

ARCTIC AND ANTARCTIC SEA ICE EXTENT FORECASTING USING HYBRID LSTM TECHNIQUES

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Abstract

Recent changes in global climate patterns have triggered the melting of polar sea ice, especially in Arctic regions. A decrease in the extent of sea ice is observed at a much faster rate than previously expected. The Antarctic region, on the other hand, has shown a stable sea ice pattern throughout the last few decades. However, the southern polar region is not completely unaffected. Recent studies of the Bellingshausen and Amundsen Seas have shown a downward trend in sea ice. The extent of sea ice is crucial for regulating global climate patterns, ocean circulation and human activities, including shipping and fishing. Hence, forecasting sea ice extent is vital for global economy planning and climatology studies. In this paper, time-series forecasting of 5 Antarctic and Arctic regions is evaluated using a hybrid convolutional long short-term memory (ConvLSTM) and a bidirectional long short-term memory (BiLSTM) and compared with a standalone long short-term memory (LSTM). This study uses regional sea ice extent data rather than considering the extent across entire hemispheres. With lower and stable RMSE scores across all lead times, the proposed hybrid BiLSTM model shows better performance in regional sea ice forecasting than does the standalone and ConvLSTM. The study also indicated that the climatic conditions of a particular region play a crucial role in forecasting efficiency, especially at longer lead times.

Keywords:

Sea ice extent, time series forecasting, long short-term memory (LSTM), bidirectional long short-term memory (LSTM), Arctic SIE, Antarctic SIE

1. INTRODUCTION

The increase in greenhouse gases, which has resulted in an increase in global temperature, has eventually caused notable changes in polar regions. The Arctic ice cover is declining at an accelerated rate, along with a significant reduction in its thickness [1]. Over the past few decades, an increase in the near-surface air temperature called the 'Arctic Amplification' has been observed [2]. The temperature increase and continuous melting have led to a feedback mechanism in the Arctic. This will result in additional ice melting. The Arctic is expected to be 'seasonally ice-free' once all layers of its multilayered ice are lost [3]. On the other hand, in contrast to its gradual increase in ice cover since the 1970s, Antarctica experienced a remarkable decline between 2014 and 2017. Over these four years, the reduction in the extent of Antarctic sea ice exceeded the total Arctic sea ice loss observed in the four decades from 1979 to 2018 [4]. However, after 2017, several recoveries were noted, but they have yet to reach the peak achieved in 2014, indicating a decreasing trend. The reason behind the irregular pattern of Antarctic ice remains a subject of debate. The climate change has a direct effect on polar sea ice extent.

The sea ice extent (SIE) is defined as the area of the ocean with a minimum of 15% ice concentration [5]. The reduction in the SIE commonly occurs during the summer

because of melting, followed by a rise in the SIE during the winter due to ice formation. The Antarctic SIE follows a seasonal pattern, with February as the month of minimum coverage and September as the month of maximum coverage [6]. Similarly, for the Arctic extent, March and September are the months with the maximum and minimum coverage, respectively [7]. The Arctic sea ice is more sensitive to climate change than the Antarctic sea ice [8].

As defined by [9], the Arctic is divided into 14 regions. As the entire Arctic region has experienced melting since the 1970s, these regions have shown a strong negative trend. A maximum negative slope is observed for the Kara and Barents Seas, Baffin Bay, Bering Sea and Greenland Sea [7] (Figure 1). While the Antarctic regions showed a positive trend until 2014, the trends during the decline were very different. A steep negative trend was observed for all regions except the Indian Ocean and a few parts of the Ross Sea [10], resulting in an overall negative trend (Figure 2).

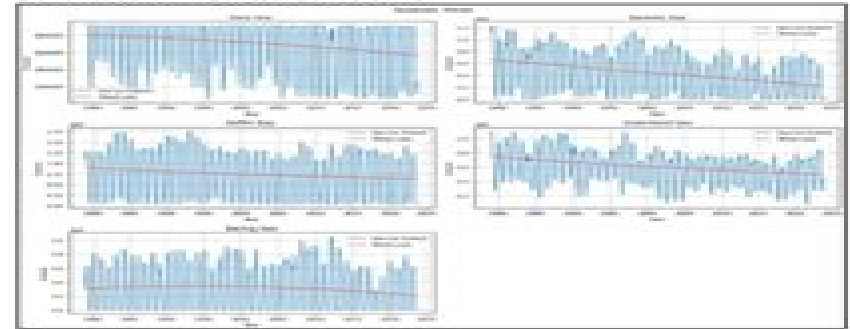


Fig.1. Time-series plots of the SIE (in km²) from 1979 to 2023 for five Arctic regions along with a quadratic regression trend line

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Ice Forecasting Techniques for the Arctic Seas. Editors: B.a. Krutskikh, Z.m. Gudkovic, A.l.s Okolov. Translated from Russian ICE FORECASTING TECHNIQUES FOR THE ARCTIC SEAS.,1976 **Ice Forecasting Techniques for the Arctic Seas** B. A. Krutskikh,Z. M. Gudkovic,A. L. Sokolov,1976 A collection of published articles which cover a number of actual questions concerning the calculations and forecasts of ice conditions in the Arctic seas *Ice Forecasting Techniques for the Arctic Seas* ,1976 *Ice Forecasting Techniques for the Arctic Seas. Translated from the Russian* B. A. KRUTSKIHK,Z. M. GUDKOVIC,A. L. SOKOLOV,1976 **Manual of Short-term Sea Ice Forecasting** Walter I. Wittmann,Gordon P. MacDowell,1964 **Avalanches** ,1977 Contributions reviewing the state of the art concerning avalanches Antarctic Journal of the United States ,1981 **The Drift of Sea Ice** Matti Leppäranta,2011-03-22 The Second Edition of The Drift of Sea Ice presents the fundamental laws of sea ice drift which come from the material properties of sea ice and the basic laws of mechanics The resulting system of equations is analysed for the general properties of sea ice drift the free drift model and analytical models for ice drift in the presence of internal friction and the construction of numerical ice drift models is detailed This second edition of a much lauded work unique on this topic in the English language has been revised updated and expanded with much new information and outlines recent results in particular in relation to the climate problem mathematical modelling and ice engineering applications The current book presents the theory observations mathematical modelling techniques and applications of sea ice drift science The theory is presented from the beginning on a graduate student level so that students and researchers coming from other fields such as physical oceanography meteorology physics engineering environmental sciences or geography can use the book as a source book or self study material First the drift ice material is presented ending with the concept of ice state the relevant properties in sea ice dynamics Ice kinematics observations are widely presented with the mathematical analysis methods and thereafter come drift ice rheology to close the triangle material kinematics stress The momentum equation of sea ice is derived in detail and its general properties are carefully analysed Then follow two chapters on analytical models free drift and drift in the presence of internal friction These are very important tools in understanding the dynamical behaviour of sea ice The last topical chapter is numerical models which are the modern tool to solve ice dynamics problem in short term and long term problems The closing chapter summarises sea ice dynamics applications and the need of sea ice dynamicknowledge and gives some final remarks on the future of this branch of science **Current Federal Meteorological Research and Development Activities** United States. Weather Bureau,1963 **Marginal Ice Zone Bibliography** ,1985 **Selected Water Resources Abstracts** ,1981 **Sealift** ,1976 **Special Bibliographies on Oceanography** ,1965 **Report of the Commander - United States. Naval Oceanographic Office**,1962 **Marine Research, Fiscal Year 1968** National Council on Marine Resources and Engineering Development (U.S.),1969 *Marine Research* ,1969 Guide to Soviet Literature Accessions in the

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