Forecast of the Change Tendency of Sea Ice Extent in Liaodong Bay

Jinwen Wu 1, Longyu Sun2, Yushu Zhang 1, Rui Feng 1, Wenying Yu 1, Ruipeng Ji 1*

1 Institute of Atmospheric Environment (IAE), CMA, Shenyang, 110166
2 Meteorological bureau of Shenyang, Shenyang, 110168
Corresponding author: Ruipeng Ji, E-mail: jiruipeng@163.com

Abstract: Since massive sea ice occurs in the sea area of Liaodong Bay area, sea ice products are greatly demanded by offshore drilling platforms, marine transportation and coastal aquaculture. It is imperative to develop from sea ice monitoring to live + forecast of development tendency. An one-month latency response can be found between the maximum sea ice extent and the minimum average temperature as per their relationship. Hence, analysis on the latency correlation has been conducted through constructing sea ice tendency forecasting models for the sea ice developing and melting stages. According to the result, the negative accumulated temperature is a favorable forecasting factor since sea ice in Liaodong Bay is affected by the accumulated change of previous temperature factor. Besides, the sea ice extent is significantly correlated with the accumulated freezing temperature of ≤-2°C in the sea ice developing stage. And in the melting stage, the average maximum temperature of 11 days has the most significant correlation. What's more, as the accumulated temperature change rate is similar to the fluctuation of curve of the sea ice extent, the accuracy of the forecast model is climbed to 79% upon studying the relationship between the difference and the accumulated temperature change rate of the forecast model and the sea ice monitoring extent.

1. Introduction
According to the National Meteorological Disaster Prevention Plan, the coastal area is one of the six strategic regions, and sea ice is a primary focus of preventing meteorological disaster[1]. Since massive sea ices can be found in the sea area of Liaodong Bay area[2-3], sea ice monitoring, a remote sensing service product that is unique in Liaoning, is mostly needed by offshore drilling platforms, marine transportation and coastal aquaculture[4]. In that case, advancement from sea ice monitoring to live + forecast of development tendency is imperative. The Bohai Sea in China encountered the most serious sea ice in nearly 30 years in 2010, resulting in direct economic losses amounted to 6.318 billion yuan[5]. In particular, Liaoning suffered the biggest direct economic loss. Losses caused by sea ices have been increased year by year with the economic development. Hence, conducting remote sensing monitoring and forecast of sea ice is a key scientific issue that urgently needs to be addressed.
2. Data and Method

2.1. Study data
Meteorological data acquired from the Liaoning Meteorological Archives were applied in the study. To ensure data quality, continuous missing data was removed from the original data. Meanwhile, comprehensive and high-quality daily temperature and wind speed data (Fig.1) recorded in 12 surface meteorological stations and 42 meteorological stations along the coast of Liaoning from 2006 to 2016 were screened for studying the relationship between changes in sea ice extent and meteorological elements. Distribution of meteorological stations is presented in the figure below. LI Yanqing (2013)[6], WANG Meng (2016) [7]show that the change in the sea ice extent in Bohai Sea lags behind the temperature change with varied latency time presented in their respective studies concerning the relationship between the sea ice extent and meteorological elements.

![Fig. 1 Distribution of meteorological stations along the Liaodong Bay](image)

2.2. Latency analysis
Sea ice changes are subject to a variety of factors, of which, temperature change is the most immediately affected one. Sea-ice growth and decay are closely bound up with local temperature. Latency relationships of the sea ice extent with the average temperature, maximum temperature, minimum temperature, average wind speed, and maximum wind speed of coastal meteorological stations were analyzed in this study, that is, taking the average temperature as an example, the sea ice extent and the current temperature, the sea ice extent and the 2-day average temperature (the current day and the previous day), the sea ice extent and the 3-day average temperature (the current day and the previous two days) ... the sea ice extent and the 50-day average temperature. As can be seen from the results, changes in the sea ice extent are significantly negatively correlated with the average temperature, maximum temperature and minimum temperature. Specifically, changes in the sea ice extent in Liaodong Bay during the sea ice developing stage are significantly correlated with the average temperature, maximum temperature and minimum temperature over 5 days, i.e., -0.785, -0.781 and -0.781, respectively. Of which, it is more significantly correlated with the average temperature. In addition, changes in the sea ice extent in Liaodong Bay during the sea ice melting stage are significantly correlated with the average temperature, maximum temperature and minimum temperature over three days, i.e., -0.724, -0.736 and -0.712, respectively. Of which, it is more significantly correlated with the average maximum temperature.

3. Result and Analysis

3.1. Relationship between the change tendency of sea ice area and temperature
In general, sea ice can be witnessed in Liaodong Bay in early December. The latency analysis indicates that the extent change of sea ice in the developing stage has the maximal relationship with the average
temperature of 37 days, while it has the maximal relationship with the average temperature of 11 days during the melting stage. Hence, the relationship between the accumulated freezing temperature since November and changes in the sea ice extent was studied in the sea ice developing stage with the accumulated temperature of the average daily temperature of ≤-4°C and ≤-2°C as indicators. And the relationship between the accumulated ice melting temperature after having the maximum sea ice extent and changes in the sea ice extent was studied in the sea ice melting stage with the accumulated temperature of the average maximum temperature of >-4°C and >-2°C as indicators. It can be found that the sea ice extent is significantly correlated with the accumulated temperature of ≤-4°C during the sea ice developing stage, showing a correlation coefficient of 0.812 (P<0.001, Fig. 2a), while the sea ice extent is more significantly correlated with the accumulated temperature of ≤-2°C, showing a correlation coefficient of 0.814 (P<0.001, Fig. 2b). Besides, the sea ice extent is insignificantly correlated with the accumulated ice melting temperature during the melting stage. When the sea ice extent is decreased continuously during the melting stage, the ice extent will be rapidly reduced with little change in the accumulated temperature. The corresponding relationship between ice extent in different areas and the accumulated temperature is varied remarkably with disperse corresponding points (Fig. 2c & 2d). Therefore, the sea ice extent during the melting stage can be forecast to the maximum using the correlation of the sea ice melting stage and the average maximum temperature of 11 days (Fig. 2e).
3.2. Forecast of the change tendency of sea ice extent in Liaodong Bay
Tendency forecasting models have been established for the sea ice extent in Liaodong Bay in the sea ice developing and melting stages.

\[
\begin{align*}
\text{sea ice developing, } Y &= -26.08X + 44 \\
\text{sea ice melting stages, } Y &= -1863X_1 + 903.6
\end{align*}
\]

Where, \( Y \) is the sea ice extent; \( X \) is the accumulated temperature of \( \leq -2 \)\(^\circ\)C of meteorological stations along the Liaodong Bay; \( X_1 \) is the average maximum temperature of meteorological stations along the Liaodong Bay within 11 days. The sea ice extent is increased by nearly 26 square kilometers during the developing stage for every 1\(^\circ\)C increase in the accumulated ice temperature. And sea ice will be melted theoretically during the sea ice melting stage when the average maximum temperature is close to 0.5\(^\circ\)C.

3.3. Correction of the forecast model
As the accumulated temperature change rate is similar to the fluctuation of curve of the sea ice extent according to the study, the relationship between the difference and the accumulated temperature change rate of the forecast model and the sea ice monitoring extent has been studied. The findings show that a significant linear relationship is presented with the correlation coefficient of 0.778 (P <0.005). On this basis, the model was corrected. The model is corrected as:

\[
\begin{align*}
\text{sea ice developing, } Y &= -26.08X + 44 - \Delta Y \\
\text{sea ice melting stages, } Y &= -1863X_1 + 903.6 - \Delta Y \\
\Delta Y &= 138.9X_2 - 2689
\end{align*}
\]

\( X_2 \) is the changing rate of accumulated temperature. The forecast accuracy of the model is 79\%.

4. Conclusion and Discussion
According to the relationship between the maximum sea ice extent and the minimum average temperature, an one-month latency response can be found between the two. Hence, analysis on latency correlation has been conducted through constructing sea ice tendency forecasting models for the sea ice developing and melting stages. The result shows that the negative accumulated temperature is a favorable forecasting factor since sea ice in Liaodong Bay is affected by the accumulated change of previous temperature factor. In addition, the sea ice extent is significantly correlated with the accumulated freezing temperature of \( \leq -2 \)\(^\circ\)C during the sea ice developing stage, while it is more significantly correlated with the average maximum temperature or 11 days during the melting stage. When the sea ice extent is decreased continuously during the melting stage, little change is observed in the accumulated temperature. The forecast change of the sea ice extent is substantially agreed with the satellite monitoring result, showing the forecast accuracy of 73\%. However, the one-peak change characteristic does not necessarily match with fluctuations in the sea ice extent during the sea ice developing stage. What's more, as the accumulated temperature change rate is similar to the fluctuation of curve of the sea ice extent, by studying the relationship between the temperature difference of the
prediction model and the change rate of accumulated temperature and the monitoring range of sea ice, the model prediction is increased to 79%.

**Funding information:**
This work was financially Co-sponsored by the Natural Science Foundation Guidance Plan of Liaoning Province (2019-ZD-0857), the basic scientific research projects of the central public welfare research institutes (2015IAE-CMA04, 2018SYIAEZD1, 2018SYIAEHZ1), and the industrialization of CHEOS application project (70-Y40G09-9001-18/20)

**References**
[1] Yuan Ben-kun, Cao Cong-hua, Jiang Chong-bo, et al. Journal of Catastrophology. 2016, 31(2): 42
[2] Emergency office of the China Meteorological Administration, Emergency management in China. 2015, 3.
[3] Wang Ning. Important parameters extraction and detection system for sea ice in Bohai based on MODIS data. Ocean University of China. 2009, 1-7
[4] Ke Chang-qing, Xie Hong-jie, Lei Rui-bo, et al. Spectral features analysis of sea ice in the Arctic ocean. Spectroscopy and Spectral Analysis, 2012, 32(4): 1081-1084
[5] Liu Yu-cheng, Gu Wei, Li Lan-tao, et al. Acta Oceanologica Sinica. 2013, 35(3): 113-118
[6] Li Yan-qing. The Retrieval, Assimilation, Pentadly Averaged Time Series Building and Analysis of Sea Ice in the Bohai Sea Using the Visible Remote Sensing Data. Ocean University of China, 2013
[7] Wang Meng, Wu Sheng-li, Zheng Wei, et al. Temporal-spatial Distribution of Bohai Sea Sea-ice in Long-Time Series and Its Correlation with Air Temperature. Meteorological, 2016, 042(010): 1237-1244.