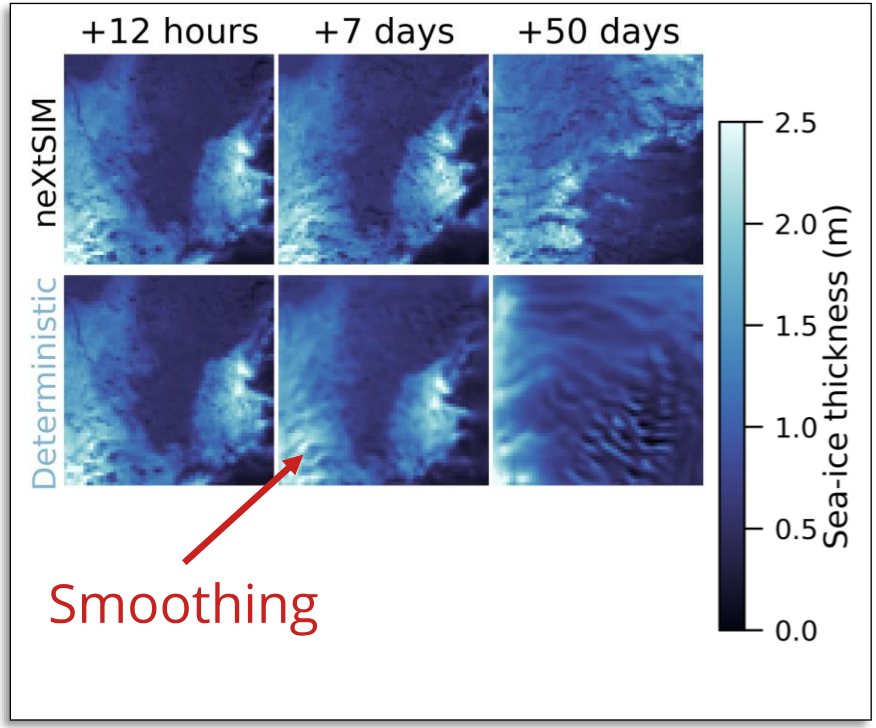

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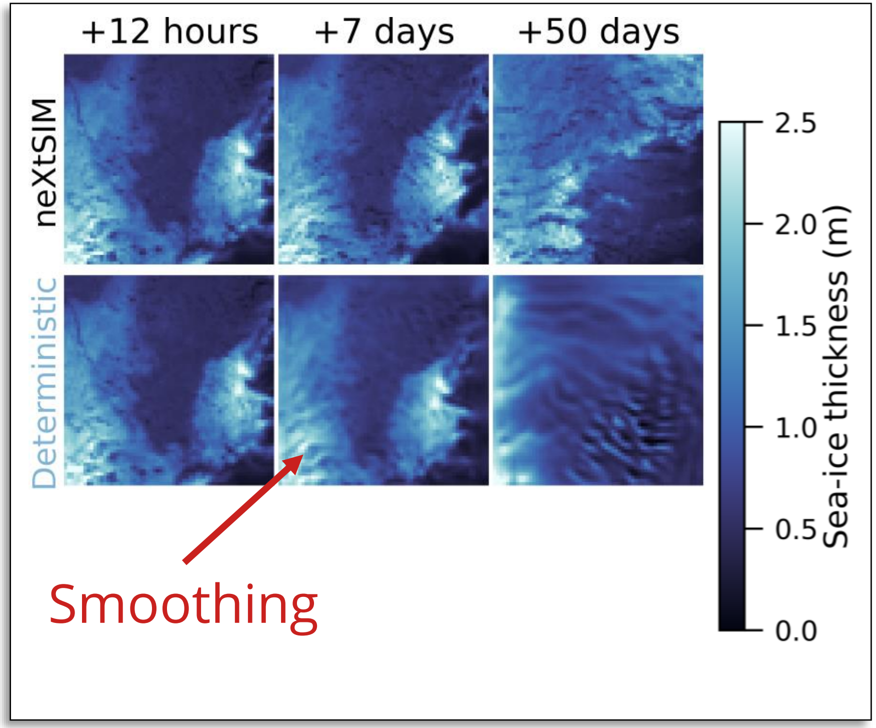
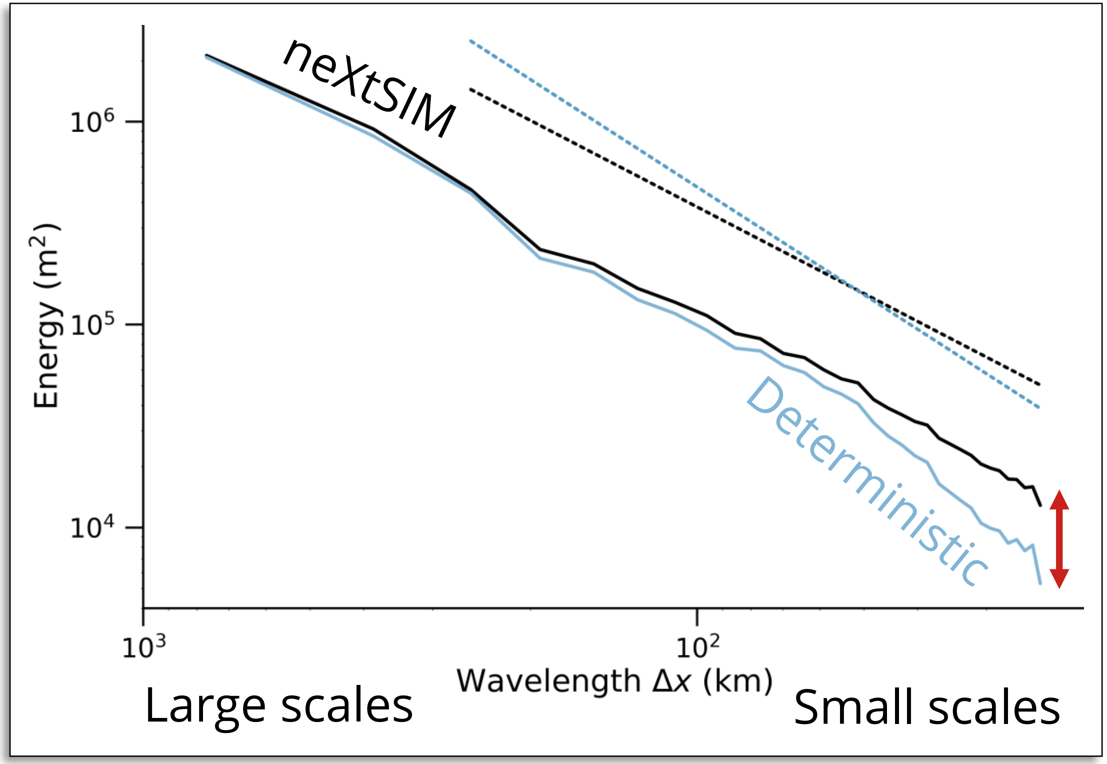
Sea-ice thickness (m)
Smoothing

Deterministic model loses small-scale information …

Similarly found in other emulators (e.g., Durand et al., 2024)





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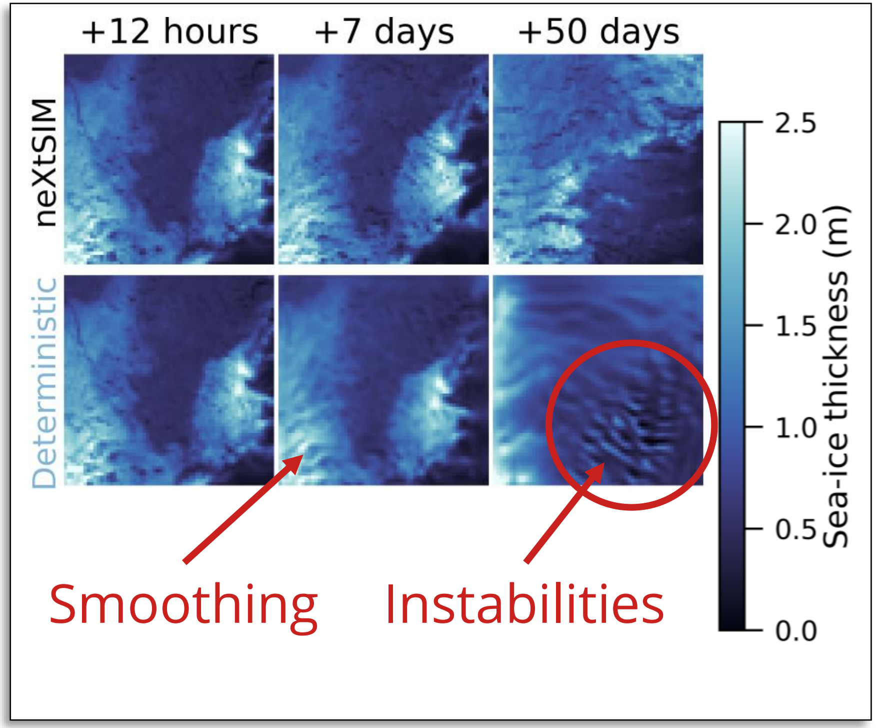
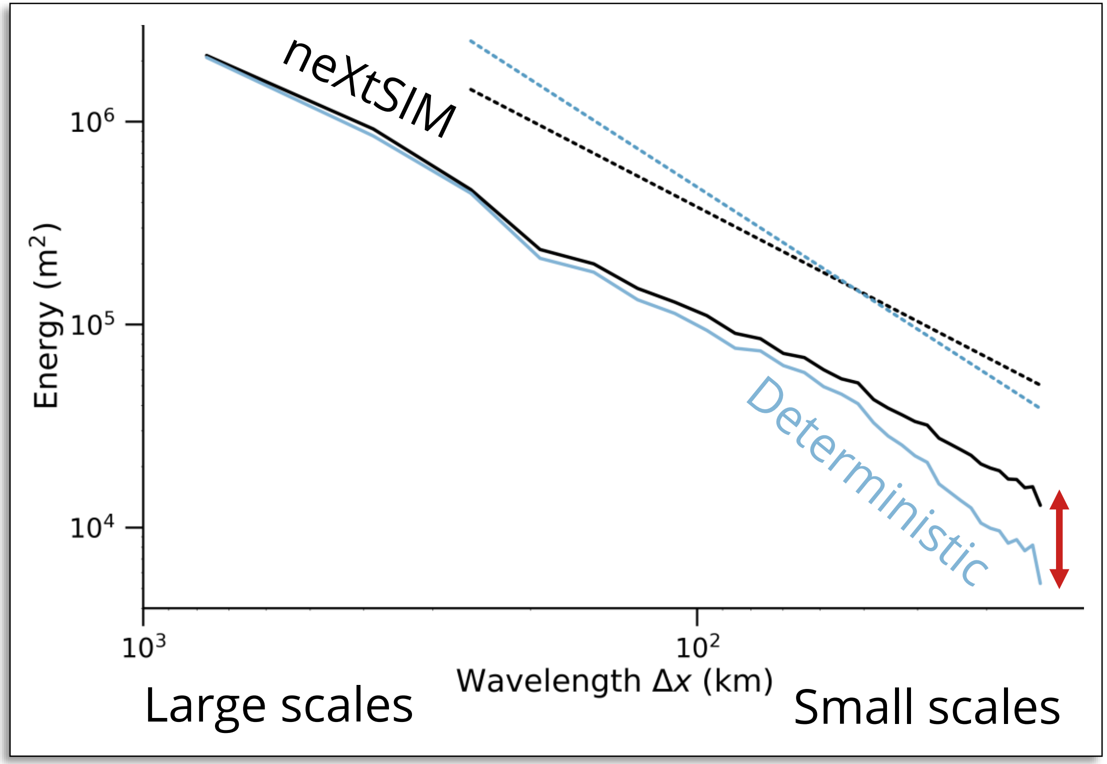
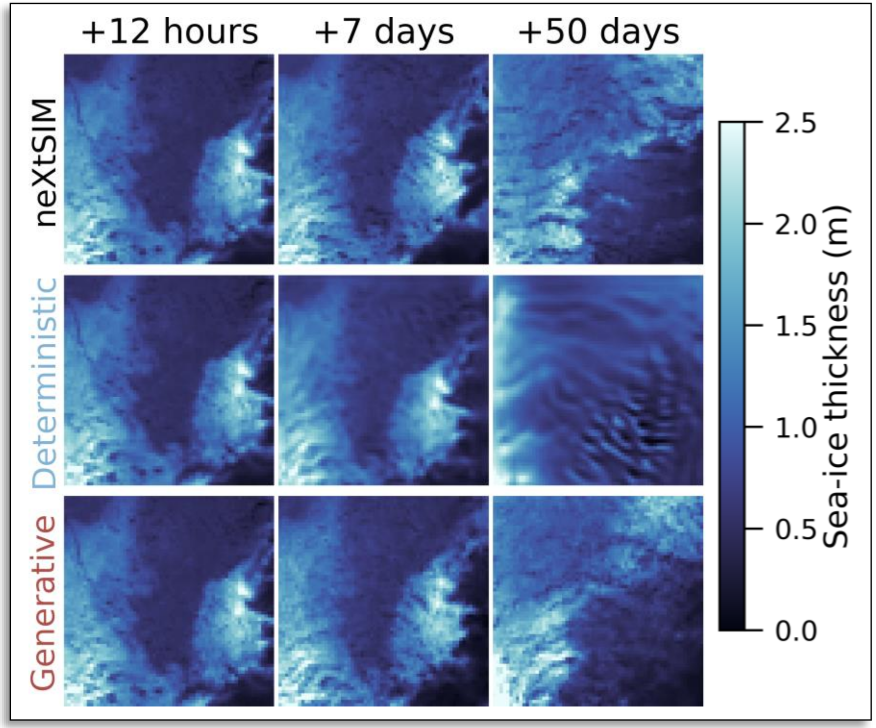
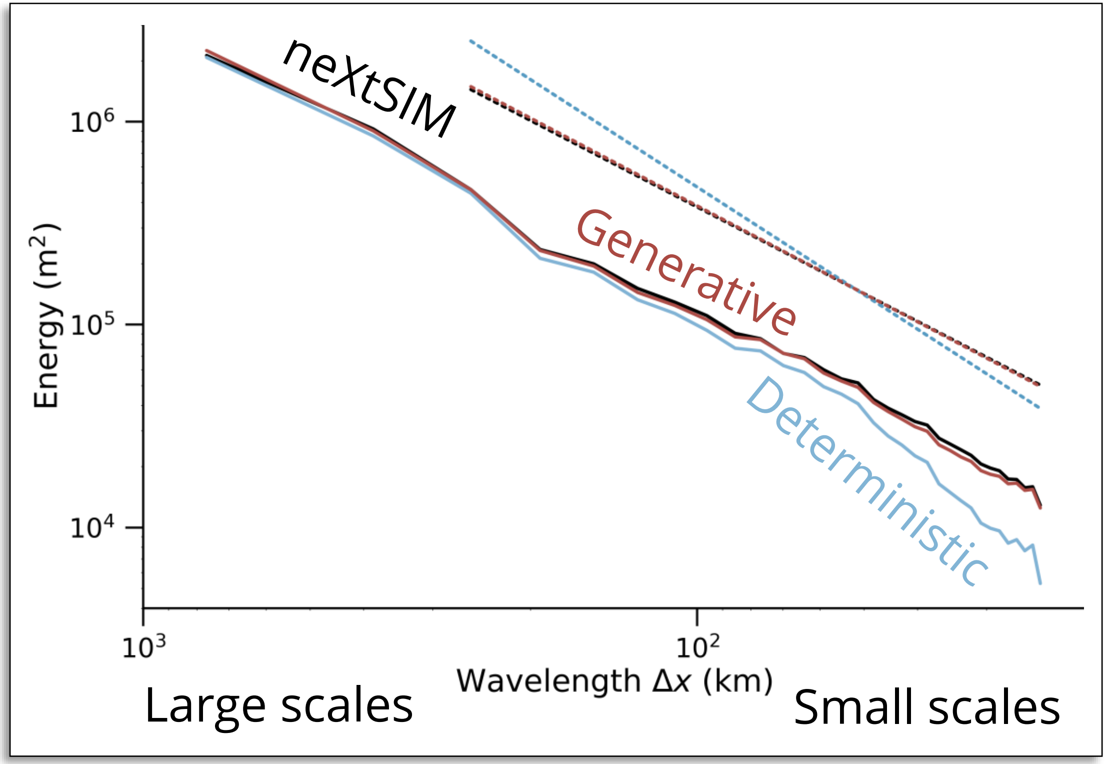




… generative model resolves the problems





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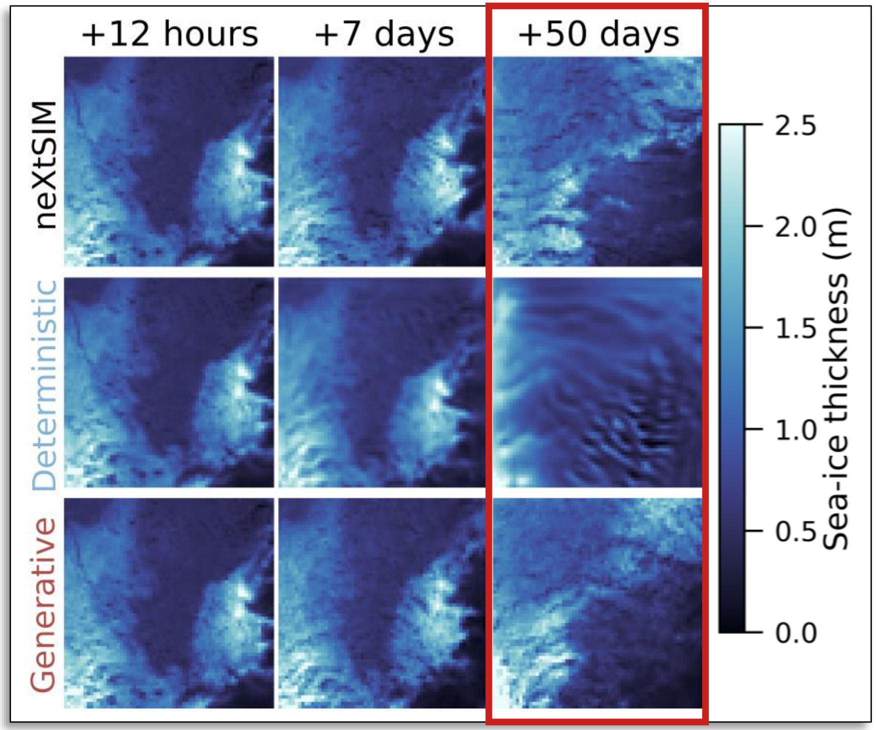
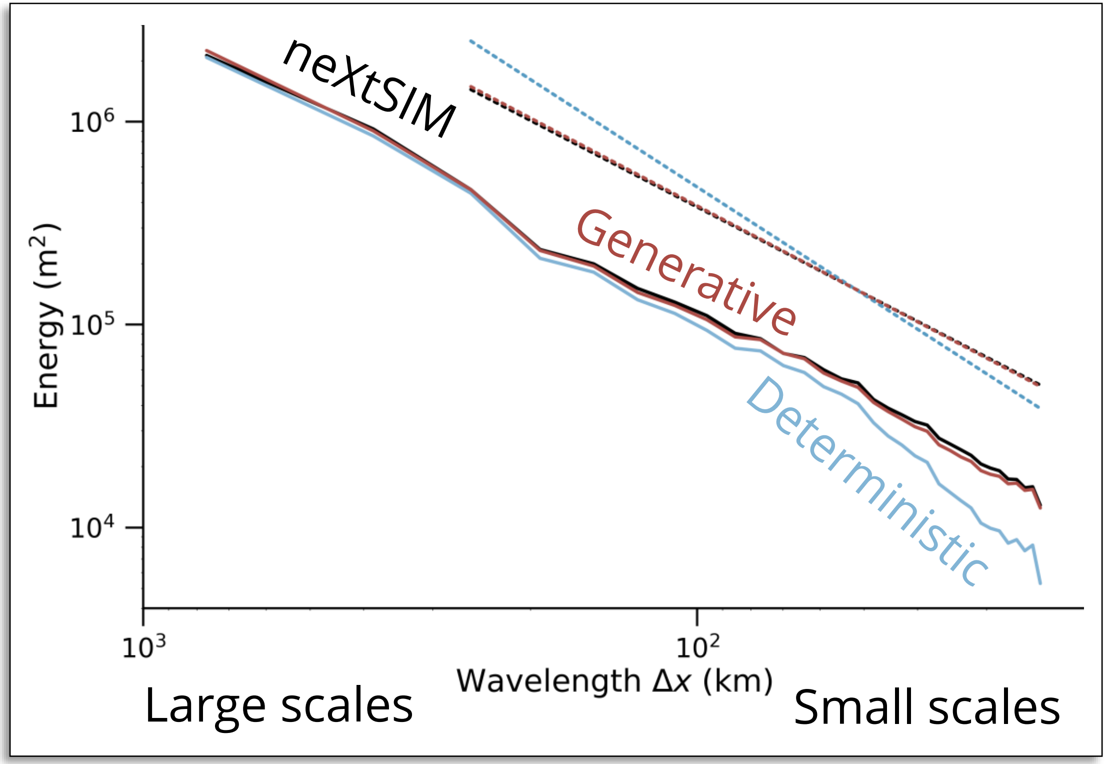
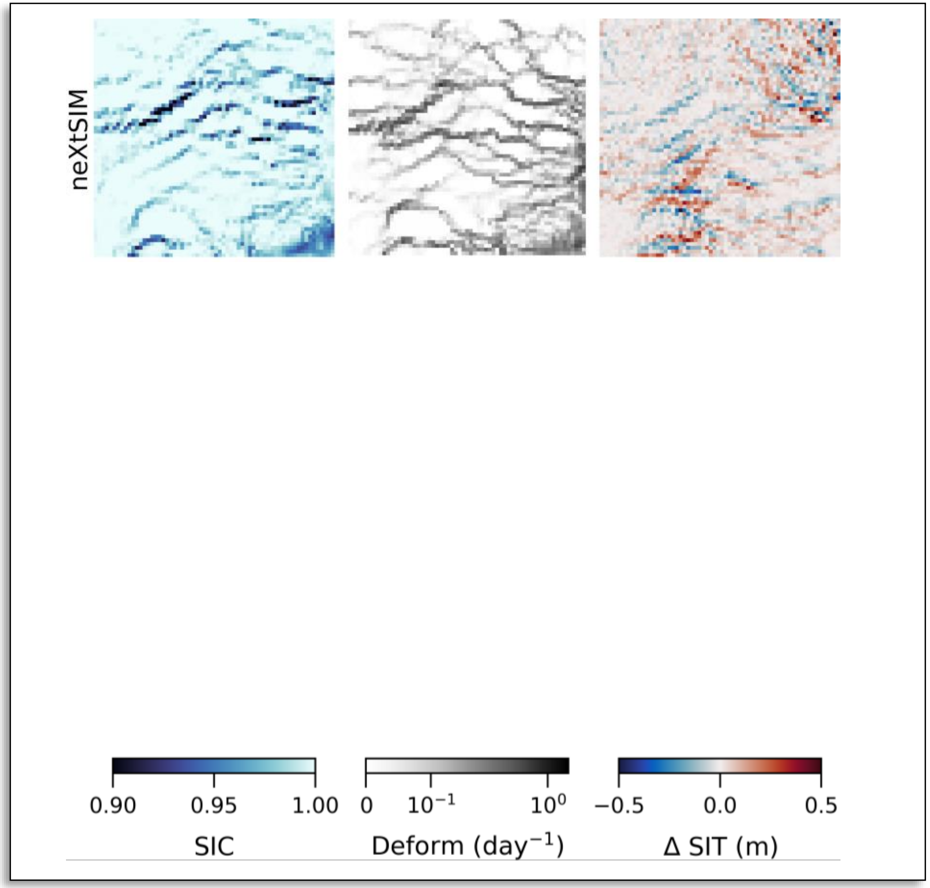




After 50 days



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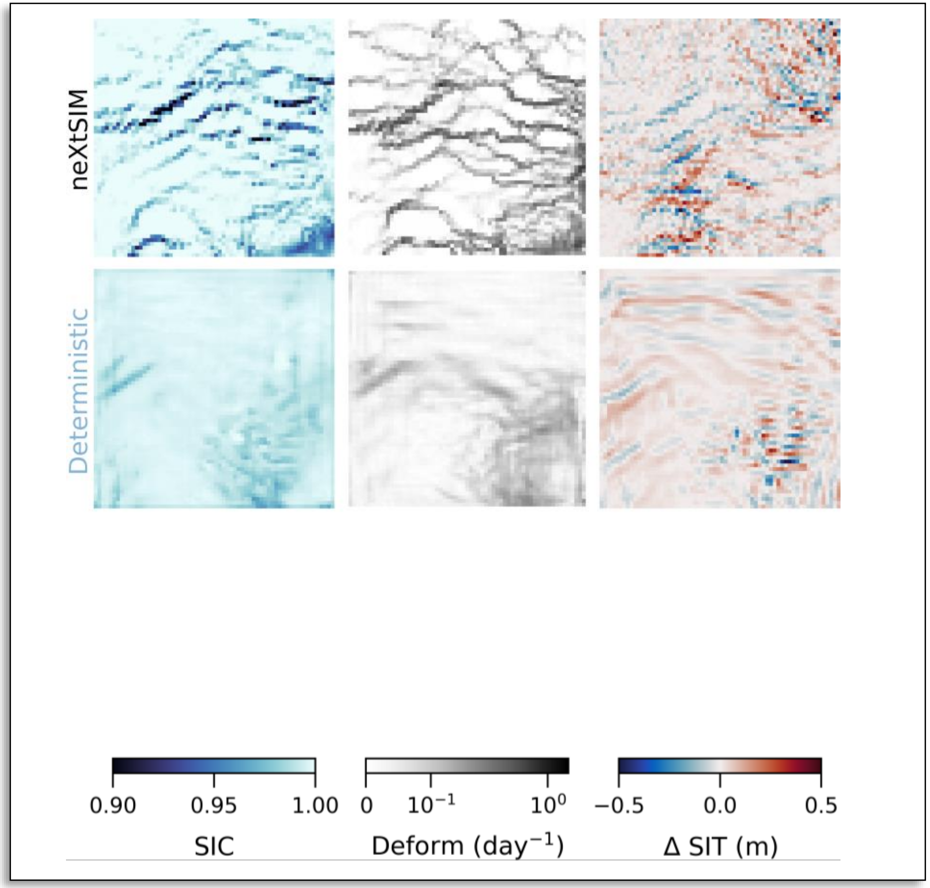

… generative model leads to consistent forecasts

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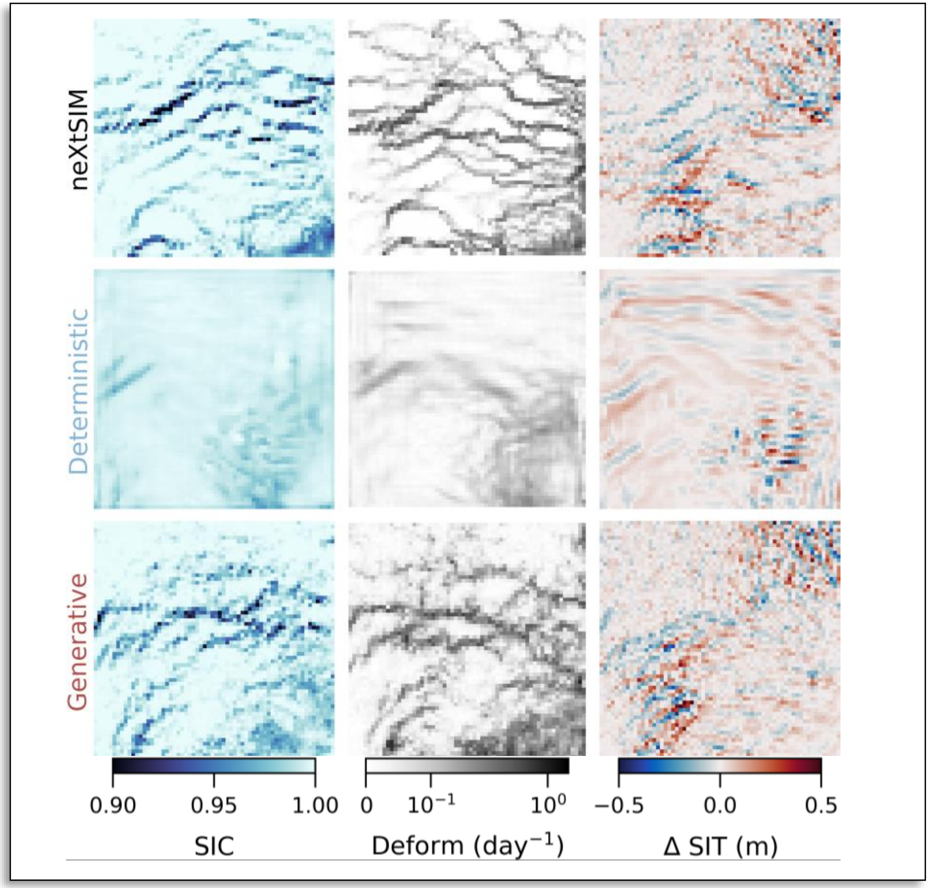

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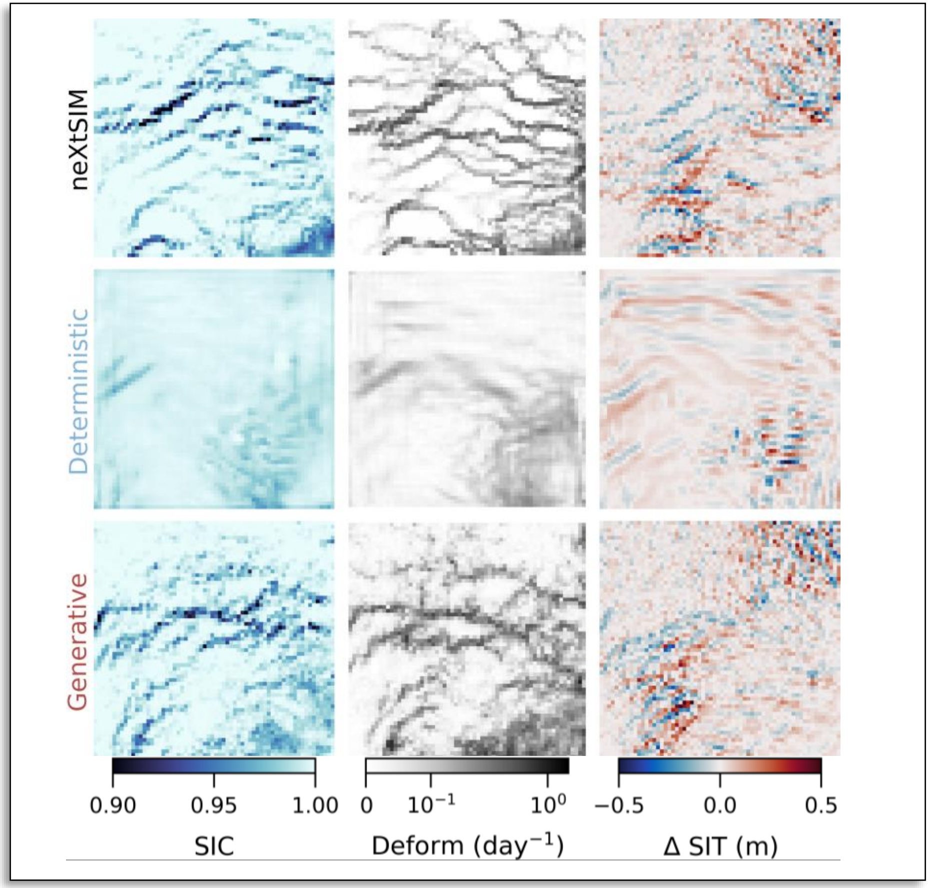

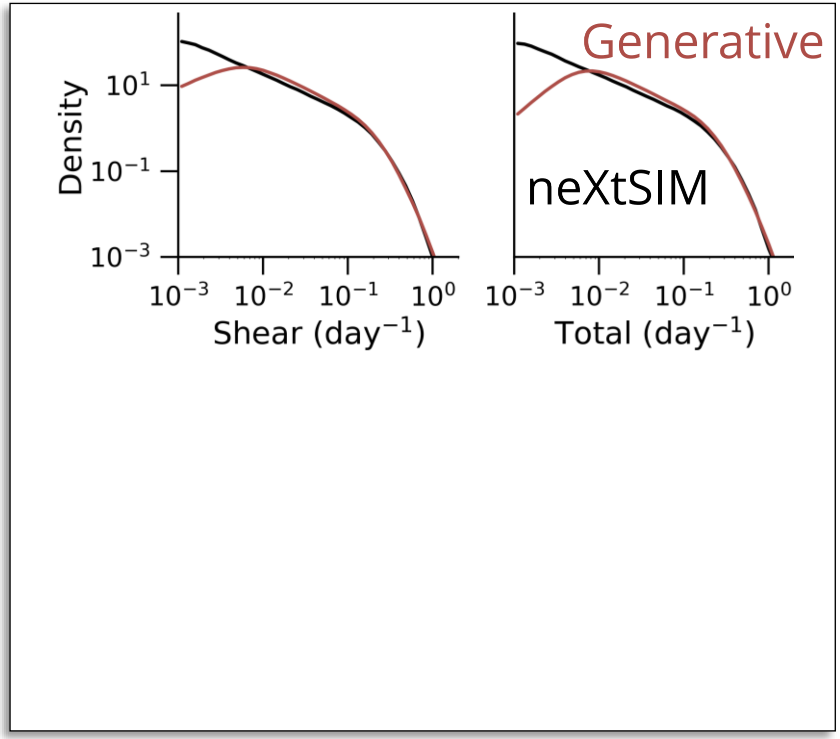

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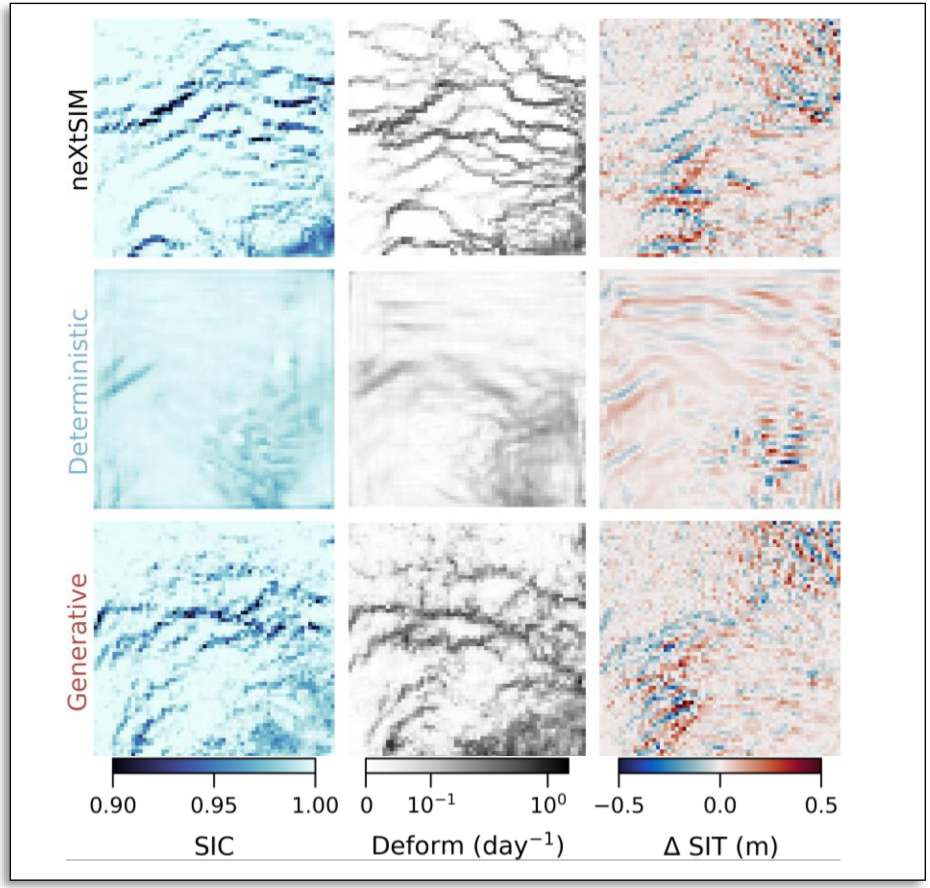
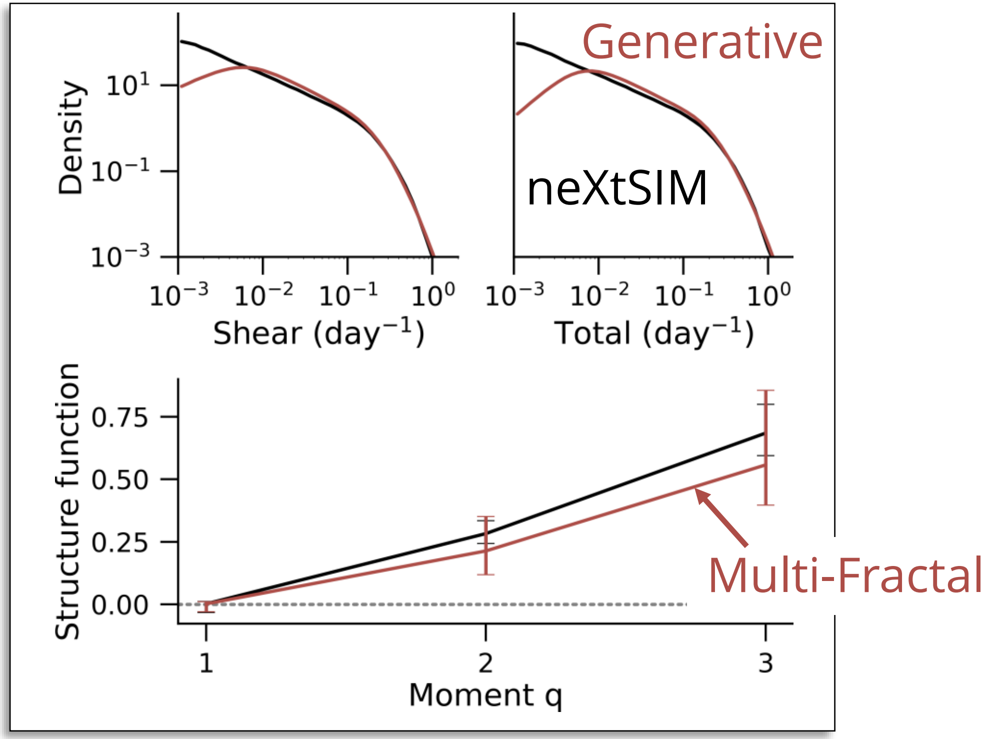
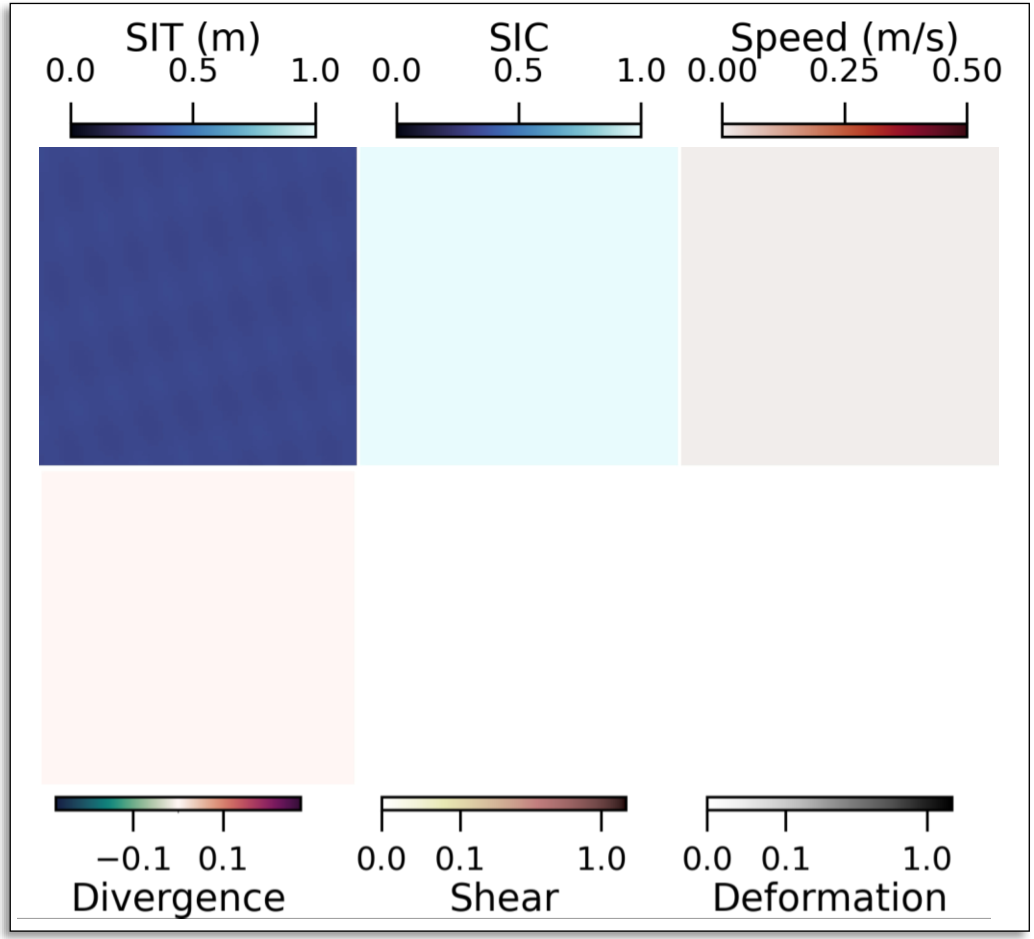




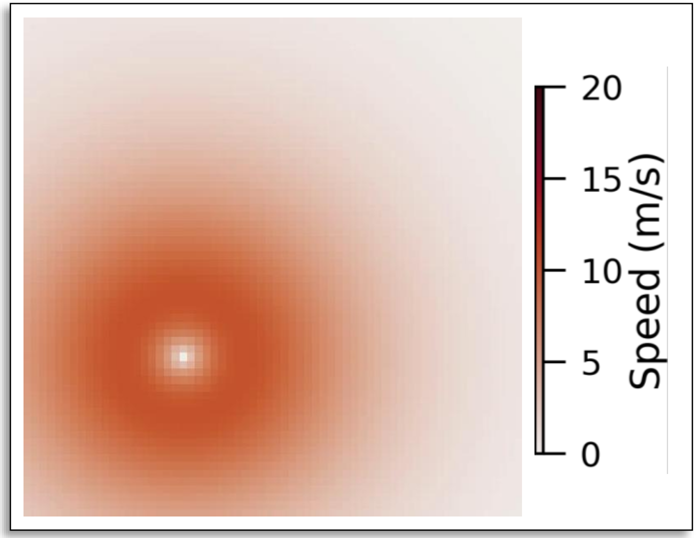
Similar "physical" laws

The model generalizes to idealized cases

Simulation



Wind forcing



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Goal: 12h prediction < 1 s, train/run on a single consumer GPU, linear scaling

Preliminary

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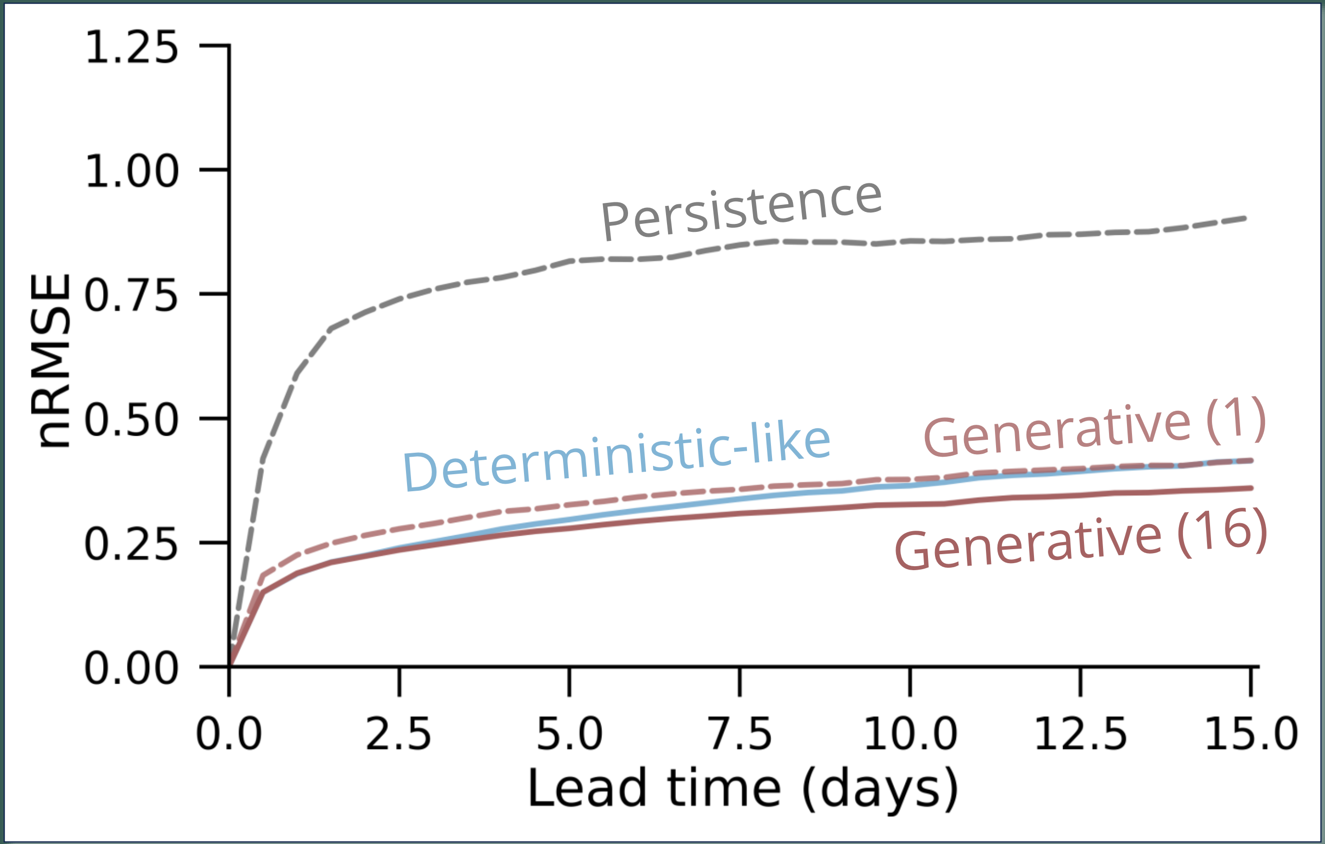

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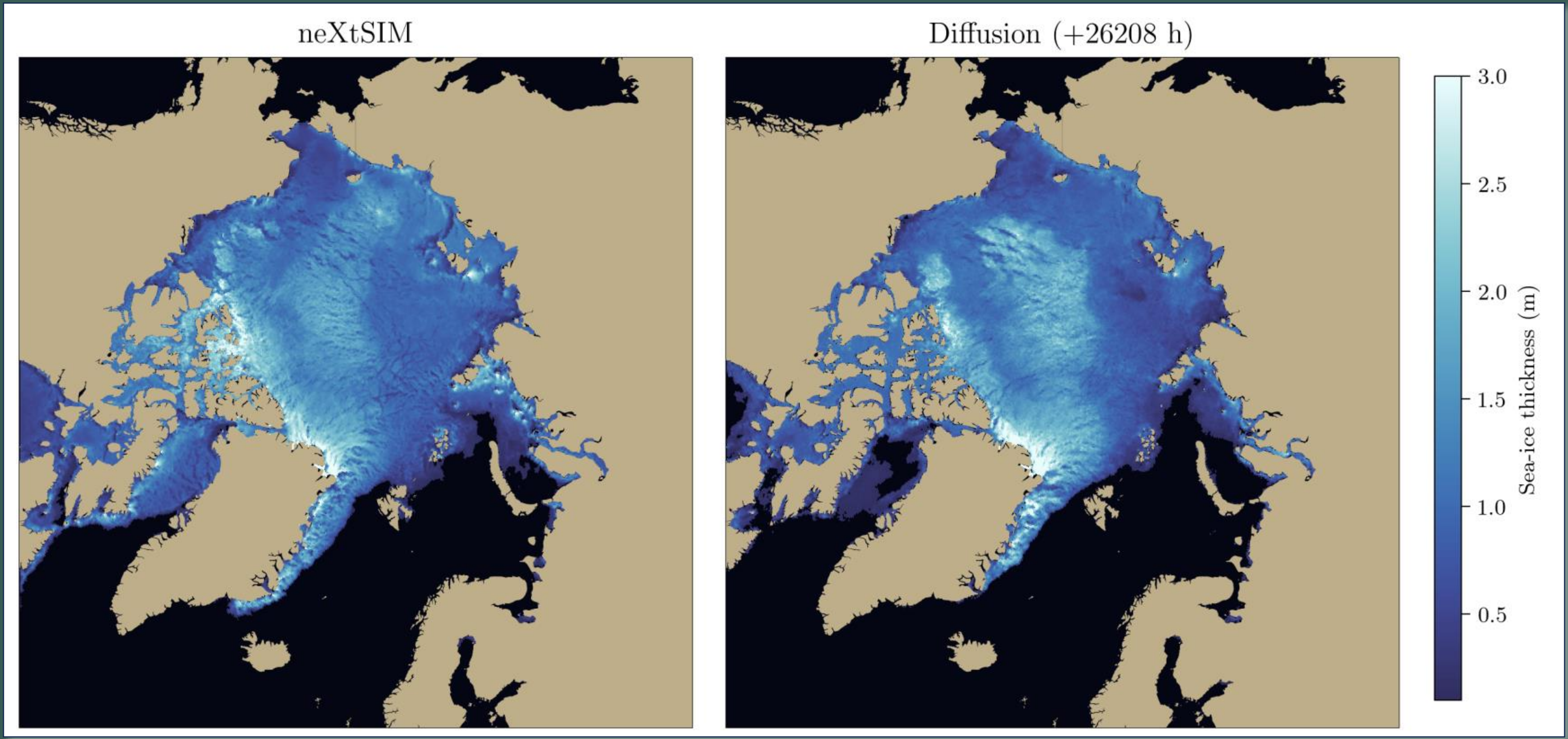

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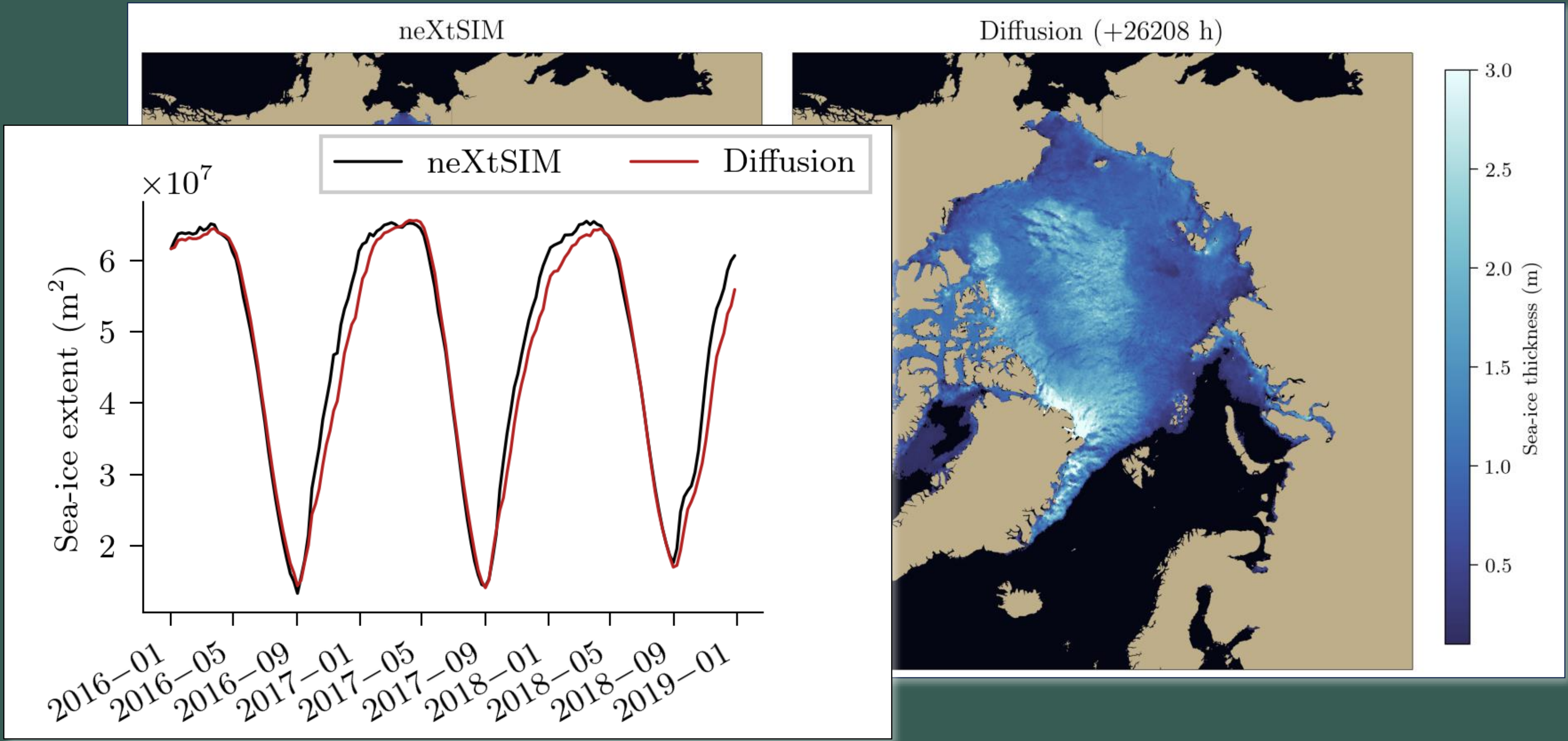

Generative deep learning for sea-ice modelling

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<u>Unlocks</u> improved data-driven modeling
and can be also used for model error corrections

<u>Exhibits</u> physical consistent forecasts
maintaing the sharpness + scaling laws

<u>Learns</u> efficient Arctic-wide models
similar results + stable for several years

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Do you have questions?

(tobias.finn@enpc.fr)