Monitor Laptev Sea Ice's Change based on MODIS and AMSR2 Data

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Abstract. In the past decade, Intensified global warming has led to an accelerated melting of Arctic sea ice, which will eventually reduce global sea ice reserves and thus damage the global ecosystem. Arctic sea ice provides an important breeding ground for plankton and microorganisms, the basis of the region's food chain. Therefore, it is of great significance to monitor the dynamic changes in polar sea ice. At present, the dynamic monitoring of polar sea ice changes can be carried out based on remote sensing data, which has the advantages of low restrictions, high efficiency and low pollution. This study aims to analyze the changes in sea ice in the Laptev Sea based on remote sensing data from MODIS and AMSR2 from 2010 to 2024, so as to explore the trend of sea ice changes. The study found that the fluctuation of sea ice changes has become gentler, but the reserves are still decreasing; the Arctic sea ice concentration(SC), sea ice proportion(SP), and surface temperature(ST)show a significant negative correlation; From 2013 to 2024, the sea ice surface temperature showed a fluctuating upward trend, rising from 242.2K to 250.7K; From 2013 to 2023, the sea ice density at the mouth of the Lena River fluctuated downward, with a maximum value of 99% and a minimum value of 93.5%. From 2010 to 2024, the sea ice distribution ratio showed a fluctuating downward trend, with a maximum value of 71.04% and a minimum value of 48.70%.

Keywords: Global warming, Arctic sea ice, MODIS, AMSR2.

1. Introduction

In recent years, global warming and the resulting melting of sea ice have attracted widespread attention. Although the melting of sea ice itself has a limited impact on sea level rise, its reduced albedo will enhance the Global warming effect. In addition, the melting of the Greenland and Antarctic ice sheets is the main factor causing sea level rise. Sea ice changes have caused an amplifying effect of climate warming, especially the famous "Arctic amplification", which is an important clue for the study of global and regional climate and environmental changes[1]. The reduction of sea ice in the Arctic not only changes the energy balance and material transfer process of the Earth system but also affects the ecosystem and human production activities. The many direct and indirect impacts of sea ice melting illustrate the extensiveness and complexity of the impact of sea ice in the Arctic [2]. Polar climate issues have become one of the problems plaguing the world.

Hakkinen et al. used data from buoys and Arctic floating ice stations to find that the speed of sea ice movement in the central Arctic Ocean has been on an upward trend since 1950. Since then, many studies based on buoy observations, satellite remote sensing, and other means have also confirmed the acceleration of Arctic sea ice [3]. The simulation study of the impact of black carbon on Arctic snow and sea ice by YU WANG et al. showed that under the forcing of CMIP6 and MERRA2 black carbon deposition, black carbon caused the average summer albedo of the Arctic Ocean to decrease by 0.82%~1.71% from 1980 to 2014, which intensified melting and ultimately caused the sea ice area to decrease by 0.97%~1.93%.[4]. The article points out that black carbon deposition, a human-generated pollutant, causes the surface temperature of sea ice(SC) to rise, leading to its melting.

Due to the important role of Arctic sea ice in the global climate system, related research has received widespread attention in recent years. However, existing studies have mostly focused on a single feature of sea ice change, such as thickness, density or surface temperature, and lack a comprehensive analysis of multiple change characteristics from a holistic perspective. Therefore, it is necessary to adopt a multidimensional research approach to fully understand the dynamic changes of sea ice in the Arctic.

Among them, sea ice remote sensing has multiple advantages over scientific expedition teams, the most prominent of which are high efficiency and reliability. Compared with manual scientific expeditions, the multi-spectral radar used in remote sensing is more reliable and can directly convert electromagnetic waves into data in no more than 1 hour. Whether it is active or passive means to obtain sea surface information, microwave remote sensing has all-weather observation capabilities, is not affected by sunlight, and is almost unaffected by weather systems[5].

In order to address the problem that a single research result cannot provide a comprehensive overview of the current situation, this study used multiple types of remote sensing data on sea ice conditions in the Laptev Sea and its northern waters from March 14, 2010, to March 14, 2024, to describe the dynamic changes of sea ice in this sea area from multiple perspectives and to rationally analyze the current status of climate change facing the Arctic Ocean. Finally, conclusions were drawn and relevant recommendations on slowing the melting of Arctic sea ice and future prospects were put forward.

2. Data and methods description

2.1. Research area

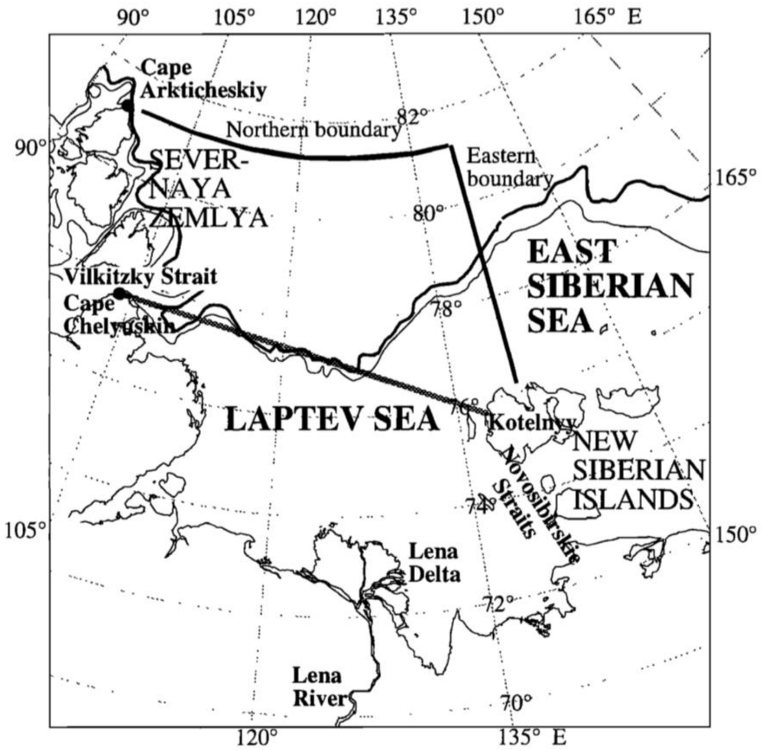

Fig.1 Research area’s map

The Laptev Sea is one of the marginal seas of the Arctic Ocean. It is located between the eastern coast of Siberia, the Taymyr Peninsula, Severnaya Zemlya, and the New Siberian Islands. Its specific spatial distribution is shown in Fig. 1. Its northern boundary starts from the Arctic Cape (81°13' N, 95°15' E) and extends eastward to 139°It is connected to the East Siberian Sea through the straits between the New Siberian Islands (Dmitri-Laptev Strait) in the east, and to the Kara Sea through the Velikitsky Strait between the Severnaya Zemlya Islands in the west [6]. The average depth is 519 meters, and the main ports are Nordvik Port and Tiksi Port. The Laptev Sea is the sea area with the most extensive distribution of fixed ice in the Arctic. Its spring fixed ice changes are closely related to the local climate, hydrological environment, and ecosystem [7]. Since the Taimyr Peninsula is located west of the Laptev Sea and blocks the influence of the North Atlantic warm current, the seasonal variation in the sea ice melting rate in the area is small, and the experiment can better control the variables.

2.2. Basic data

The experimental data for this study are all from the Terra and Aqua satellite MODIS (Moderate Resolution Imaging Spectroradiometer) data and the GCOM-W1 satellite AMSR2 (Advanced Microwave Scanning Radiometer 2) data on the worldview.earthdata.nasa.gov website, including sea ice distribution, sea ice surface temperature, sea ice density, a total of 46 scenes. In addition to being free to obtain, MODIS data also has certain advantages in terms of resolution [8]; AMSR-2 provides high-resolution the Arctic sea ice concentration(SC) data, which is more advantageous in describing the thin ice area at the edge. Since microwave radiation is almost unaffected by clouds, microwave data has good spatiotemporal continuity [9].Typical passive microwave imagery had a coarse resolution of around 30 km, which was suitable for overall trend observation rather than studying a particular area or location[10,11]. The data time window is from March 14, 2010, to March 14, 2024, with a time resolution of 1-2 years. The data are integrated and processed using relevant platforms to draw percentage line graphs.

2.3. Methods

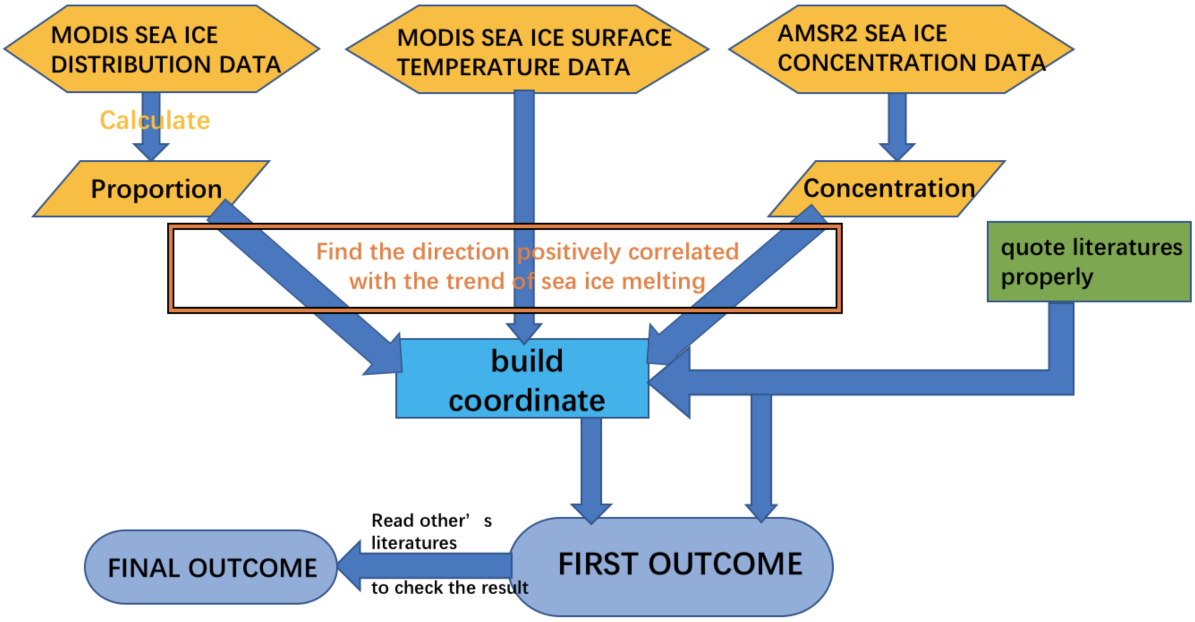

Fig. 2 Methods' flow chart

The method flow used in this study is shown in Fig. 2

Since the remote sensing data obtained from MODIS and AMSR2 have different specific factors, they are merged through their common points or common trends. Common trends include but are not limited to the trend of sea ice melting. When processing sea ice proportion(SP) data, the sea ice area is divided by the area of the study area and then multiplied by 100%; when obtaining the SC average value, the average of the maximum and minimum density values in the area is selected.

Technical process: Obtain the above three types of data from the website in the form of images and pre-process them. Use the "enhance contrast" and other tools to display, analyze, and enhance images, making the elements to be measured easier to identify and distinguish, Use plug-ins to classify images into different categories containing specific elements and other objects, and convert the classified raster data into vector data, Use the Field Calculator to calculate the area of each vector polygon. So that the ratio can be calculated using the formula. Finally, with the positive direction of the Y-axis being positively correlated with the trend of sea ice melting, three sets of data were introduced to produce relevant conclusions in line with the research purpose.

3. Results and discussion

Using MODIS data, after "sea ice element extraction", the SP line chart of the Laptev Sea was obtained, as shown by the orange curve in Fig. 3. The study area is 71.5°N 139.9°E to 78.2°N 101.3°E. Using AMSR2 data, after "averaging", the interannual variation chart of SC at the mouth of the Lena River was obtained (in percentage form), as shown by the green curve in Fig. 3. Using MODIS data, after positioning (75°N 129°E) and integration processing, the interannual variation chart of ST was obtained, with temperature in Kelvin (K), as shown by the blue curve in Fig. 3. The three data are reflected in the same figure, and the dotted line is the general trend of the data.

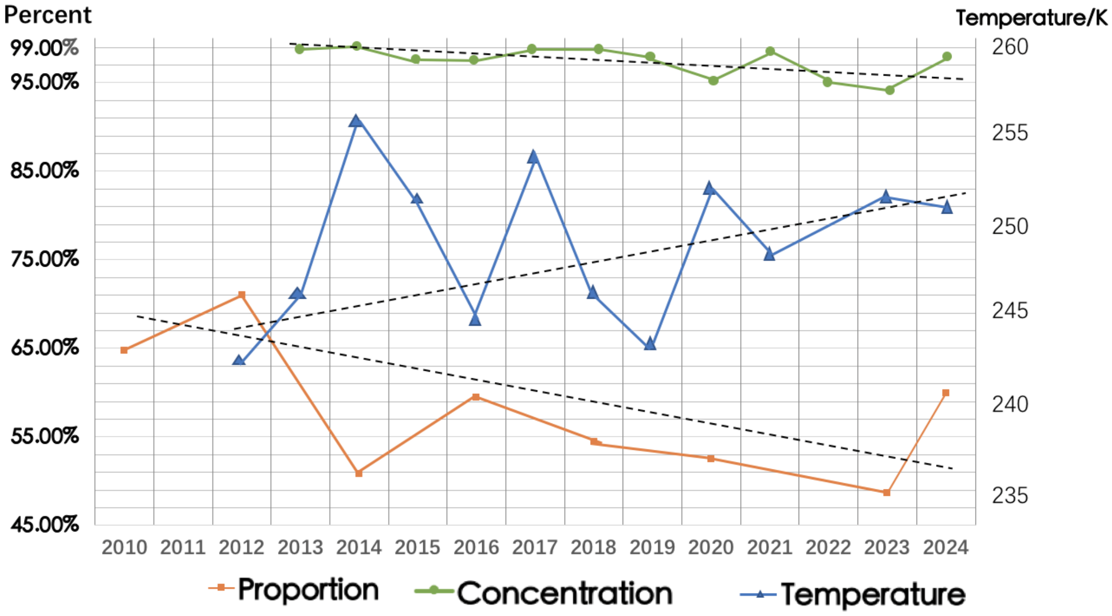

Fig. 3 Combined graph of sea ice proportion, concentration, and surface temperature

The yellow data line in Fig. 3 shows that the SP value dropped from 64.72% in 2010 to 59.94% in 2024, showing a clear downward trend. The maximum SP value is 71.04% and the minimum value is 48.70%, with large interannual variations. The average value from 2010 to 2016 is 61.53%, and the average value from 2016 to 2024 is 53.90%. Specifically, the decline in the SP value is not linear but shows a characteristic of decreasing volatility. For example, from 2012 to 2014, the proportion dropped from 71.04% to 50.86%, and from 2016 to 2023, it dropped from 59.49% to 48.70%. It can prove that the sea ice in the Laptev Sea is melting, and the overall sea ice reserves are decreasing.

The Lena River estuary delta is located in the southern part of the Laptev Sea. The SC value of the nearby waters changes significantly and the data is intuitive. The green data line in Fig. 3 shows that from 2013 to 2023, the SC value at the mouth of the Lena River fluctuated and decreased. Although there is a rebound trend in 2024, it decreases overall. Specifically, between 2013 and 2015, the sea ice density SC dropped from 98% to 96%, followed by a brief rebound between 2016 and 2018. Between 2018 and 2020, the SC value dropped to 95%, and continued to drop to 93.5% between 2021 and 2023. This fluctuating downward trend indicates that the sea ice at the mouth of the Lena River is gradually decreasing.

The blue data line in Fig. 3 shows that from 2013 to 2024, the ST value at 75°N 129°E in the Arctic Ocean showed a fluctuating upward trend. Between 2013 and 2015, the temperature surged from 242.2K to 255.6K, and then fell back to 244.5K between 2015 and 2017. Between 2020 and 2024, the temperature rose from 243.1K to 250.7 K. This fluctuating upward trend shows that despite the decline, the ST value is on an overall upward trend. Temperature change is the first driving force for sea ice melting, so monitoring temperature can effectively predict sea ice changes.

Table1. Sea Ice Quality Classification Table

Proportion	71.04%	64.72%	59.94% 59.49%	54.46%	52.48%	50.86%	48.70%
state	The sea ice reserves are large and the thickness is large; there are small holes in the sea ice near the coast	The thickness of sea ice in the far coastal areas has decreased; there are many small holes in the near-shore sea ice	There are fewer small holes in the far-shore sea ice, but more small holes in the near-shore	There are many small holes in the far-shore sea ice, but few large holes and many small holes in the near-shore sea ice.	There are more small holes and few large holes in the far-shore sea ice, while there are few large holes and more small holes in the near-shore	There are more small holes and few large holes in the far-shore sea ice; there are more small holes and large holes in the near-shore	There are more small holes and large holes in the far-shore sea ice; there are more small holes and large holes in the near-shore sea ice

As can be seen from Table 1, the sea ice conditions in the far and nearshore areas are different: when the ratio is high, the sea ice thickness on the far coast is large, and there are a few small holes in the nearshore area; as the ratio decreases, the small holes in the far and near coasts increase, and large holes also begin to appear, especially when the ratio is low, the number of large and small holes in the far and near coasts increases significantly, which reflects the degradation trend of the sea ice environment. The sea ice reserves are reduced and the sea ice structure is more fragile.

Table 2. Time, SP, SC, ST corresponding table

Time	SP	SC（%）	ST（k)
2010	0.6472		
2011			
2012	0.7104		242.2
2013		98	245.9
2014	0.5086	99	255.6
2015		96	251.5
2016	0.5949	96	244.5
2017		98	253.7
2018	0.5446	98	246
2019		97	243.1
2020	0.5248	95	251.9
2021		97.5	248.2
2022		95	
2023	0.487	93.5	251.5
2024	0.5994	97	250.7

Table 2 shows some sea ice-related data from 2010 to 2024. The table contains four columns: Time, SP, SC (%), and ST (K). SC and ST fluctuate in different years but do not show an obvious linear trend. SP reached its highest value (0.7104) in 2012 and dropped to its lowest value (0.487) in 2023; SC dropped from 98% to below 97%; ST rose from 242.2k to 250.7k. These data reflect the complex changes in the gradual deterioration of the sea ice environment.

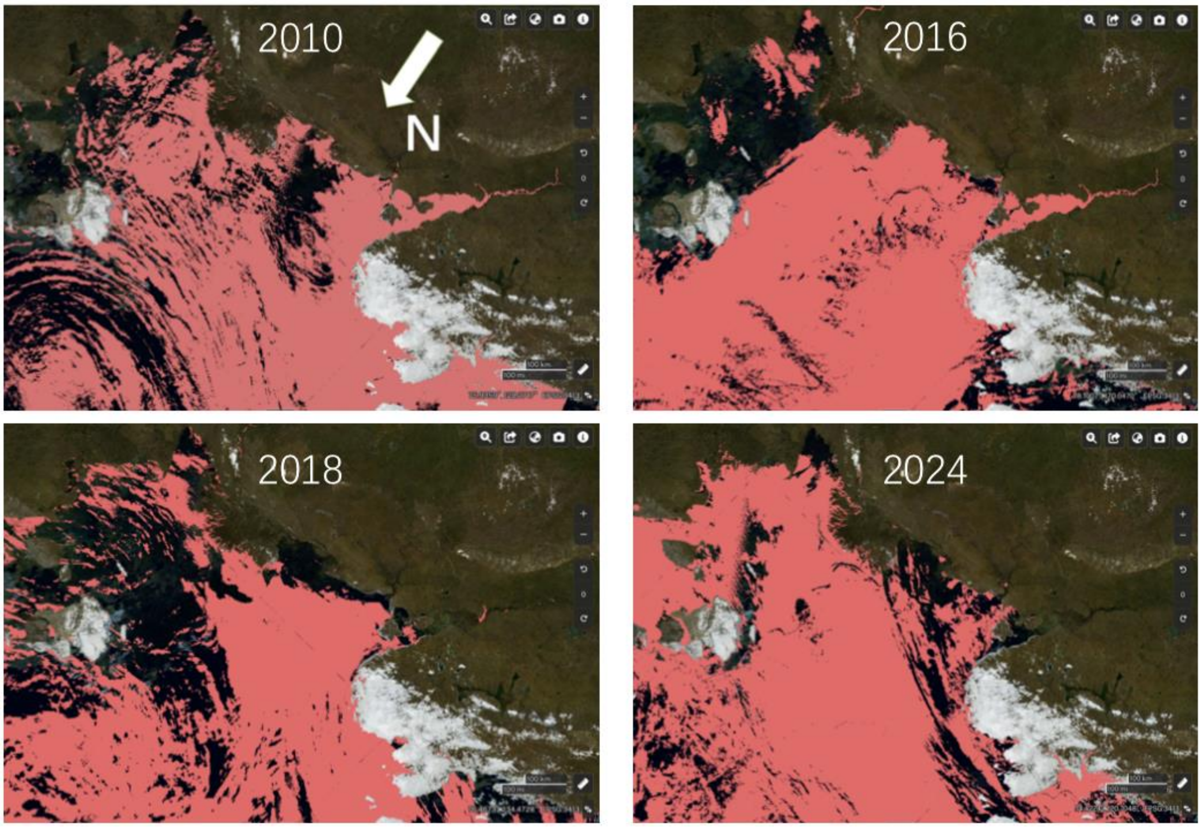

Fig. 4 2010-2024 MODIS SP yearly changes

As can be seen from Fig. 4, the sea ice in this sea area gradually melts from low latitudes to high latitudes, and there are more and more large-scale holes.

In the data of the Arctic Ocean in the past decade, there is a significant correlation between the SC, ST and SP values: in the past decade, the SC, SP and ST values of the Arctic Ocean showed a significant negative correlation, that is, as the surface temperature increased, the SC value decreased and the sea ice coverage decreased. For example, when the ST value increased from 242.2K to 250.7K, the SC value decreased from 98% to a minimum of 93.5%, and the SP value decreased from 64.72% to 59.94%; the SC value was positively correlated with the SP value, and the decrease in the SC value was also accompanied by a decrease in the SP value.

4. Conclusion

This paper mainly uses MODIS and AMSR2 data to monitor changes in Arctic sea ice. The data show that rising temperatures directly lead to the melting of sea ice. This trend is highly consistent with the background of global warming, further confirming the sensitivity of the Arctic region to global climate change.

From the time series, the sea ice density SC and surface temperature ST in the Arctic Ocean showed obvious fluctuations between 2010 and 2024. Combined with the background of global warming, this fluctuation may be related to the intensification of climate change. Global warming has caused the temperature in the Arctic to rise faster, and the melting of sea ice has also accelerated. The reduction of sea ice has not only affected the Arctic ecosystem but also had a profound impact on the global climate system. Through the results of this study, it can be predicted that if intervention is not strengthened immediately, the sea ice situation will continue to deteriorate, resulting in irreversible consequences.

Although environmental protection and related measures to curb global warming have been implemented, they only play a mitigating role, making the fluctuation range of data smaller. The temperature is still rising, the climate is still changing, the sea ice is melting, and global warming is intensifying. Understanding these changes is crucial to developing effective response strategies and protecting the future of the earth.

In addition, with the advancement of science and technology the development of the times, and the development of various sensors, satellite remote sensing technology has gradually played an irreplaceable role in Arctic sea ice monitoring. Therefore, combining multiple remote sensing modes to monitor the Arctic natural environment will be a major development direction.

In summary, the decrease in the density of Arctic sea ice is closely related to global warming. As global temperatures continue to rise, the trend of Arctic sea ice reduction may further intensify, causing more serious impacts on the global climate system and ecological environment. Therefore, taking effective measures to slow down global warming and protect the Arctic ecosystem has become a top priority, and using remote sensing to detect sea ice dynamics and conduct polar exploration is a good strategy.

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