Surrogate Modelling for Sea Ice Concentration using Lightweight Neural Ensemble

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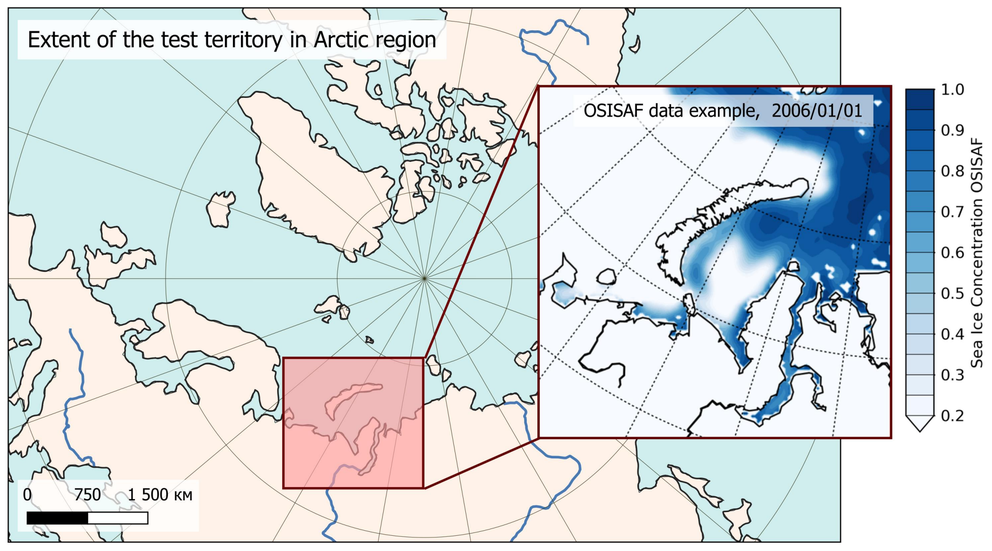
Introduction

We propose the adaptive surrogate modeling approach named *LANE-SI* (**L**ightweight **A**utomated **N**eural **E**nsembling for **S**ea **I**ce) that uses ensemble of relatively simple deep learning models with different loss functions for forecasting of spatial distribution for sea ice concentration in the specified water area.

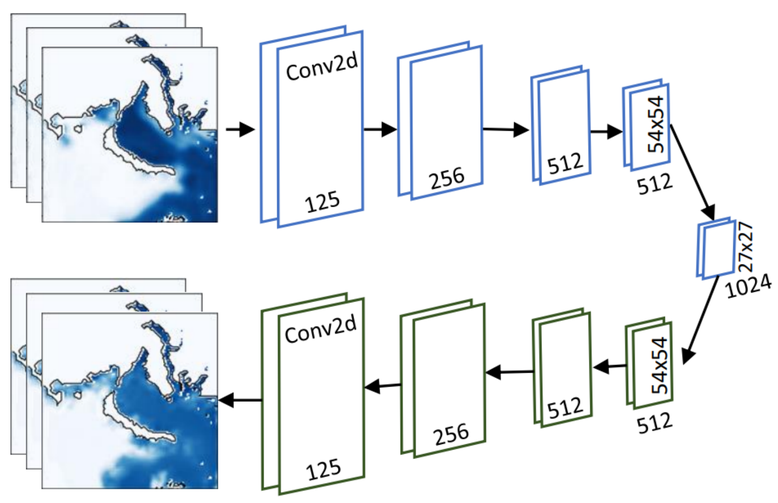
Experimental studies confirm the quality of a long-term forecast is comparable to resource-intensive physical modeling.

We achieved a 20% improvement against the state-of-the-art physics-based forecast system SEAS5 for the Kara Sea.



Methods

Architecture of deep learning model for sea ice concentration forecasting



CNNs were trained on two loss functions:

- *Mean Absolute Error (MAE, L1Loss)* - represents the closeness of the absolute values of prediction with the target image;
- *Structural Similarity Index (SSIM)* - shows similarity in the spatial distribution of the parameter at predicted and target images.

The multi-model ensemble was used to improve the quality of the surrogate model in LANE-SI. The first CNN reflects the spatial distribution of the parameter (SSIM), and the second reproduces the parameter's absolute values (MAE). Also, a naive forecast in the form of repeating the average values for five years for each day of the year was added to reproduce long-term dynamics not represented in pre-history.

Ensembling method was CNN trained with SSIM loss function unites the ensemble's elements in the form of multi-channel images into one prediction.

We use OSI SAF Global Sea Ice Concentration (SSMIS) product as training data for sea ice concentration forecasting in specific water areas.

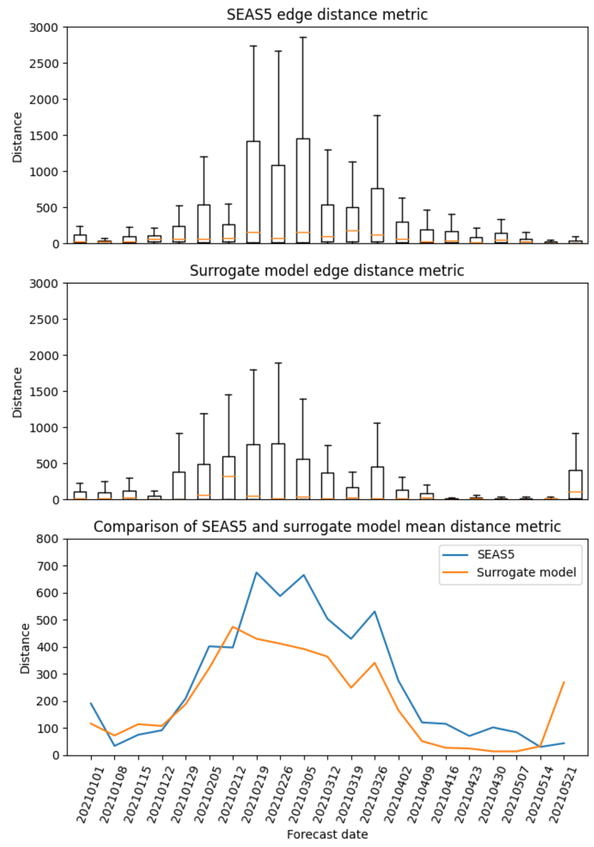
Results

Quality assessment was conducted using several objectives: (1) the coincidence of the absolute values of the parameter with actual data (MAE), (2) the coincidence of the spatial distribution of the parameter (SSIM), and (3) the distance between ice edges. The results of experiments for Kara sea confirms that, according to the SSIM metric, an ensemble always gives better quality than single models; according to the MAE metric, in most cases, an ensemble always gives better quality.

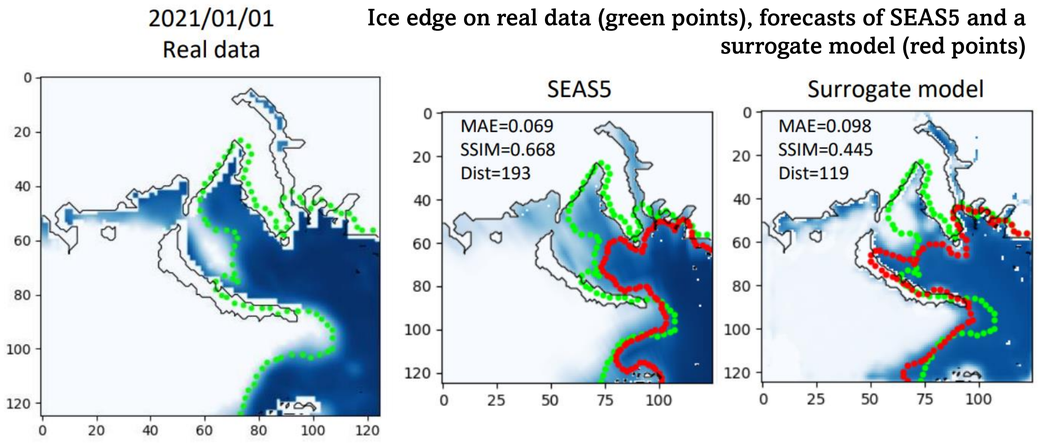
Experiments have shown that the LANE-SI approach allows forecasting with a quality close to the physics-based SOTA model. While we used the Kara Sea for validation, LANE-SI can be used to design the forecasting model with a specified resolution and forecast horizon for any water area in the Arctic.

Comparison of LANE-SI surrogate ensemble model and SOTA - SEAS5

Metric	Mean Absolute Error (MAE)		Structural Similarity Index (SSIM)	
Year and quater	SEAS5	Surrogate model	SEAS5	Surrogate model
2020Q1	**0,097**	0,103	**0,602**	0,516
2020Q2	0,113	**0,108**	**0,542**	0,474
2020Q3	0,082	**0,021**	**0,583**	0,571
2021Q1	**0,099**	0,103	**0,630**	0,521
2021Q2	**0,078**	0,094	**0,610**	0,490
2021Q3	0,063	**0,029**	**0,626**	0,560
2022Q1	0,103	**0,092**	**0,587**	0,540
2022Q2	0,095	**0,081**	**0,546**	0,508
2022Q3	0,074	**0,025**	**0,576**	0,563



Ice edge on real data (green points), forecasts of SEAS5 and a surrogate model (red points)



Acknowledgment:
This work was supported by the Analytical Center for the Government of the Russian Federation (IGK 000000D730321P5Q0002), agreement No. 70-2021-00141.

Results available via QR-code

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