

# Climate Coffees

## Deterministic and probabilistic forecasts of Arctic sea ice with deep neural networks



June 10<sup>th</sup>, 2021  
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Universiteit Utrecht

- **Deep learning and weather forecasts**
- **Arctic sea ice forecast with deep neural networks**
- **Make the black-box a glass-box**



Jisk



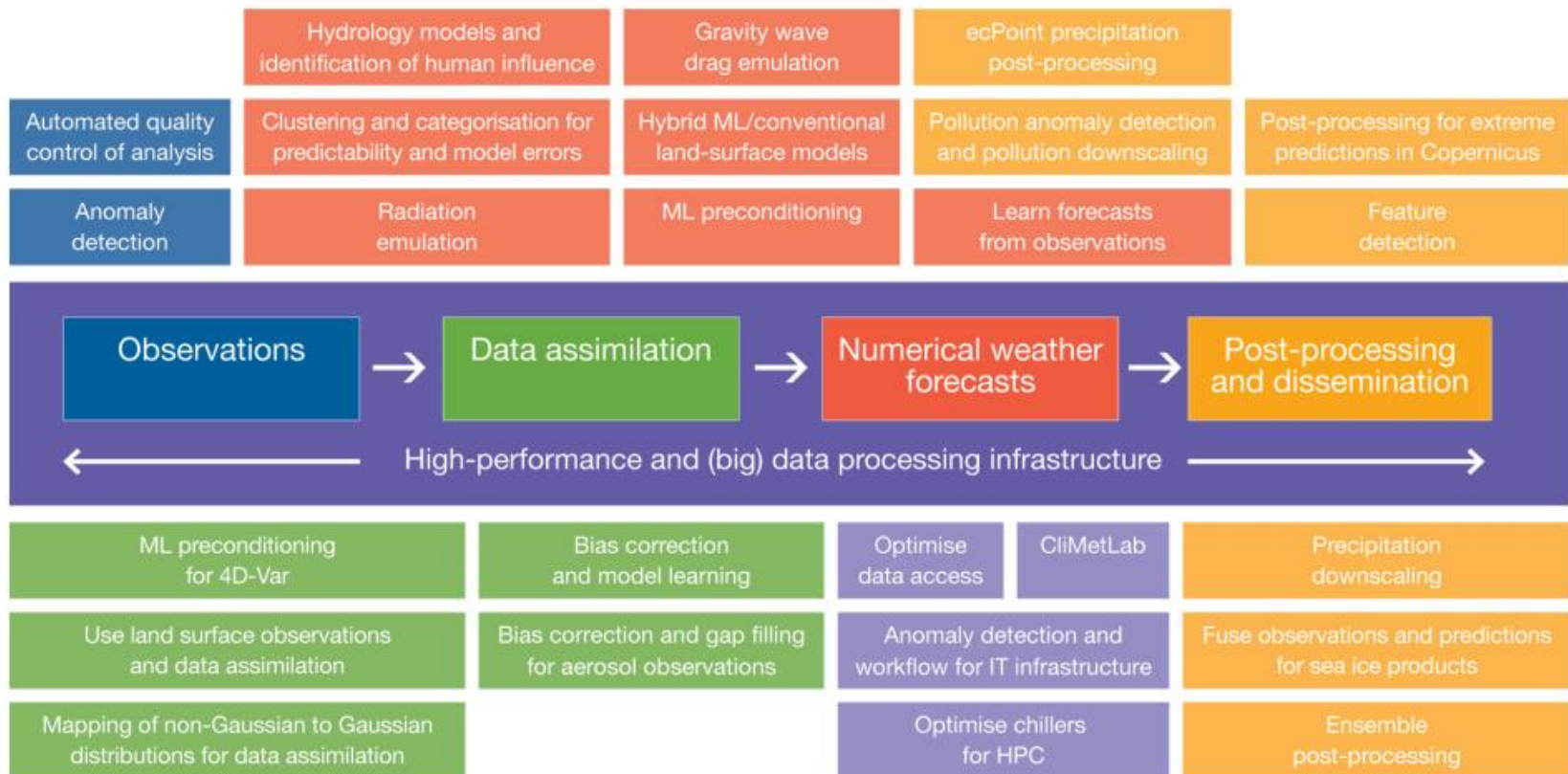
Wilco

**Machine learning at ECMWF:  
A roadmap for the next 10 years**

Peter Dueben, Umberto Modigliani, Alan Geer, Stephan Siemen, Florian Pappenberger, Peter Bauer, Andy Brown, Martin Palkovič, Baudouin Raoult, Nils Wedi, Vasileios Baousis

January 2021

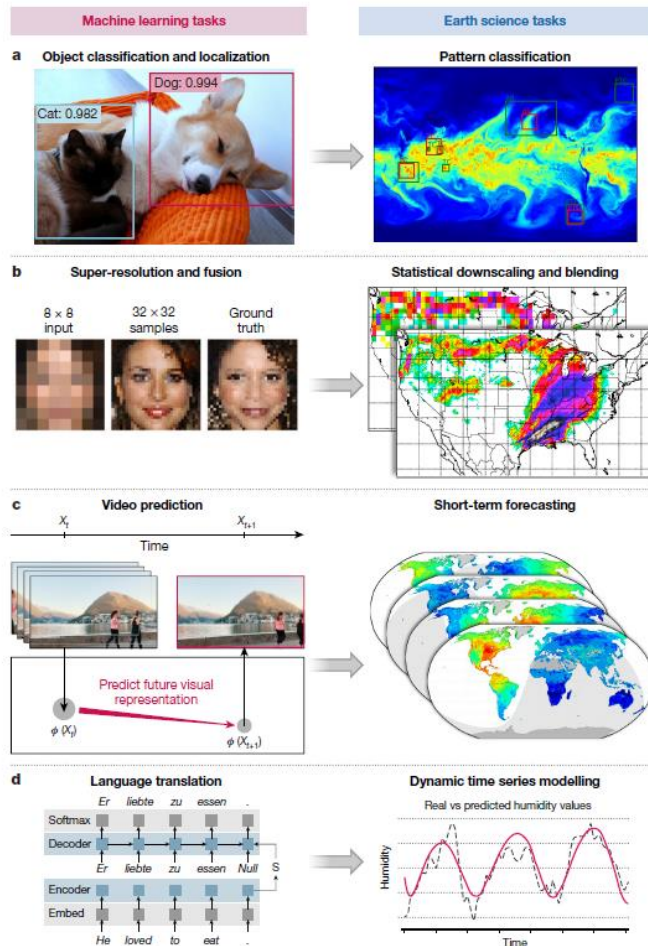
**ECMWF machine learning roadmap**



## PERSPECTIVE

<https://doi.org/10.1038/s41586-019-0912-1>

## Deep learning and process understanding for data-driven Earth system science

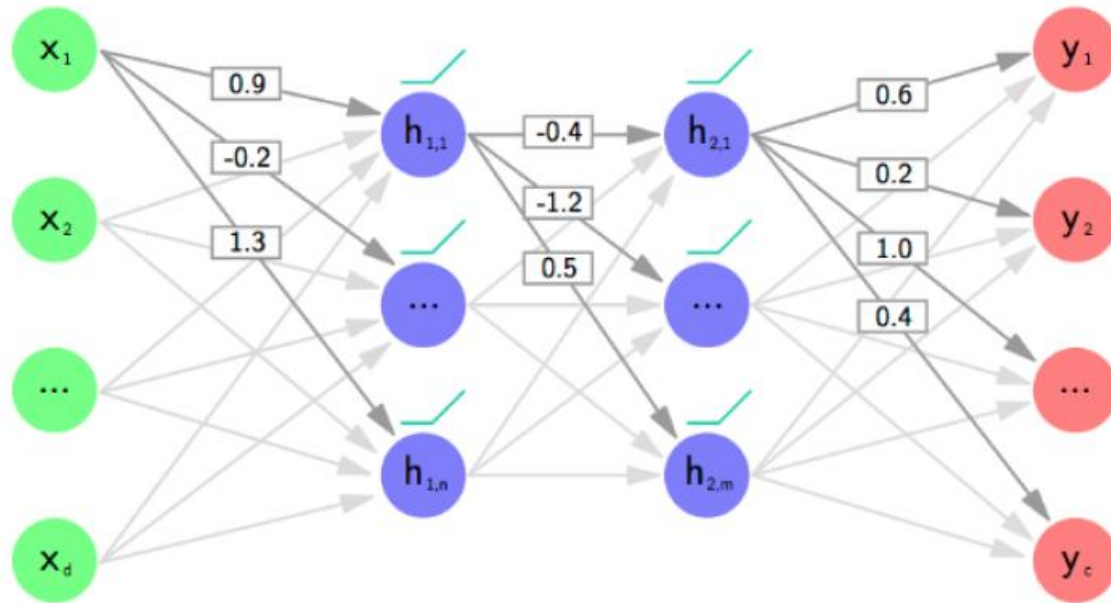
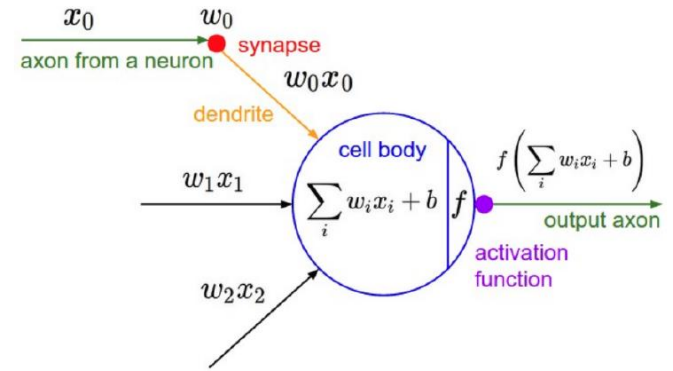
Markus Reichstein<sup>1,2\*</sup>, Gustau Camps-Valls<sup>1</sup>, Bjorn Stevens<sup>1</sup>, Martin Jung<sup>1</sup>, Joachim Denzler<sup>2,5</sup>, Nuno Carvalhais<sup>1,6</sup> & Prabhat<sup>7</sup>

## Weather forecasting with deep learning

- Innovative data-driven approaches for weather forecasts
- Easy adaption of deep learning techniques to some questions in the climate science
- Large amount of data for training (reanalysis, model output...)
- Think out of black-box

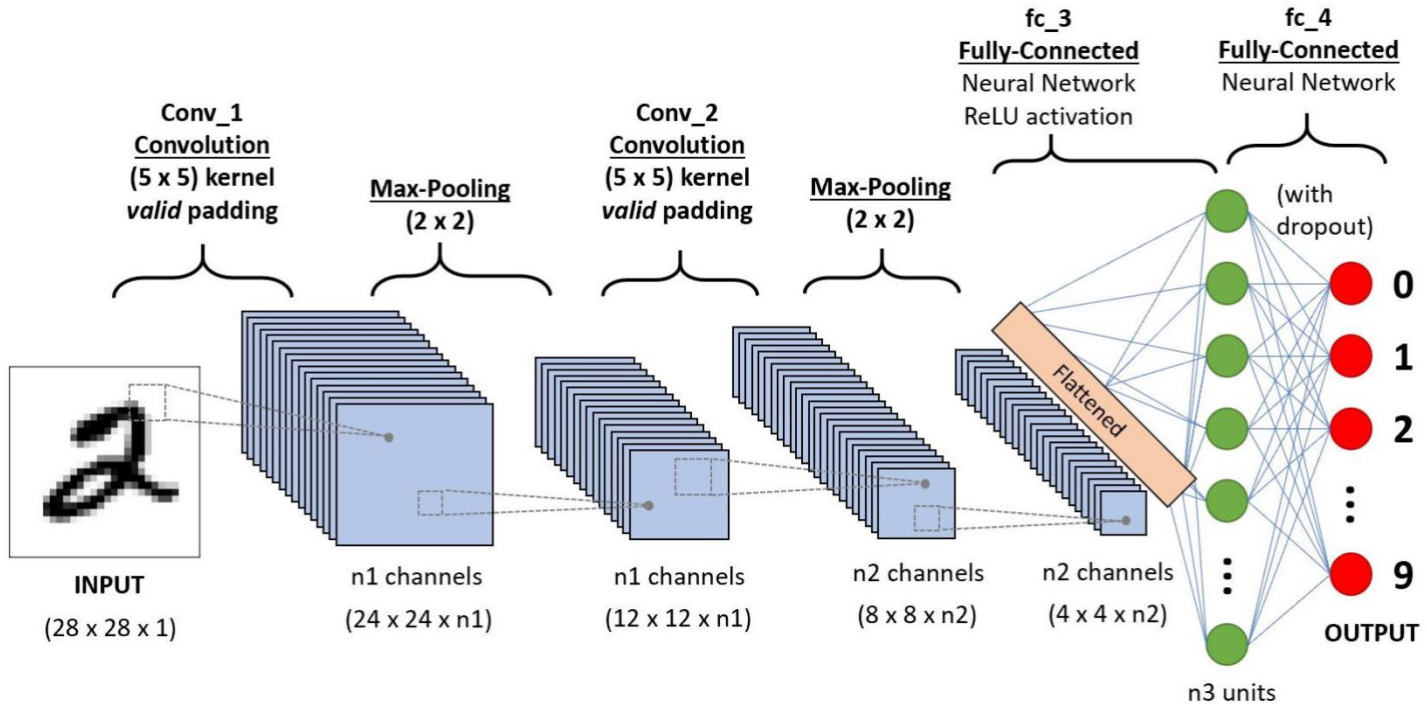


# Deep neural network



$$f(x) = a_n x^n + a_{n-1} x^{n-1} + \dots + a_2 x^2 + a_1 x + a_0$$

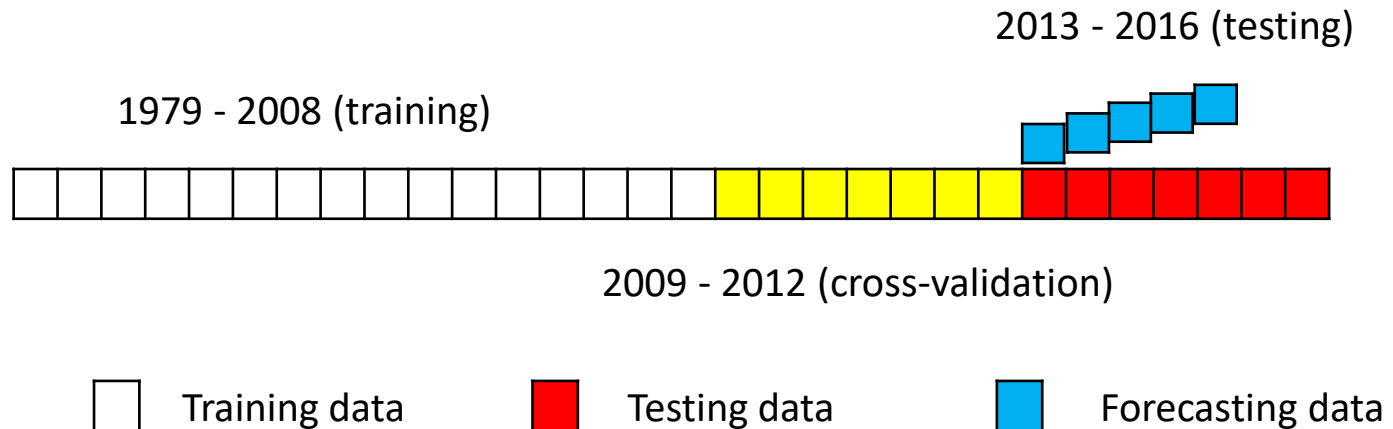
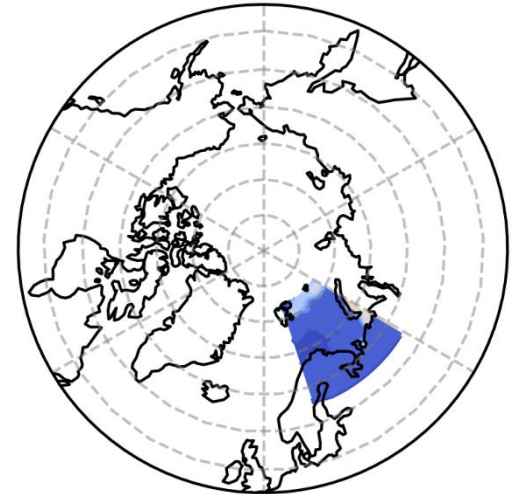
# Deep convolutional neural network

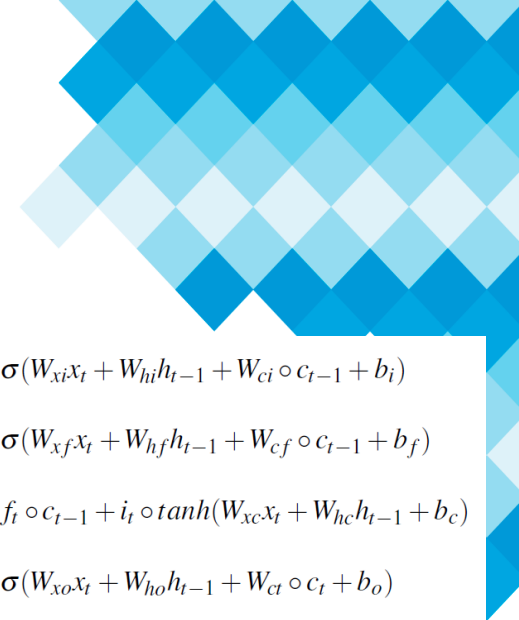


$$f(x) = a_n x^n + a_{n-1} x^{n-1} + \dots + a_2 x^2 + a_1 x + a_0$$

## Sea ice forecast with deep neural networks

- Operational sea ice forecast in the Barents Sea
- Extended range sea ice forecast (weekly to sub-monthly)
- Lead time dependent sea ice forecast
- ERA-Interim and ORAS4 (SIC, T2M, SLP, Z850, SFlux, OHC...)





## Sea ice forecast with deep neural networks

- Convolutional Long-Short Term Memory Networks (ConvLSTM)
- Spatial temporal sequence forecasting

$$i_t = \sigma(W_{xi}x_t + W_{hi}h_{t-1} + W_{ci} \circ c_{t-1} + b_i)$$

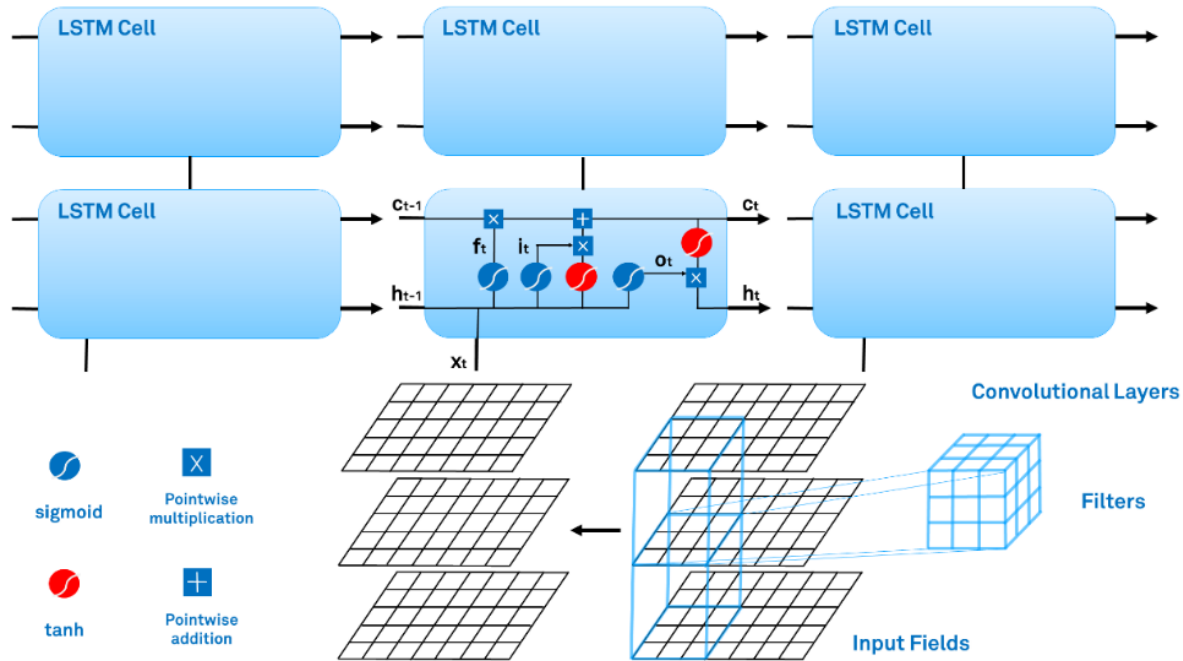
$$f_t = \sigma(W_{xf}x_t + W_{hf}h_{t-1} + W_{cf} \circ c_{t-1} + b_f)$$

$$c_t = f_t \circ c_{t-1} + i_t \circ \tanh(W_{xc}x_t + W_{hc}h_{t-1} + b_c)$$

$$o_t = \sigma(W_{xo}x_t + W_{ho}h_{t-1} + W_{co} \circ c_t + b_o)$$

$$h_t = o_t \circ \tanh(c_t)$$

Convolutional LSTM

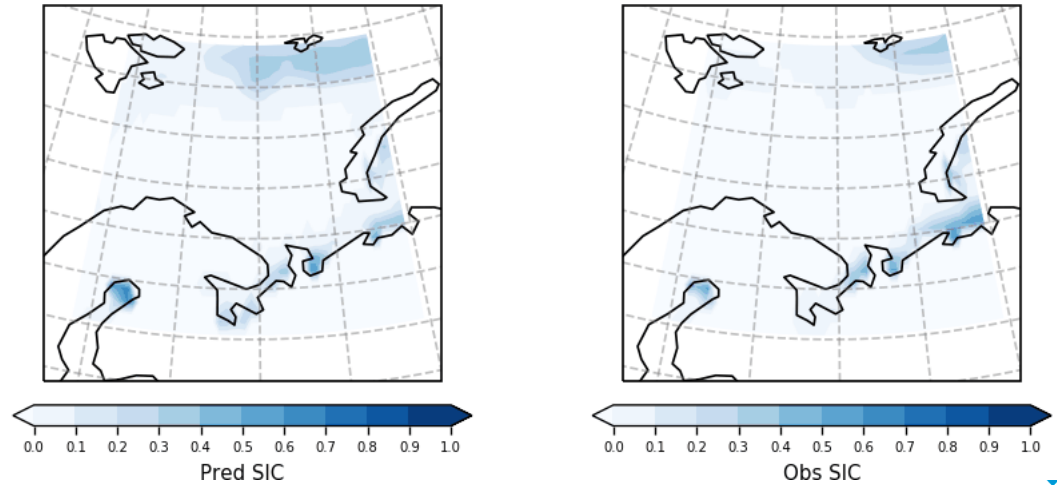




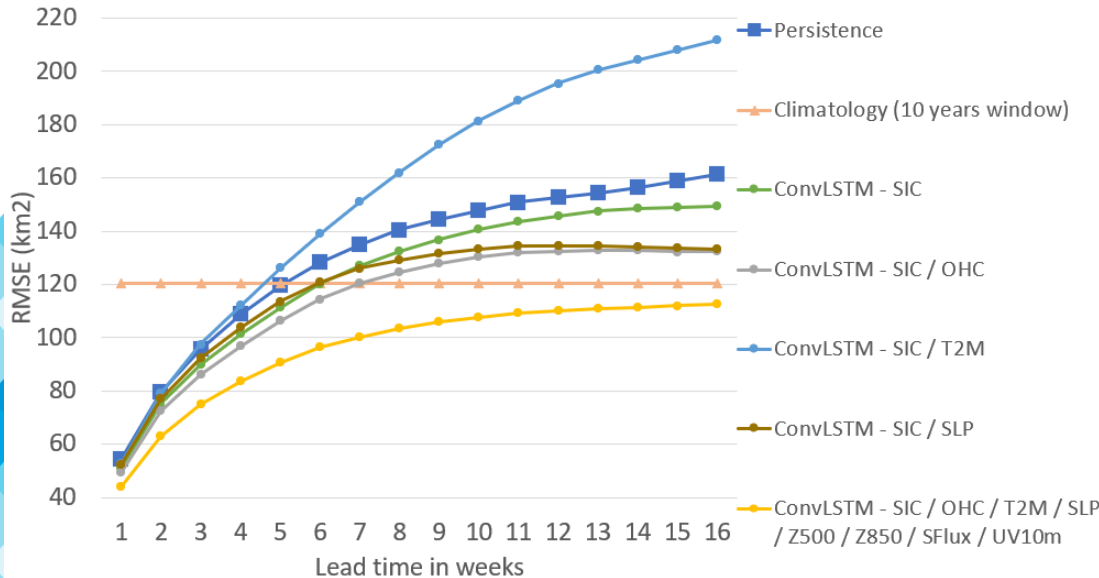
## Deterministic weather forecast with ConvLSTM

Liu, Y., Bogaardt, L., Attema, J., & Hazeleger, W. (2021). Extended-Range Arctic Sea Ice Forecast with Convolutional Long Short-Term Memory Networks. Monthly Weather Review, 149(6), 1673-1693.

ConvLSTM SIC prediction year year 2013 month 1 week 1

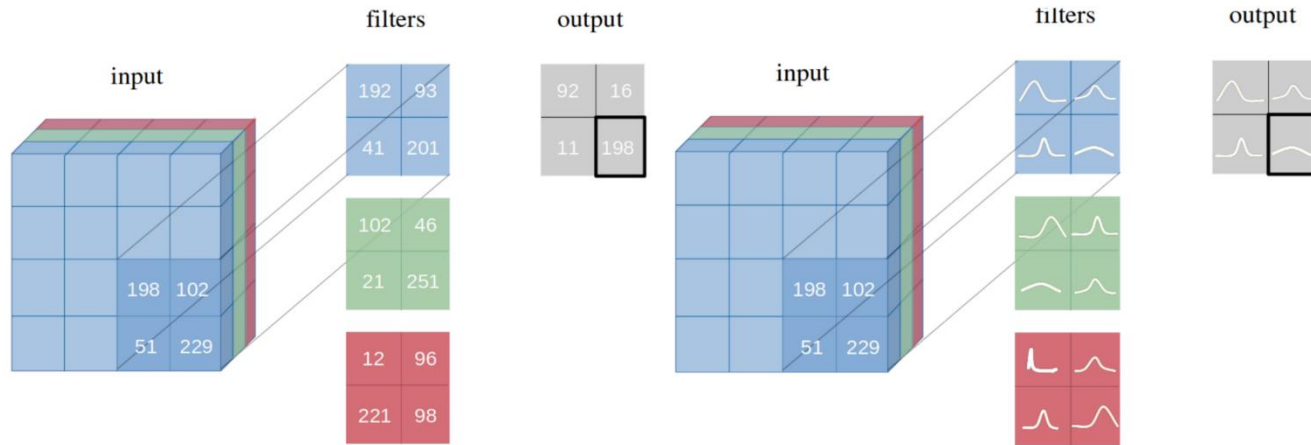


Sea ice forecast of ConvLSTM (left) with SIC and OHC (lead week 1) and observation (right)



RMSE of sea ice forecast by ConvLSTM and persistence

Shridhar, K., Laumann, F., & Liwicki, M. (2018).  
 Uncertainty Estimations by Softplus normalization in  
 Bayesian Convolutional Neural Networks with Variational  
 Inference. arXiv preprint arXiv:1806.05978.

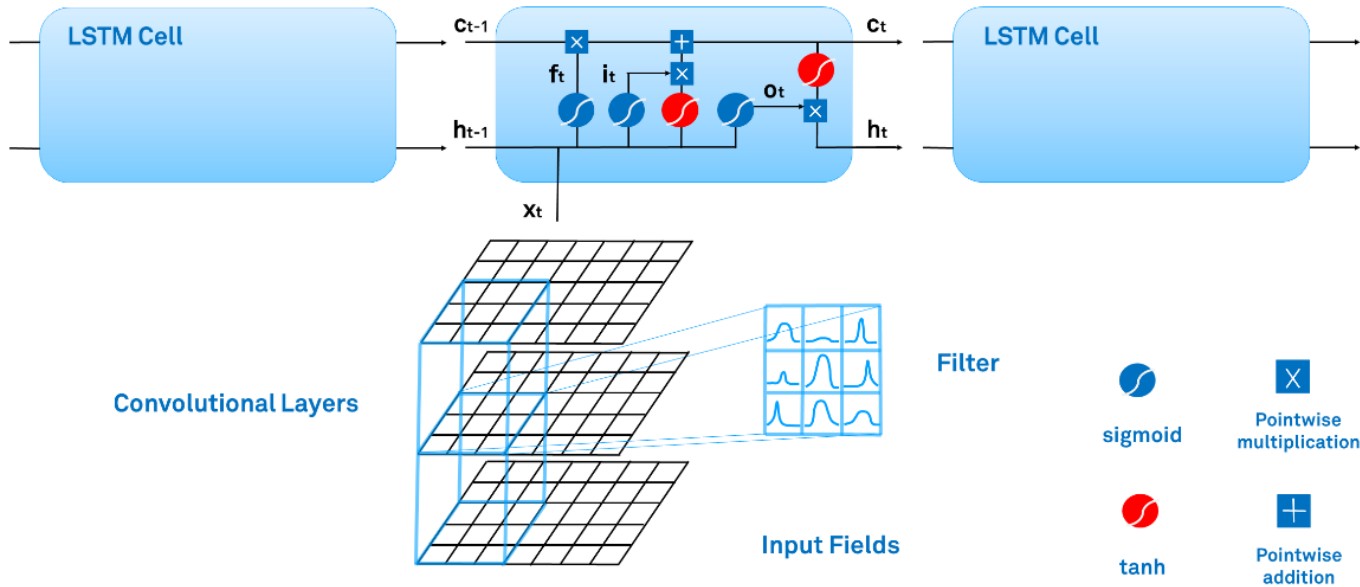


Deterministic neural network v.s. probabilistic neural network

## Weather forecasting with probabilistic deep learning

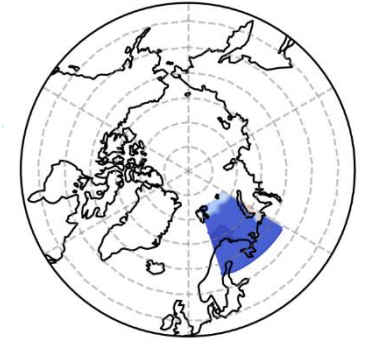
- Address uncertainties with Bayesian deep learning

Bayesian Convolutional LSTM



## Weather forecasting with probabilistic deep learning

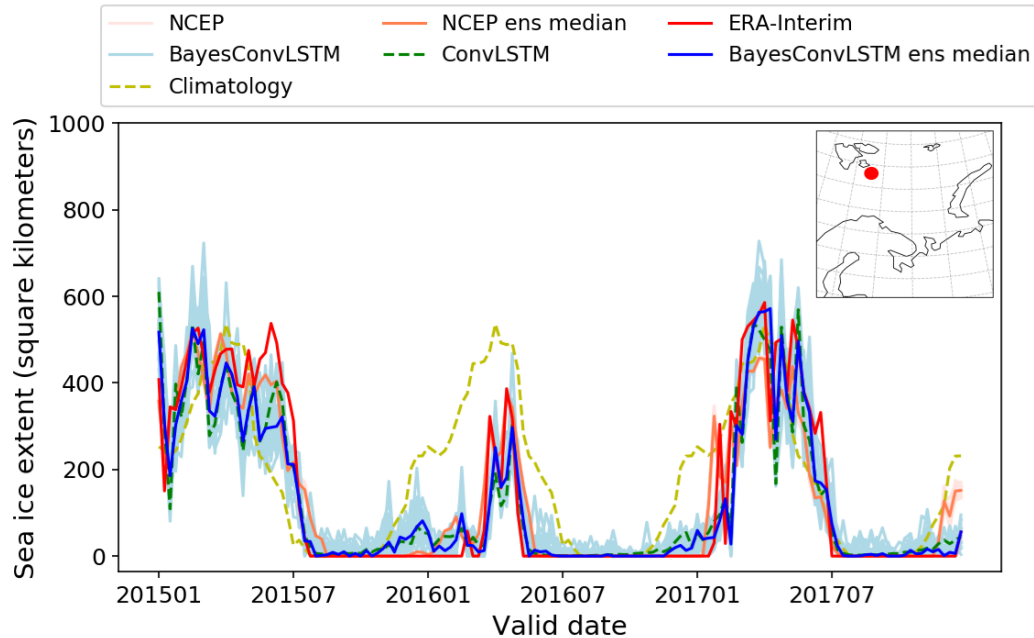
- Address uncertainties with Bayesian deep learning
- Bayesian Convolutional Long-Short Term Memory Networks (BayesConvLSTM)



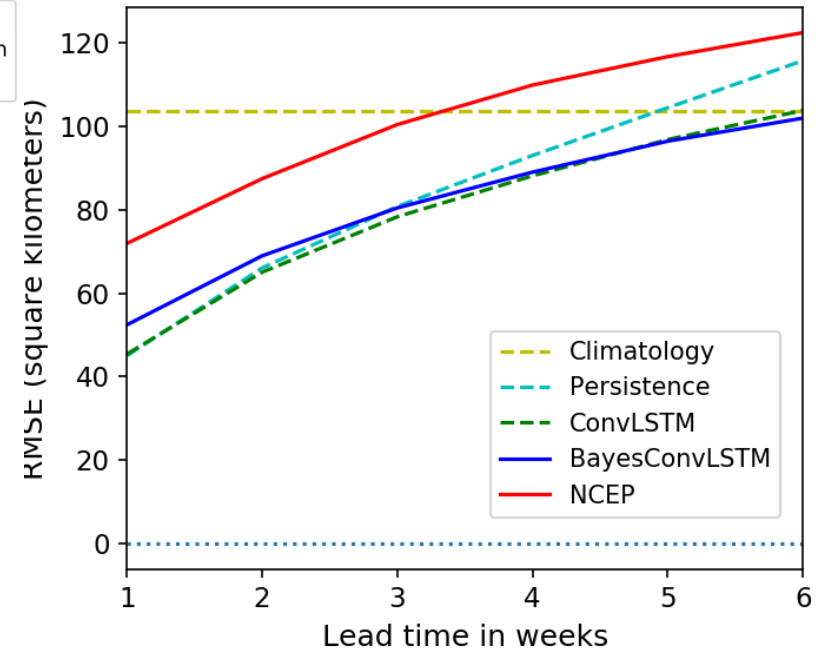
## Weather forecasting with probabilistic deep learning

- Lead time dependent sea ice forecasts in the Barents sea

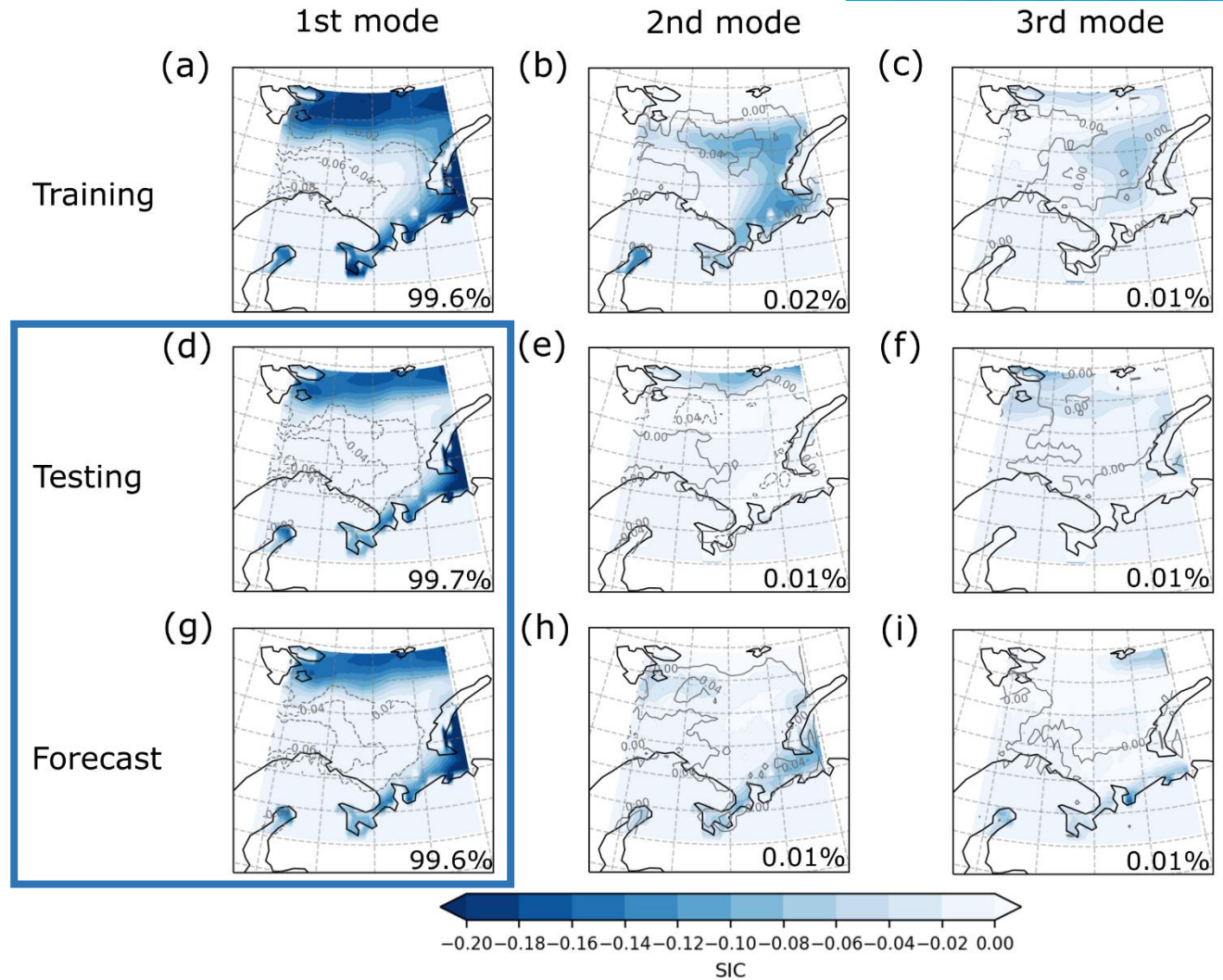
Probabilistic sea ice forecast at  
76.75E and 25.5N  
lead week 1



Probabilistic sea ice extent forecast  
RMSE



Covariance map of SIC and OHC for the 1st, 2nd and 3rd SVD modes



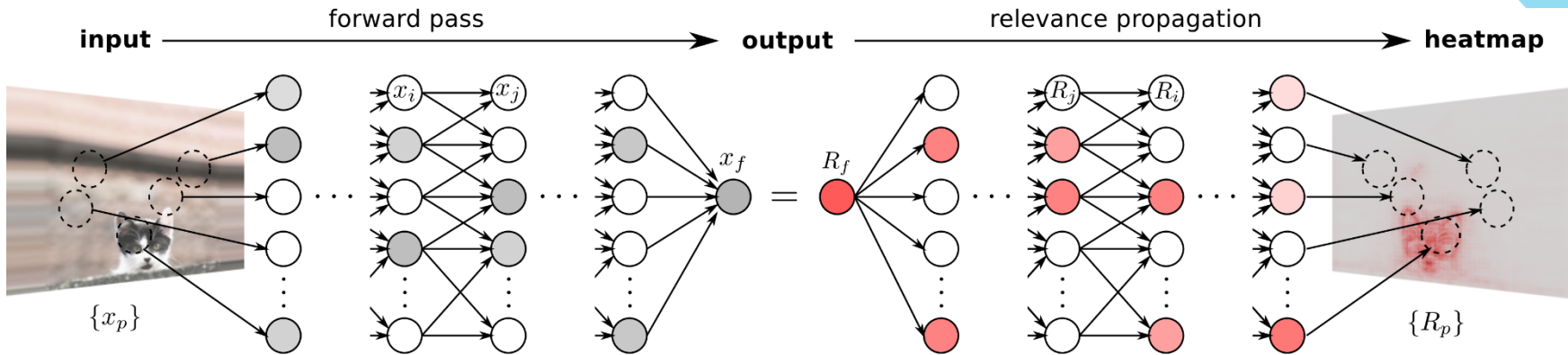
### Forecasting with deep neural networks

Shades: dimensionless SIC  
Contour: dimensionless OHC.

- Physical/domain knowledge is essential!
- Try to understand your black-box through diagnostics



## Black box -> Glass box : Explainable AI (XAI)



## Bring home message

- Combine domain knowledge with deep learning and make the black-box transparent



**Thanks for your attention!**

**Questions?**



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