# Four-dimensional variational data assimilation with a sea-ice thickness emulator

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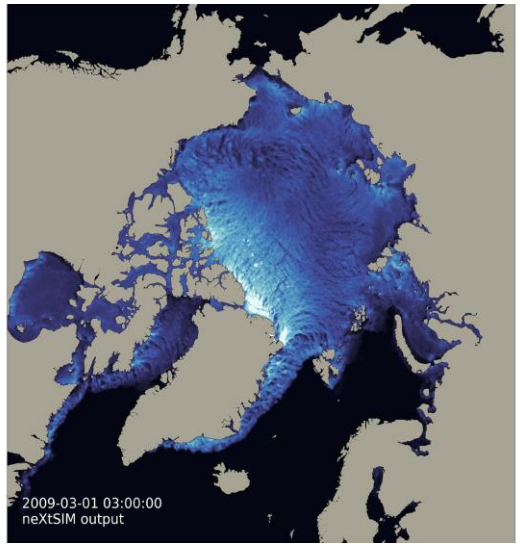
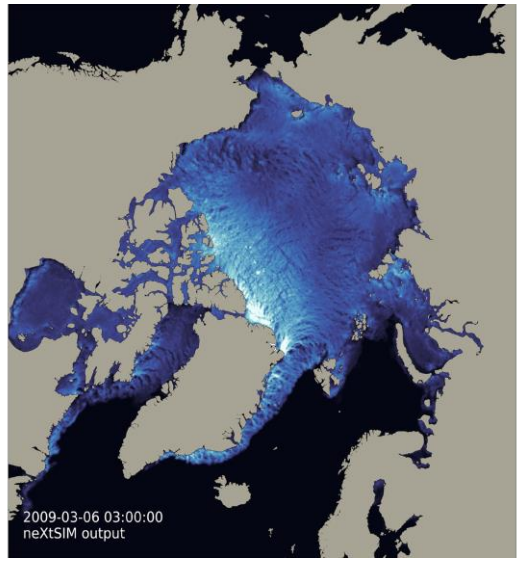
# Building an emulator for neXtSIM SIT

neXtSIM is a Lagrangian sea-ice model, based on brittle Bingham-Maxwell rheology,
Guillaume Boutin [1] has coupled it to an ocean model to create ~12km simulation running from 1995 to 2018




**Neural Network**
**?**

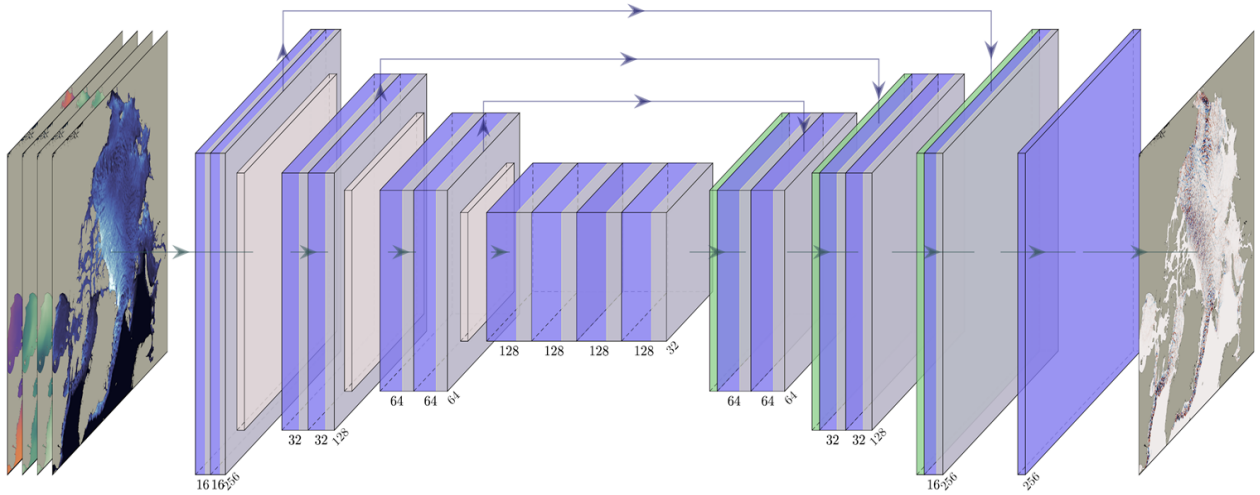



[1] Boutin, G., Òlason, E., Rampal, P., Regan, H., Lique, C., Talandier, C., Brodeau, L., & Ricker, R. (2023). Arctic sea ice mass balance in a new coupled ice–ocean model using a brittle rheology framework. The Cryosphere, 17 (2), 617–638.

# Emulating neXtSIM SIT with a NN

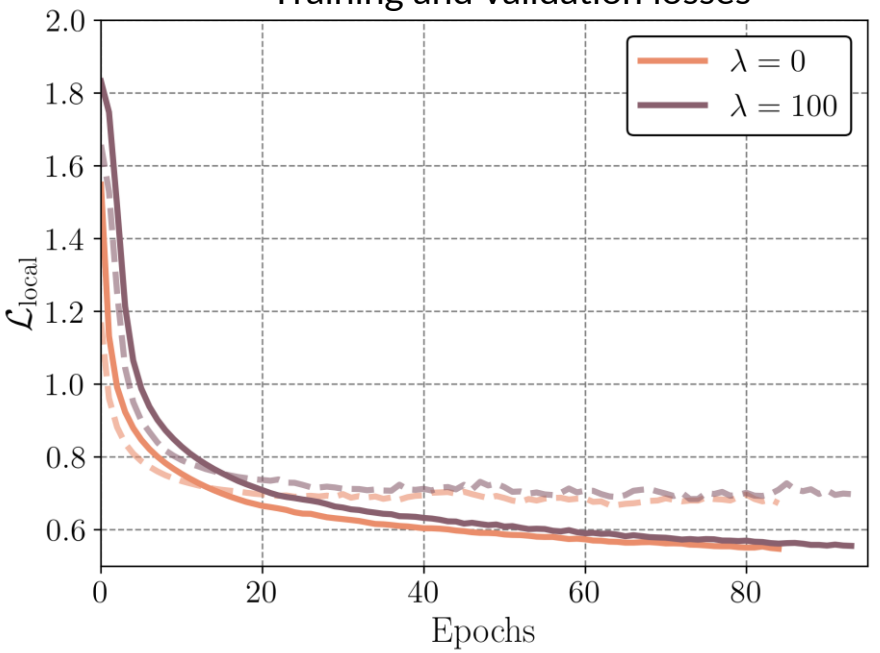
Training a NN to predict 12 hours dynamics

Paper

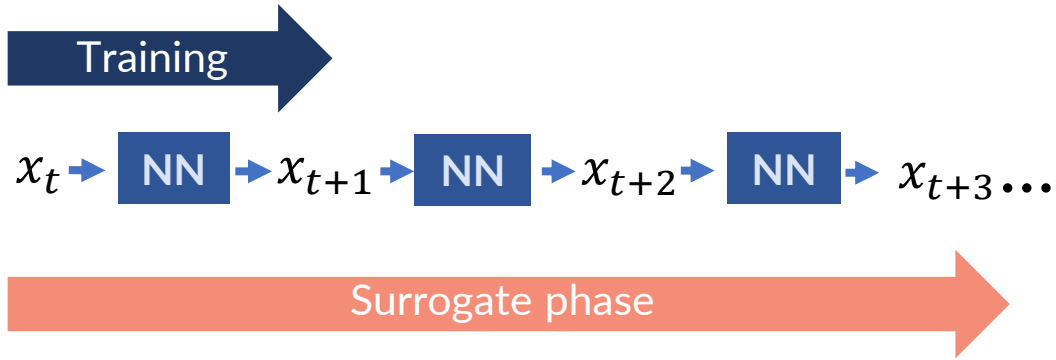


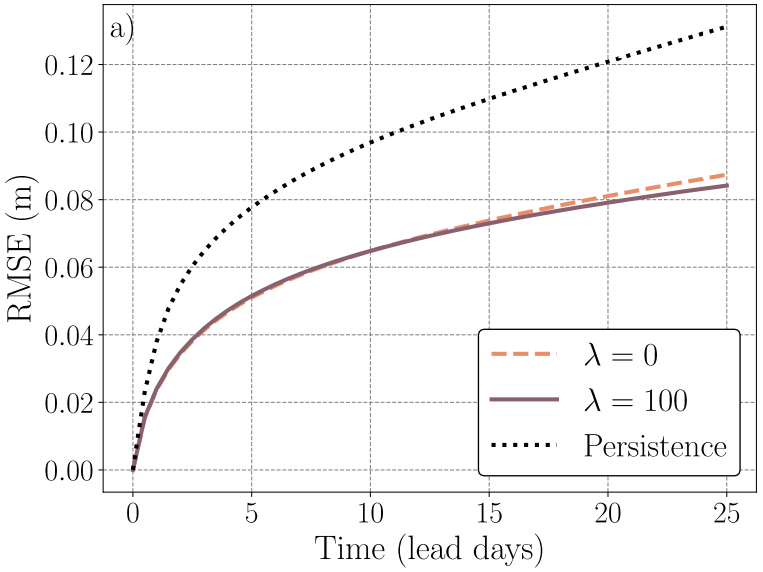

UNet based architecture
Additionnal ERA5 atmospheric forcings (U10, V10, T2M at t, t+6h, t+12h)
NN is constrained within the loss to minimize the bias error ($\boldsymbol{\lambda}$)

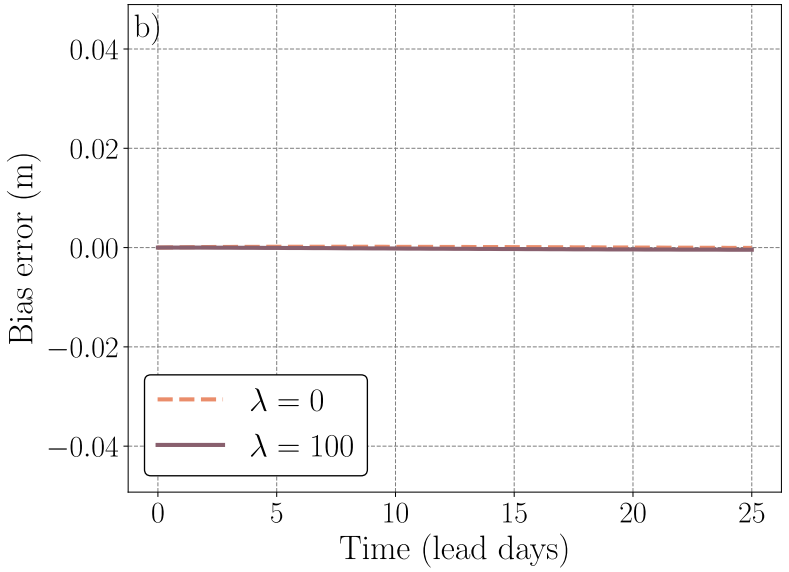
Training and validation losses



# Emulating neXtSIM SIT with a NN

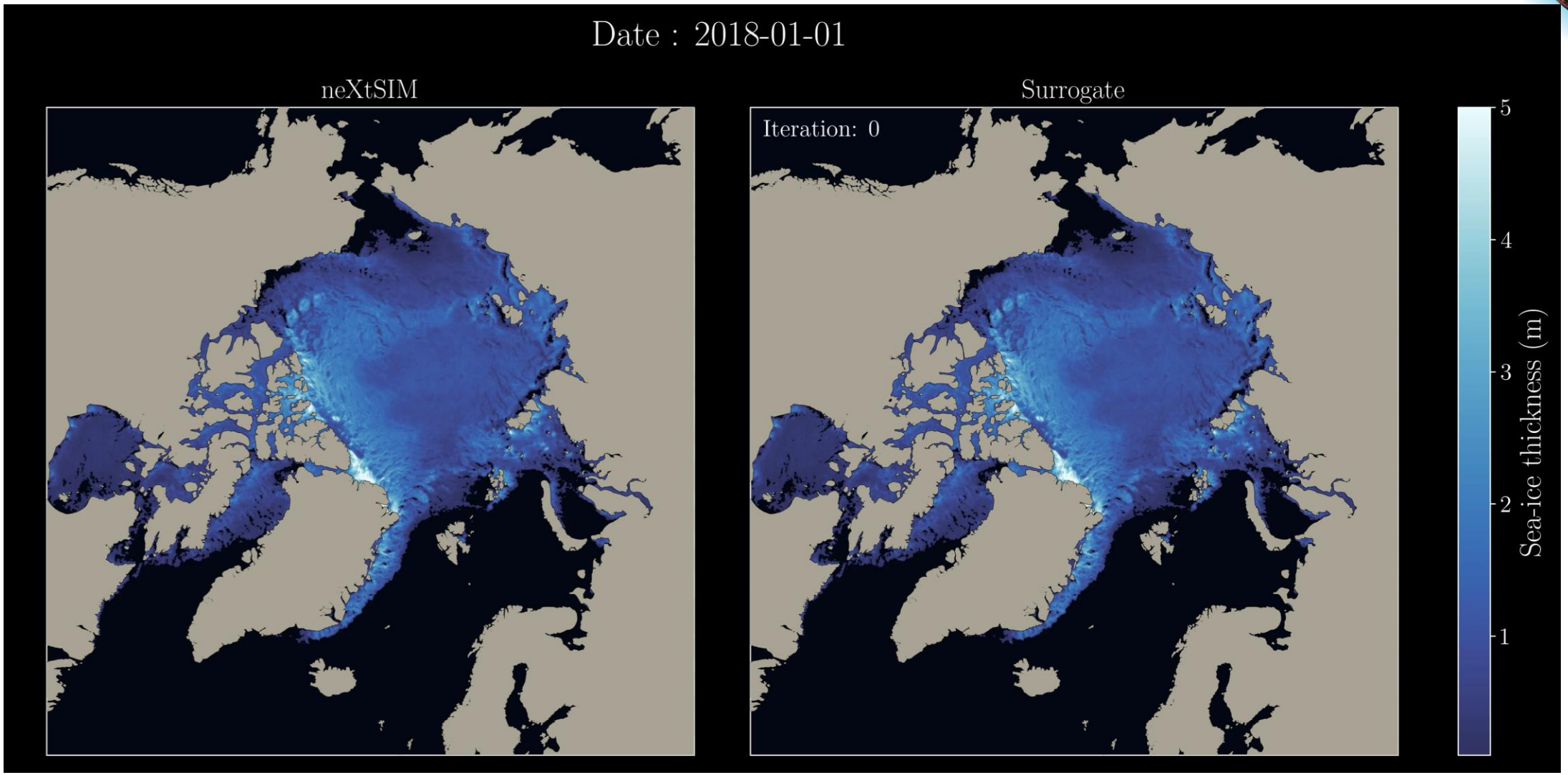



Constraining the bias during training significantly reduce the bias spread in inference stage

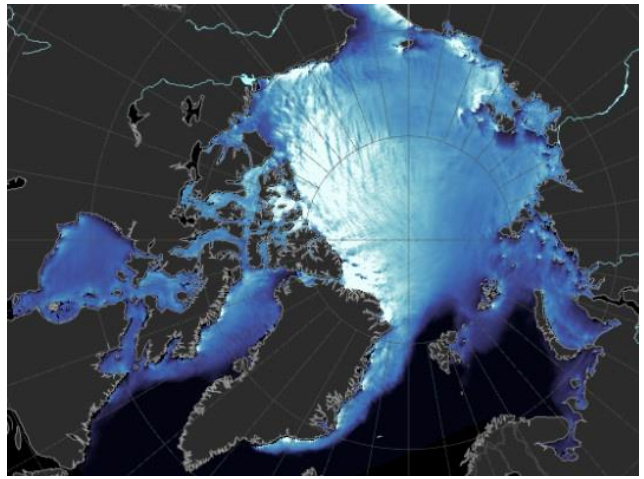
# Year-long forecast



# 4D-Var: the use of the adjoint for DA

## ENKF based methods

State of the art DA for sea-ice : ENKF based methods
- Computationnaly expensive (need to run the model for each member)

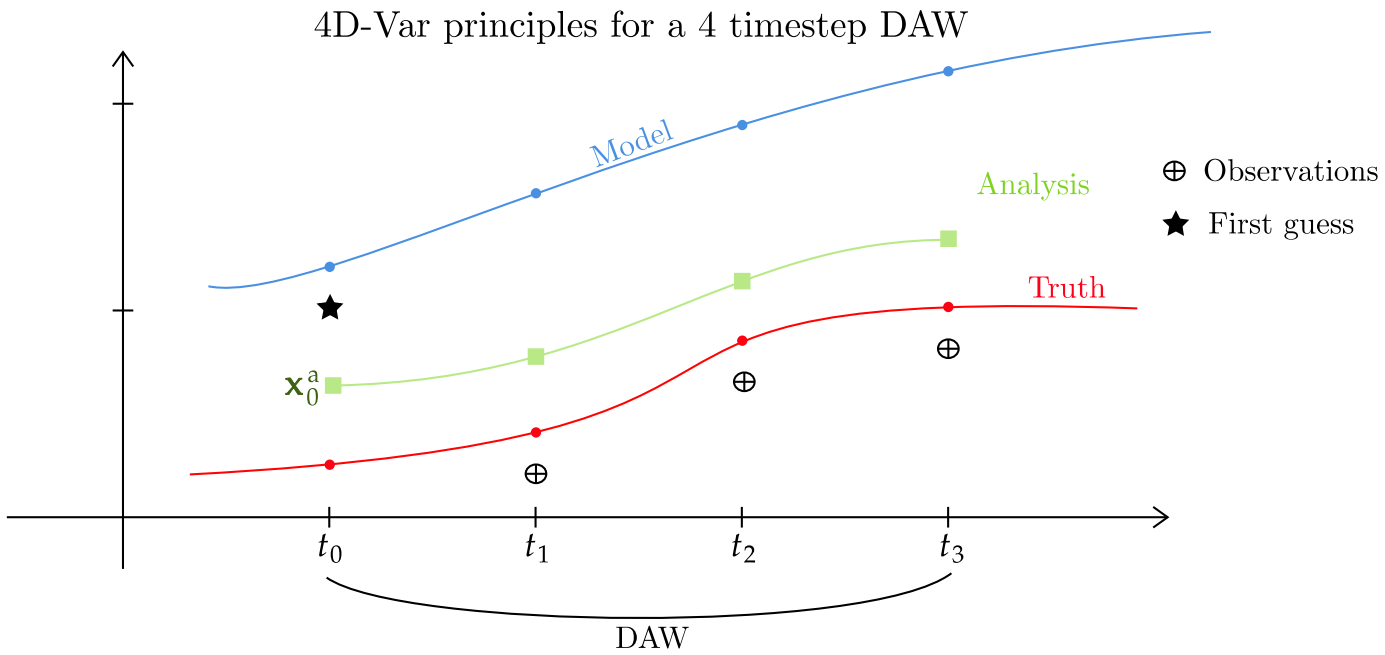


Williams, neXtSIM-F

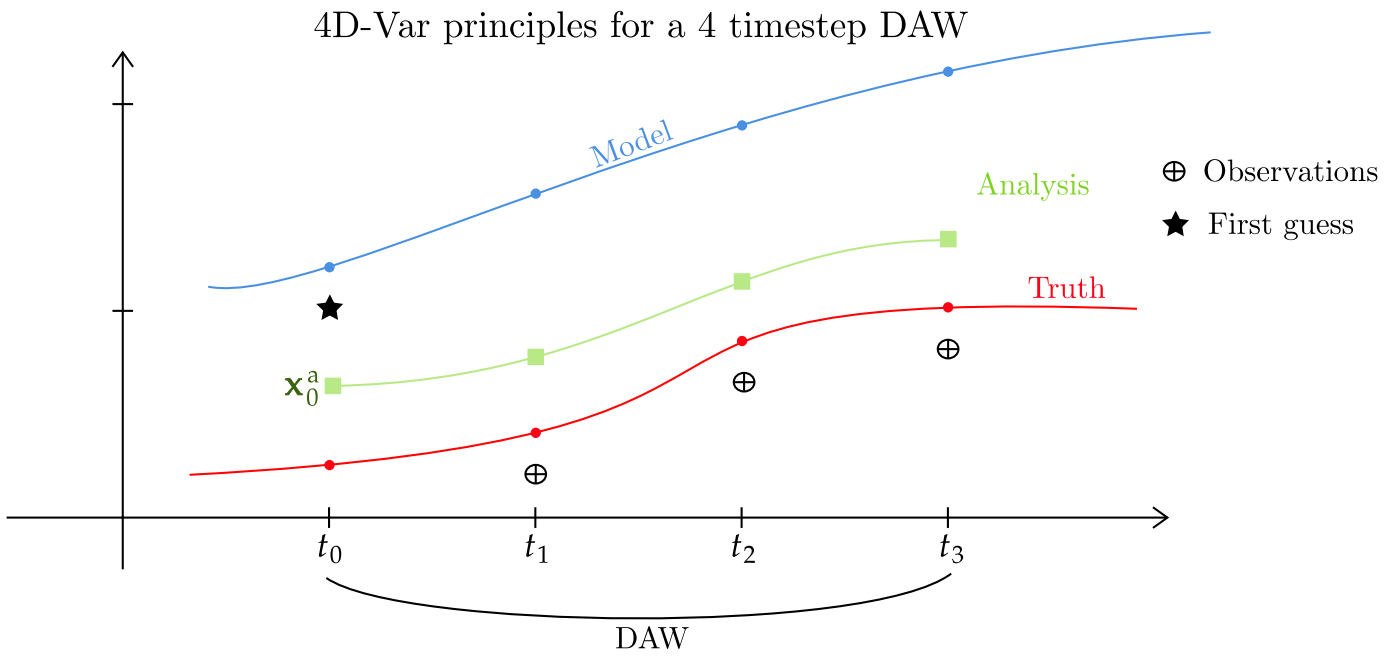
## Variational methods

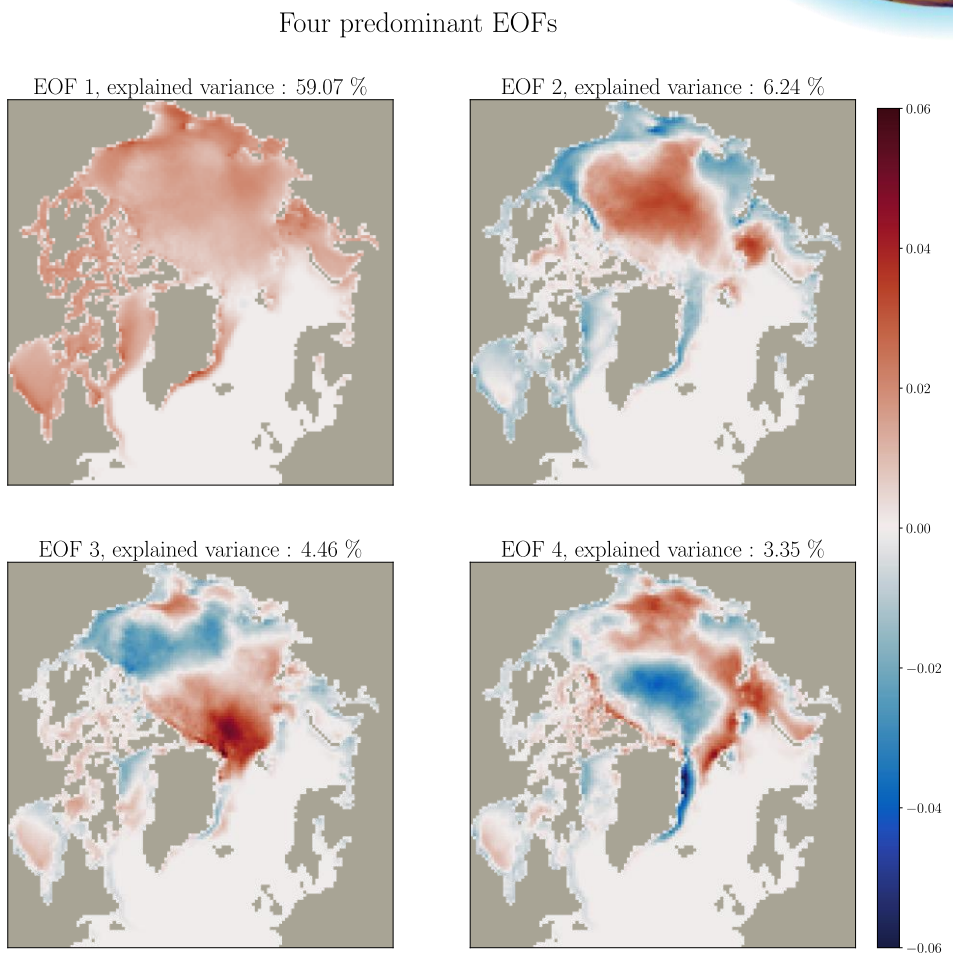
- Cheaper in computation cost, no ensemble statistics
- Need the adjoint of the model

Adjoint 'for free' with a NN



# 4D-Var principles




Minimizing the cost function taking into account the background term and the observations across the DAW

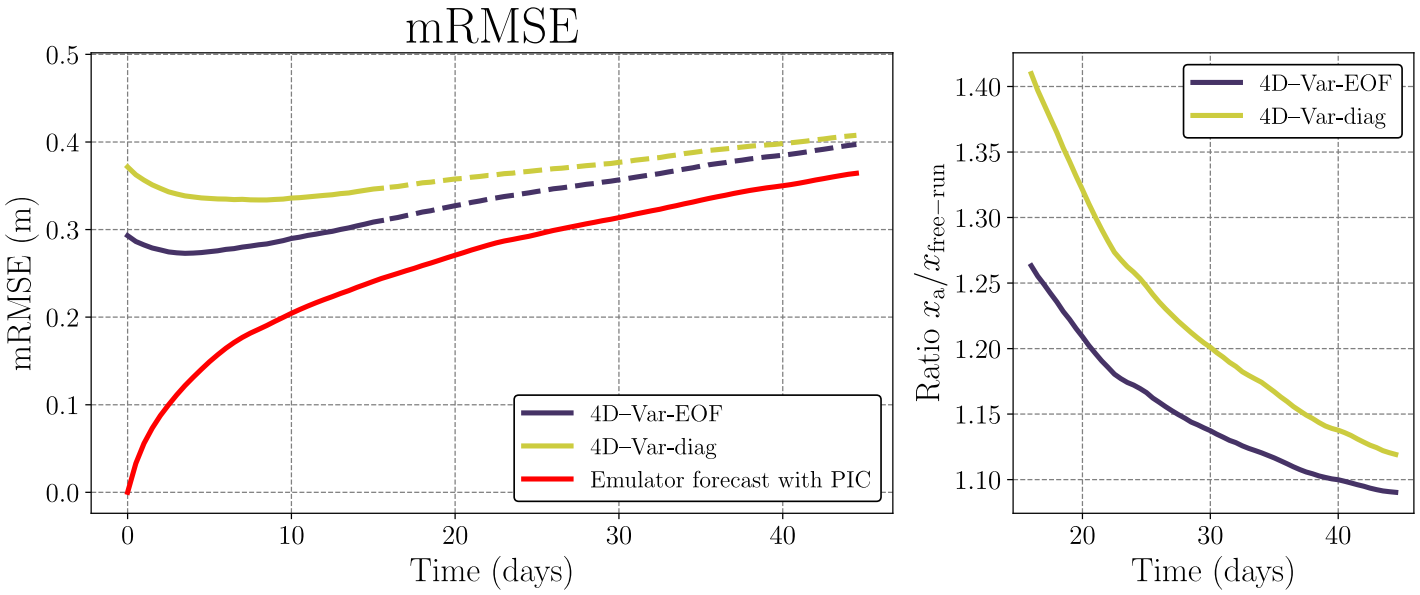
Background term estimation:

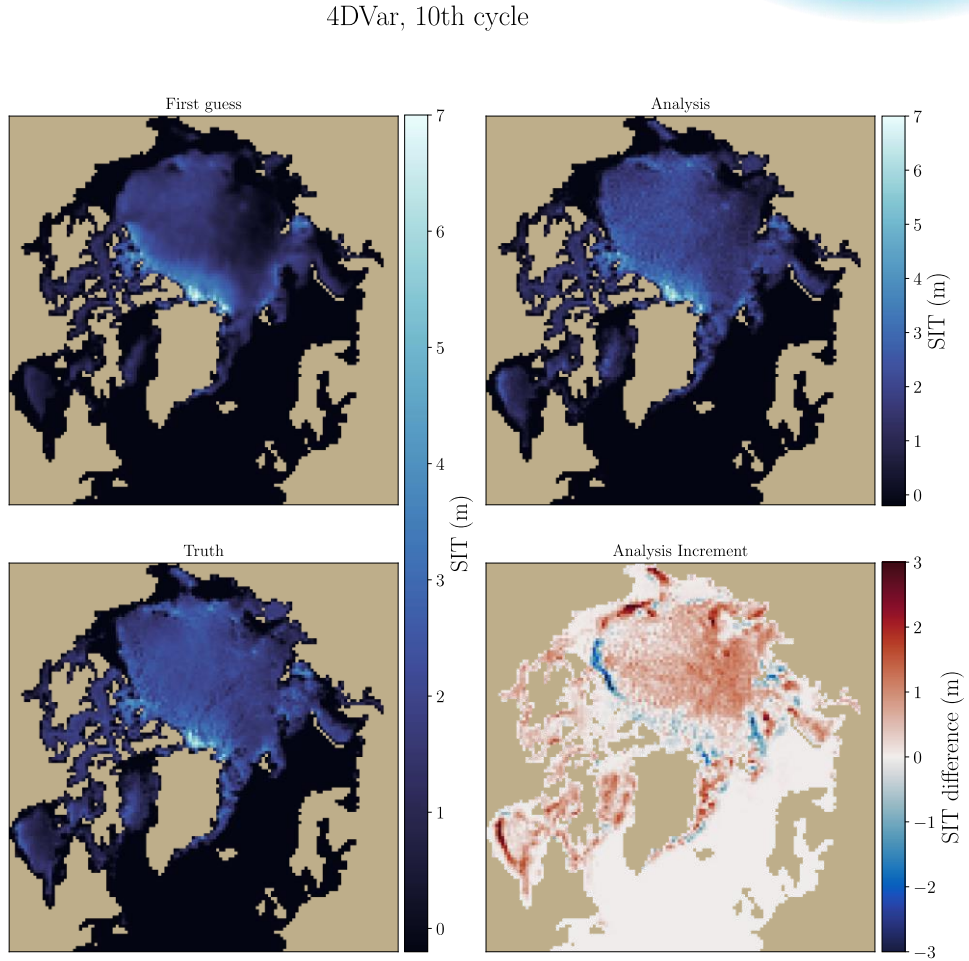
- Classical diagonal B matrix
- Projection onto the EOF of the system

# 4D-Var – twin experiments

16 days assimilation with simulated observations every 2 days for 2017 – 2018
Tuning of the background term with model inflation
Additional 30 days forecast

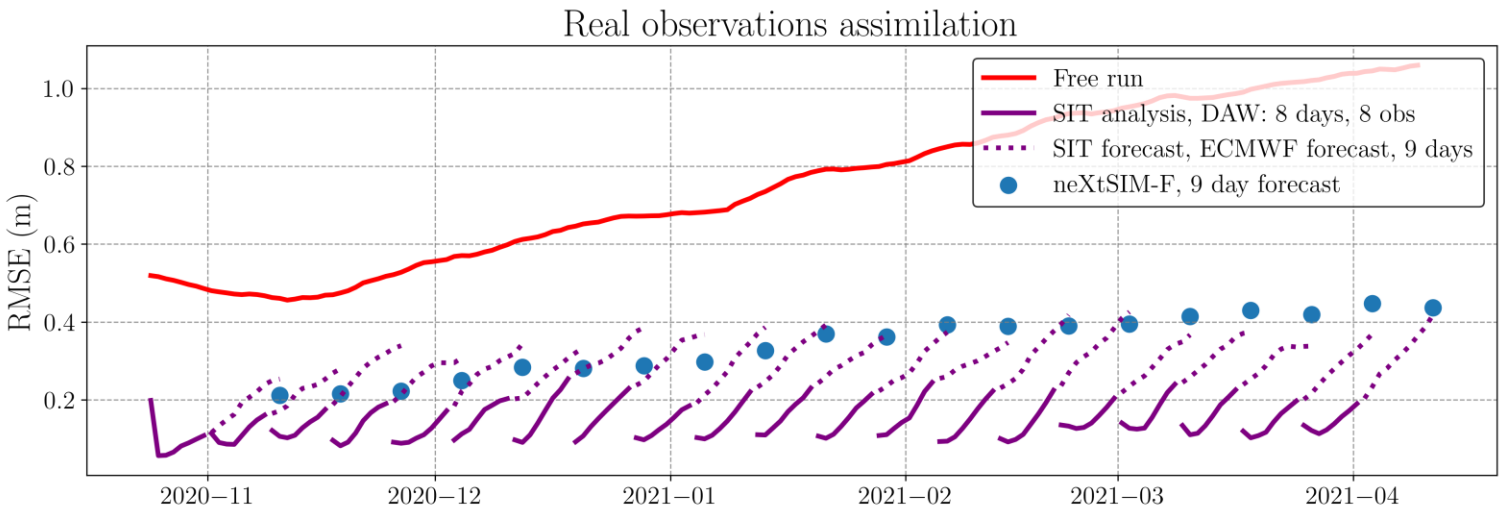
Gain of ~16% by projecting the 4DVar onto the EOF



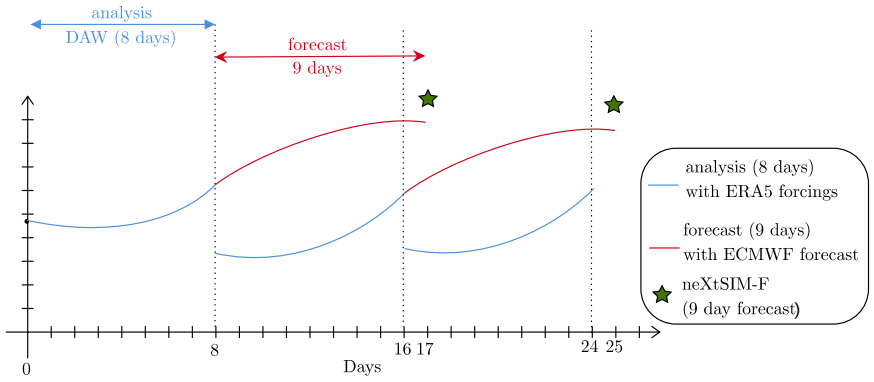



# Assimilating CS2SMOS

Assimilation in October 2020 – April 2021
Comparison with neXtSIM-F [1]
Truth considered as CS2SMOS; DAW of 8 days with 8 obs

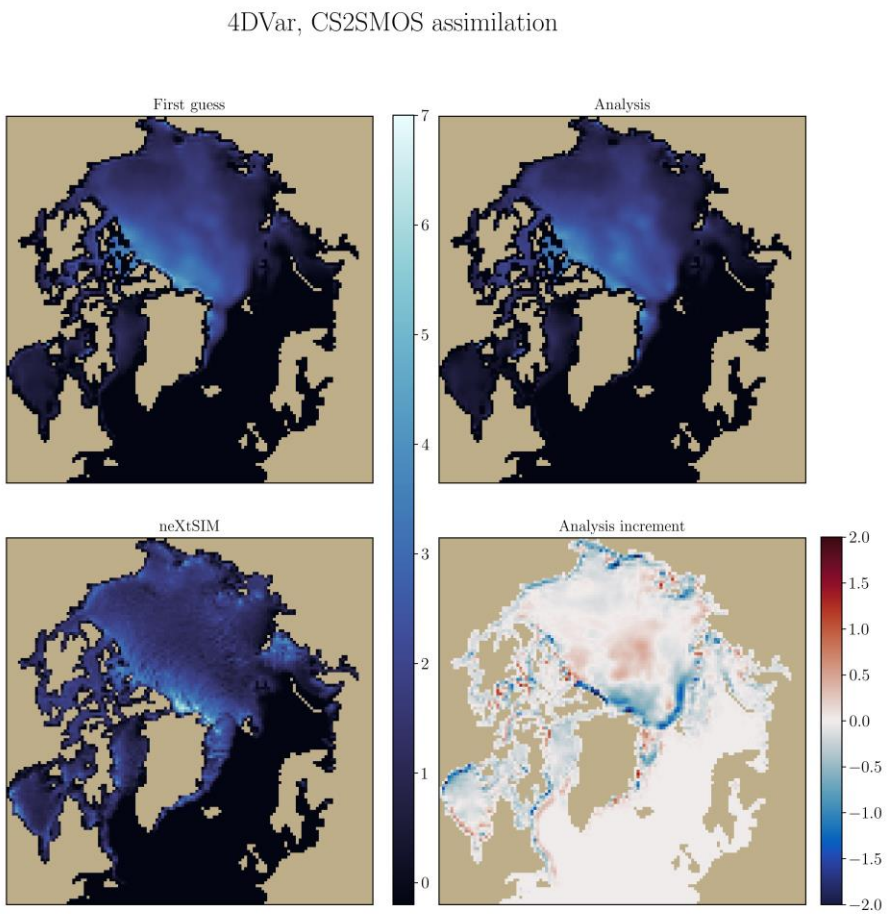



CS2SMOS




[1] Williams, T., Korosov, A., Rampal, P., and Ólason, E.: Presentation and evaluation of the Arctic sea ice forecasting system neXtSIM-F, The Cryosphere, 15, 3207–3227, https://doi.org/10.5194/tc-15-3207-2021, 2021.

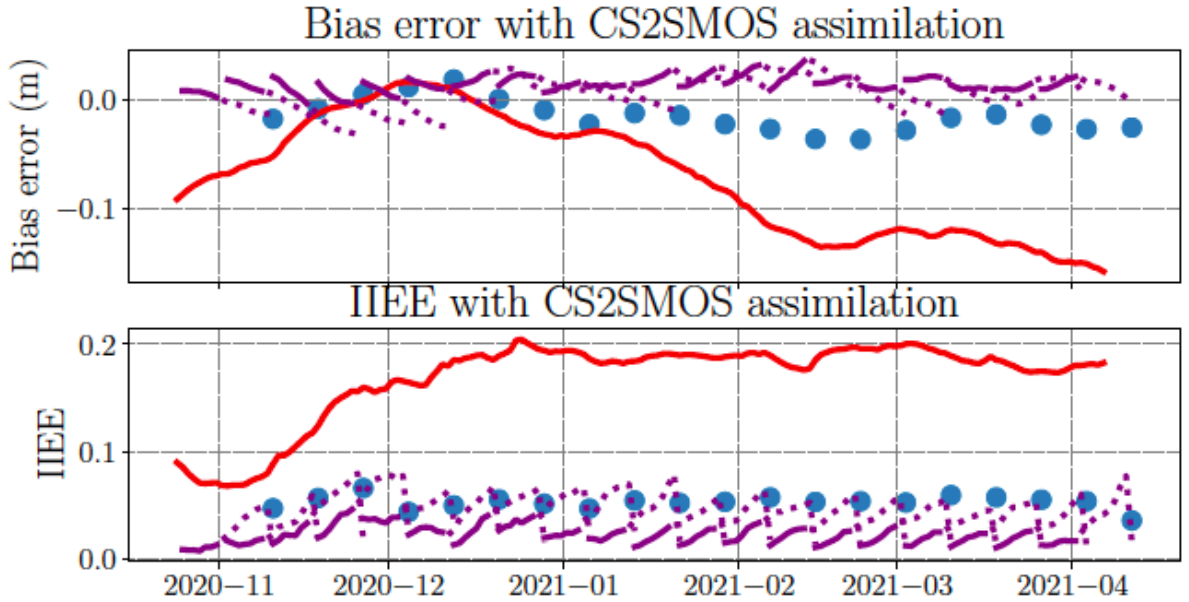
# Assimilating CS2SMOS




Smooth emulator
Smooth observations

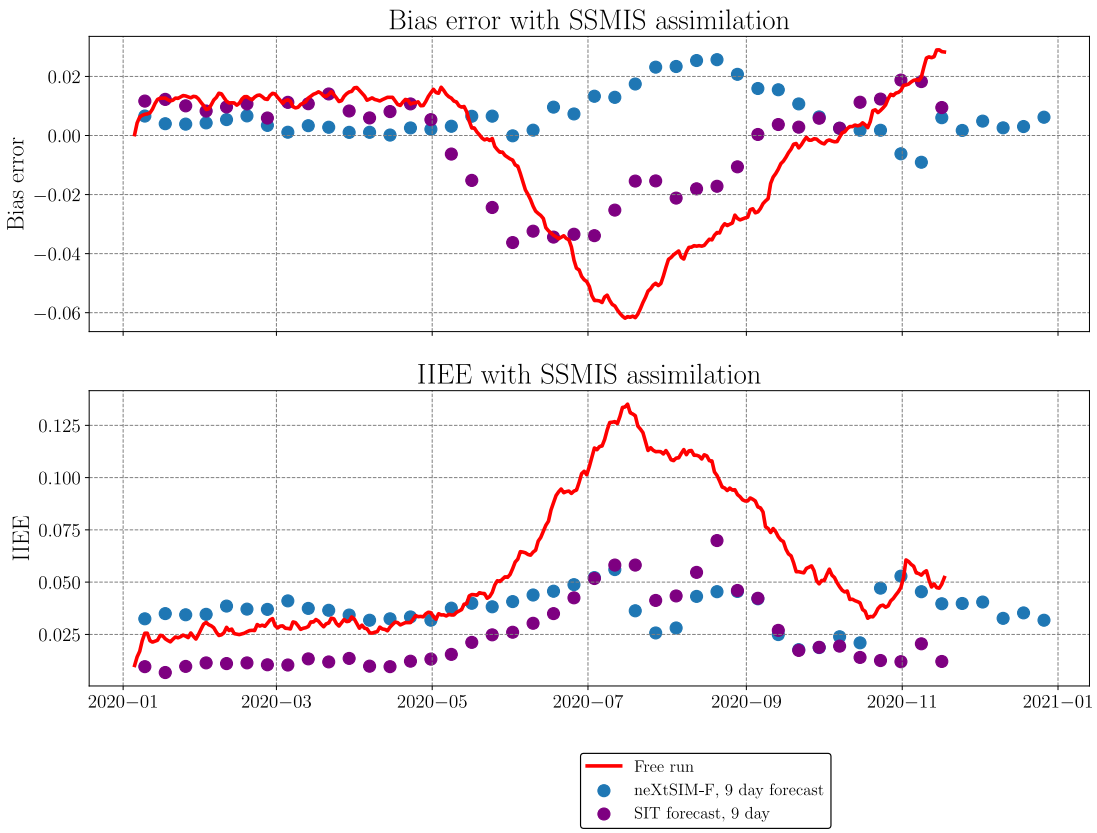
= Smooth analysis

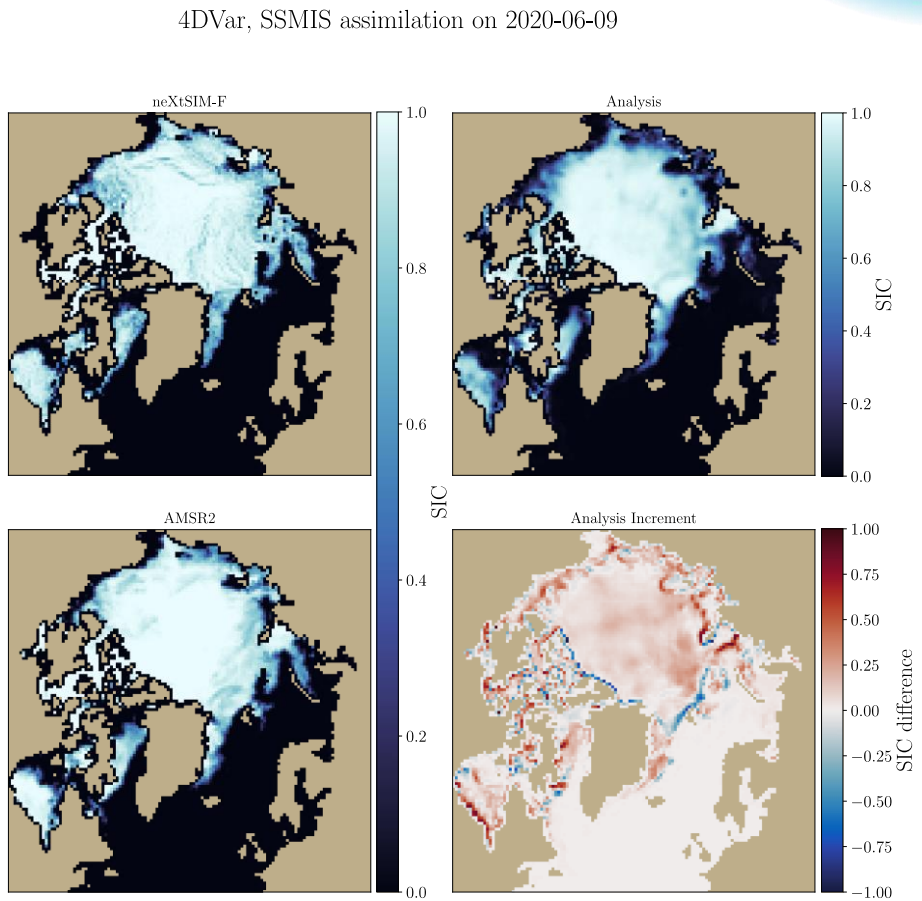
→ Model bias correction



# Similar results with SIC

SSMIS assimilation
AMSR2 considered as truth

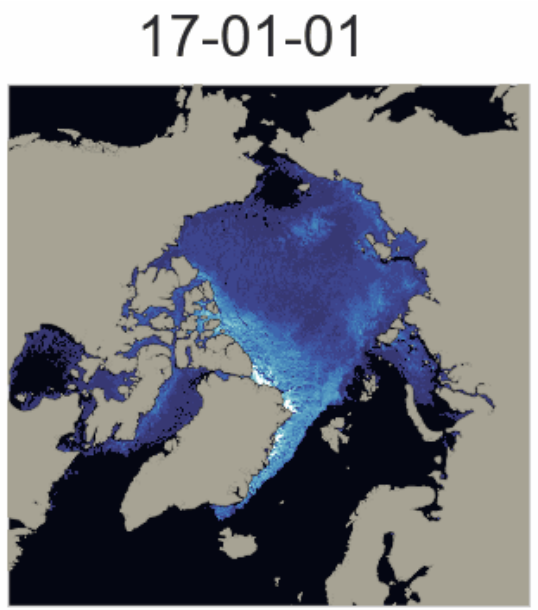


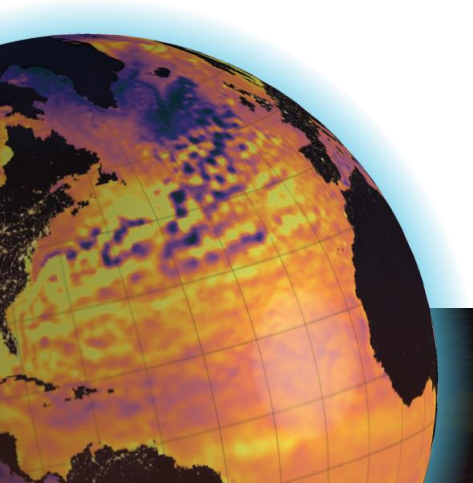



# Take-home messages

- NN can emulate SIT dynamics, but deterministic NN leads to a loss of fine-scale dynamics
- Cheap to run (1 year forecast in less than 1 minute)
- Access to the emulator gradient

- Model emulator can be used in a 4D-Var framework with results close to operational systems
- But we would need more fine-scale dynamics observations to benefit them
- Cheap DA scheme: 1 cycle takes ~3min



## Thank you for your attention!

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