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Deep learning for monthly Arctic sea ice concentration prediction

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Over recent decades, the Arctic has warmed faster than any region on Earth. The rapid decline in Arctic sea ice extent (SIE) is often highlighted as a key indicator of anthropogenic climate change. Changes in sea ice disrupt Arctic wildlife and indigenous communities, and influence weather patterns as far as the mid-latitudes. Furthermore, melting sea ice attenuates the albedo effect by replacing the white, reflective ice with dark, heat-absorbing melt ponds and open sea, increasing the Sun's radiative heat input to the Arctic and amplifying global warming through a positive feedback loop. Thus, the reliable prediction of sea ice under a changing climate is of both regional and global importance. However, Arctic sea ice presents severe modelling challenges due to its complex coupled interactions with the ocean and atmosphere, leading to high levels of uncertainty in numerical sea ice forecasts.

Deep learning (a subset of machine learning) is a family of algorithms that use multiple nonlinear processing layers to extract increasingly high-level features from raw input data. Recent advances in deep learning techniques have enabled widespread success in diverse areas where significant volumes of data are available, such as image recognition, genetics, and online recommendation systems. Despite this success, and the presence of large climate datasets, applications of deep learning in climate science have been scarce until recent years. For example, few studies have posed the prediction of Arctic sea ice in a deep learning framework. We investigate the potential of a fully data-driven, neural network sea ice prediction system based on satellite observations of the Arctic. In particular, we use inputs of monthly-averaged sea ice concentration (SIC) maps since 1979 from the National Snow and Ice Data Centre, as well as climatological variables (such as surface pressure and temperature) from the European Centre for Medium-Range Weather Forecasts reanalysis (ERA5) dataset. Past deep learning-based Arctic sea ice prediction systems

tend to overestimate sea ice in recent years - we investigate the potential to learn the non-stationarity induced by climate change with the inclusion of multi-decade global warming indicators (such as average Arctic air temperature). We train the networks to predict SIC maps one month into the future, evaluating network prediction uncertainty by ensembling independent networks with different random weight initialisations. Our model accounts for seasonal variations in the drivers of sea ice by controlling for the month of the year being predicted. We benchmark our prediction system against persistence, linear extrapolation and autoregressive models, as well as September minimum SIE predictions from submissions to the Sea Ice Prediction Network's Sea Ice Outlook. Performance is evaluated quantitatively using the root mean square error and qualitatively by analysing maps of prediction error and uncertainty.