

## Spatiotemporal Variations and Influencing Factors of Lake Ice Phenology in Large Lakes of the Arid Region of Northwest China (Postprint)

**Authors:** Lingmin Zhou, Imran Kurban, Yusupjan Rusuli, Wu Haizhi, Nazakat Nijat

**Date:** 2026-03-24T22:05:26+00:00

### Abstract

Based on the Bayesian ensemble change detection algorithm, this study integrates passive microwave data, MODIS, and meteorological and hydrological data to comprehensively analyze the phenological change characteristics and influencing factors of lake ice for seven large lakes in the arid region of Northwest China from 1978 to 2022. The results indicate that: (1) The mean coefficient of determination for the cross-validation between passive remote sensing data and Landsat data is 0.86, with a mean absolute error and root mean square error of 1.56 d and 2.52 d, respectively, demonstrating that the method of obtaining lake ice phenology information from passive remote sensing data is feasible and reliable, despite local variations. (2) The average freeze-up start date for the seven lakes in the arid region of Northwest China occurs between November 17 and January 19 of the following year, while the average complete break-up date occurs between July 11 and October 25, with an average ice cover duration of 143 d. The ice cover duration shows a shortening trend across all lakes, with Bosten Lake showing the smallest shortening rate at  $0.24 \text{ d} \cdot (10\text{a})^{-1}$  and Sayram Lake showing the largest shortening rate at  $0.55 \text{ d} \cdot (10\text{a})^{-1}$ . (3) From 1978 to 2022, the freeze-up dates of lakes in the arid region of Northwest China exhibited both advancing and delaying trends, while the break-up dates consistently showed an advancing trend. For most lakes, the freeze-up start and complete freeze-up dates showed a delaying trend, with delay rates ranging from 0.09 to  $0.38 \text{ d} \cdot (10\text{a})^{-1}$  and 0.24 to  $0.29 \text{ d} \cdot (10\text{a})^{-1}$ , respectively; a few lakes (such as Jili Lake and Bosten Lake) showed an advancing trend in freeze-up dates. High-latitude lakes (except Ebinur Lake) showed a significant advancing trend in break-up, with rates between 0.27 and  $0.48 \text{ d} \cdot (10\text{a})^{-1}$ , while high-altitude lakes showed a slower advancing trend in break-up, with rates between 0.12 and  $0.27 \text{ d} \cdot (10\text{a})^{-1}$ . (4) The freezing and thawing of large lakes in the arid region of Northwest China are jointly influenced by meteorological factors (wind speed,

snow cover, precipitation, near-surface temperature) and hydrological factors (lake area, transparency). Specifically, near-surface temperature directly affects the freezing and thawing of lake ice, while lake area and transparency indirectly influence lake ice phenological processes by regulating the heat capacity of the water body and the absorption of solar radiation.

## Full Text

# Spatiotemporal Variations and Influencing Factors of Lake Ice Phenology in Large Lakes of Arid Northwestern China

Zhou Lingmin, Imuran Kuruwan, Yusupujiang Rusuli, Wu Haizhi, Nazaketi Nijiati (*School of Geography and Tourism, Xinjiang Normal University, Urumqi 830000, China*)

## Abstract

Lake ice phenology serves as a sensitive indicator of regional climate change. This study investigates the spatiotemporal characteristics and driving mechanisms of lake ice phenology in large lakes across the arid regions of Northwestern China. By utilizing the Bayesian Ensemble Change Detection (BECD) algorithm, we integrate passive microwave data, MODIS imagery, and meteorological and hydrological observations from 1978 to 2022. The results indicate significant spatial heterogeneity and temporal shifts in ice phenology across the study area. Average ice cover duration is approximately 143 days, with a universal shortening trend observed across all studied lakes. These shifts are primarily driven by variations in temperature, solar radiation, and local geographical factors such as lake area and depth. These findings provide critical insights into the hydrological responses of arid-zone lakes to global warming.

## 1 Introduction

Lake ice phenology, which includes the timing of freezing (ice-on), thawing (ice-off), and the total duration of ice cover, is a key component of the cryosphere and a sensitive “sentinel” of climate change [?]. In the arid regions of Northwestern China, large lakes play a vital role in maintaining regional ecological balance, regulating local climate, and supporting water resources. However, under the context of global warming, these lakes have undergone significant changes in their seasonal ice cycles.

Previous studies have shown that rising surface air temperatures are the primary driver behind the delayed freezing and earlier thawing of lake ice globally [?]. In the specific context of Northwestern China, the complex topography and extreme aridity introduce unique variables—such as high evaporation rates and significant diurnal temperature fluctuations—that influence ice dynamics differently than in humid or high-altitude regions like the Tibetan Plateau [?].

Understanding these spatiotemporal variations is essential for predicting future water availability and ecological shifts in these fragile environments.

## 2 Materials and Methods

### 2.1 Study Area

The study area encompasses the vast arid and semi-arid regions of Northwest China ( $73^{\circ} \sim 123^{\circ}\text{E}$ ,  $32^{\circ} \sim 50^{\circ}\text{N}$ ), characterized by a temperate continental climate with sparse precipitation and intense evaporation. The “mountain-basin-desert” topographical transition shapes complex hydrothermal gradients. Seven large lakes with surface areas exceeding  $500 \text{ km}^2$  were selected: Ulungur Lake, Aydingkol Lake, Bosten Lake, Sayram Lake, Jili Lake, Hara Lake, and Qinghai Lake .

### 2.2 Data Sources

To ensure high temporal resolution and long-term monitoring, we utilized multi-source remote sensing and meteorological data:

1. **Passive Microwave Data:** Calibrated passive microwave brightness temperature (CETB) data from SMMR, SSM/I, and SSMIS sensors (1978–2022) with a spatial resolution of  $3.125 \text{ km}$  [?].
2. **MODIS Data:** MOD10A1 and MYD10A1 snow cover products ( $500 \text{ m}$  resolution) used for cross-validation, providing daily observations of snow and ice cover [?].
3. **Meteorological and Hydrological Data:** Near-surface temperature, precipitation, solar radiation, and wind speed from ERA5-Land reanalysis ( $0.1^{\circ}$  resolution). Lake area and transparency data (1990–2018) were provided by the National Tibetan Plateau Data Center.

### 2.3 Bayesian Ensemble Change Detection (BECD)

The BECD algorithm [?] serves as the core analytical framework. Unlike deterministic methods, the Bayesian approach quantifies uncertainty by calculating the posterior probability of change events. The model identifies four key transition points in the brightness temperature ( $T_b$ ) time series: - **Freeze-up Start (FUS):** The date when  $T_b$  begins a sustained shift, indicating initial ice formation. - **Freeze-up End (FUE):** The date when the lake is completely ice-covered and  $T_b$  stabilizes. - **Break-up Start (BUS):** The onset of ice melting, marked by a rapid increase in  $T_b$ . - **Break-up End (BUE):** The date when the lake is ice-free and  $T_b$  reaches a stable high value.

The algorithm filters for points with high change-point probability and significant slope variations, automating the extraction process without manual threshold setting.

## 3 Results and Discussion

### 3.1 Accuracy Assessment

Cross-validation between passive microwave results and high-resolution Landsat/MODIS data yielded an average coefficient of determination ( $R^2$ ) of 0.86. The mean absolute error (MAE) and root square error (RMSE) were 1.56 days and 2.52 days, respectively. This demonstrates that the BECD method is highly reliable for extracting long-term phenological sequences [Figure 1: see original paper].

### 3.2 Spatiotemporal Variations

From 1978 to 2022, the average start date for lake freezing across the seven lakes occurred between November 17 and January 19. The average ice cover duration was 143 days. A universal shortening trend in the ice cover period was observed: - **Bosten Lake**: Smallest shortening rate at  $0.24 \text{ d} \cdot (10\text{a})^{-1}$ . - **Sayram Lake**: Most significant shortening trend at  $0.55 \text{ d} \cdot (10\text{a})^{-1}$ .

In high-latitude regions, break-up dates showed significant advancement rates ( $0.27$  to  $0.48 \text{ d} \cdot (10\text{a})^{-1}$ ), while high-altitude lakes exhibited a more gradual advancement ( $0.12$  to  $0.27 \text{ d} \cdot (10\text{a})^{-1}$ ). Freeze-up dates generally showed a delaying trend, with rates ranging from  $0.09$  to  $0.38 \text{ d} \cdot (10\text{a})^{-1}$ .

### 3.3 Driving Mechanisms

The thermodynamics of lake ice are governed by the energy balance:

$$R_n = H + LE + G$$

where  $R_n$  is net radiation,  $H$  is sensible heat,  $LE$  is latent heat, and  $G$  is heat storage. Near-surface temperature is the primary driver of the freezing process, modeled by the Stefan problem where ice thickness  $h(t)$  is:

$$h(t) = \sqrt{\frac{2k \int (T_f - T_a) dt}{\rho L}}$$

Hydrological factors also play a role; larger and deeper lakes possess greater thermal inertia, delaying freeze-up. Transparency influences the absorption of solar radiation, indirectly affecting the break-up timing.

## 4 Conclusion

This study demonstrates that the Bayesian Ensemble Change Detection approach effectively synthesizes multi-source data to monitor lake ice phenology in arid regions. The observed trends—delayed freezing, earlier thawing, and shortened ice duration—reflect the sensitivity of Northwest China's hydrological systems to global warming. Future work will focus on the ecological impacts of these phenological shifts on aquatic habitats and regional water security.

**Keywords:** Lake ice phenology; Spatiotemporal differences; Bayesian ensemble change detection; Influencing factors; Arid regions of Northwest China

*Note: Figure translations are in progress. See original paper for figures.*

*Source: ChinaXiv –Machine translation. Verify with original.*