

Ice breakup dates on 18 Eurasian lakes estimated by MODIS data from 2001 to 2005.

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Abstract

Ice breakup date is one of the important indices showing climate changes, and we had developed the ice breakup date estimation method using satellite data to infer the ice breakup date of the lakes with no available in-situ data. In this study, ice breakup dates on 18 Eurasian lakes from 2001 to 2005 were estimated using water temperature trend derived from MODIS data. The annual changes of the ice breakup dates were different by the location, elevation, local climate, and so on. In the next stage, we evaluated the relationships between ice breakup dates and mean air temperature. The result showed that 1 day change of the ice breakup date represented the 0.2 °C changes of the mean air temperature.

1. Introduction

Snow and ice is widely taken up as one of the important indices showing climate change (IPCC 2001). It is reported that the ice breakup date of lake and river has become early about fewer weeks over the past century (Magnuson *et al.* 2000). Here, the ice breakup date means that a first day when a specific area of lake surface is completely free of ice. However, few ice breakup date data of the lakes on the central part of the Eurasian continent, for example Lake Baikal (Shimaraev *et al.* 1994), are recorded. We have developed ice breakup date estimation method using water temperature trend derived from satellite thermal infrared data to obtain the information for the lakes with no available records (Nonaka *et al.* accepted). In this study, we estimated the ice breakup date on 18 Eurasian lakes from 2001 to 2005 using Moderate Resolution Imaging Spectroradiometer (MODIS) data. From the time series analysis, the relationships between ice breakup dates and local climates were also discussed.

2. Ice Breakup Date Estimation Method

The ice breakup date estimation method we developed was based on Bussieres *et al.* (2002), and using the water temperature trend. The method uses the slow seasonal lake surface temperature variation, and ice breakup date is estimated by going back from a time series of the surface temperature data derived from satellite thermal infrared data (Fig. 1).

Fig. 2 shows the flowchart of the developed ice breakup date estimation method and used data when

the ice breakup date is estimated by MODIS data. It consists of two parts, the threshold surface temperature estimation and water temperature trend analysis. First, the surface temperature when the lake surface is completely free of ice (threshold surface temperature, T_{TH}) is determined. The surface temperature data of the lake are derived from the Sea Surface Temperature (SST) products (Brown and Minnett 1999). In the process, we use the reflectance data of near infrared band as well as SST data. Secondly, lake surface temperature data on a clear day are derived using the cloud mask, and the surface temperature (ST) is plotted against date (t). In the next stage, ST data after snow and ice on the lake is completely melted and ST rises are selected, and expressed as a quadratic regression equation by t

$$ST = at^2 + bt + c \quad (1)$$

where a , b , and c are coefficients determined by least square fit. Finally, the intersection of the regression equation and T_{TH} is the ice breakup date.

The accurate T_{TH} estimation is important for the method because 1 °C change of the T_{TH} corresponds to more than 10 days change of the ice breakup date for some study lakes. The estimated T_{TH} for freshwater was 2 °C, while that for seawater was 0.5 °C (Nonaka *et al.* accepted). When we evaluated the developed method using in-situ data of Saroma-ko Lagoon and Lake Baikal, the accuracy was better than 3 days.

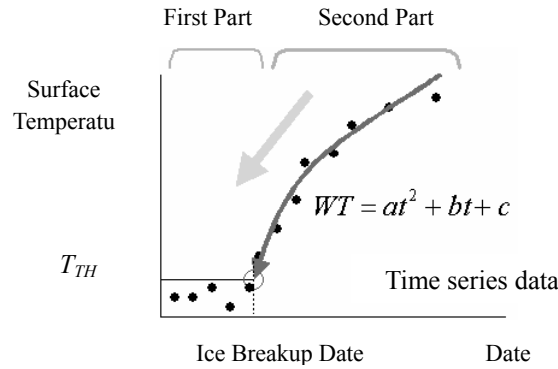


Fig. 1. Schematic of the ice breakup date estimation method using water temperature trend.

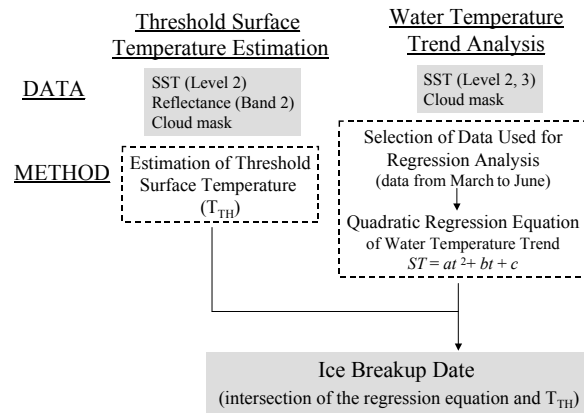


Fig. 2. The flowchart of the ice breakup date estimation method and used data when ice breakup date is estimated by MODIS data.

3. Ice Breakup Date on 18 Eurasian Lakes from 2001 to 2005

3.1 Used Data

Satellite sensor data are generally only useful for estimating ice breakup dates if the satellite has a short revisiting time. When using sensors with thermal infrared bands, such as the MODIS and the Advanced Very High Resolution Radiometer (AVHRR) satisfy this condition. In this study, we rely on MODIS data to estimate the ice breakup dates in order to take the advantages of thoroughly prepared information on products such as cloud mask, SST, and so on.

The sensor performs quite well estimating SST, with an estimation accuracy of 0.25 °C within the range of -2 °C to 32 °C (Evans 2002). Our estimation of the ice breakup dates on the 18 lakes investigated in this study were performed using MODIS Level 3 mapped SST data products with 4.89 km resolution collected during daytime from 2001 to 2005.

3.2 Study Lakes

Using ILEC (2001), we selected 18 freshwater lakes (Table 1, Fig. 3) in the central part of the Eurasian continent for investigation in this study. All of the lakes are larger than about 2000 km². Some are manmade reservoirs, and one is partially saltwater (the east part of Lake Balkhash).

Table 1. Features of the 18 Eurasian lakes investigated in this study.

No	Lake	Country	Latitude, Longitude	Elevation (m)	Volume (10 ³ km ³)	Surface Area (km ²)
1	Peipsi	Russia/ Estonia	58.4 °N, 27.4 °E	30	25	3558
2	Ladoga	Russia	60.5 °N, 31.2 °E	5	908	18135
3	Onega	Russia	61.5 °N, 35.2 °E	35	280	9890
4	Rybinsk	Russia	58.0 °N, 38.5 °E	102	25	4550
5	Tsimlyansk	Russia	48.2 °N, 43.1 °E	36	24	2702
6	Volgograd	Russia	50.2 °N, 45.4 °E	15	31	3120
7	Kuibyshev	Russia	54.5 °N, 49.4 °E	53	57	5900
8	Kama	Russia	58.3 °N, 56.1 °E	109	12	1910
9	Balkhash	Kazakhstan	45.4 °N, 76.2 °E	341	106	18200
10	Chany	Russia	54.5 °N, 77.4 °E	106	4	2010
11	Zaisan	Kazakhstan	48.0 °N, 83.5 °E	341	53	5510
12	Krasnoyarsk	Russia	54.5 °N, 91.4 °E	243	73	2000
13	Khubsugul	Mongolia	51.0 °N, 100.2 °E	1645	Not obtained	2760
14	Bratsk	Russia	54.4 °N, 102.1 °E	402	169	5478
15	Baikal	Russia	53.4 °N, 106.4 °E	456	230000	31500
16	Vilyuisk	Russia	62.5 °N, 111.1 °E	244	36	2170
17	Zeya	Russia	54.2 °N, 128.1 °E	315	68	2119
18	Khanka	Russia	44.5 °N, 132.2 °E	69	18	4190

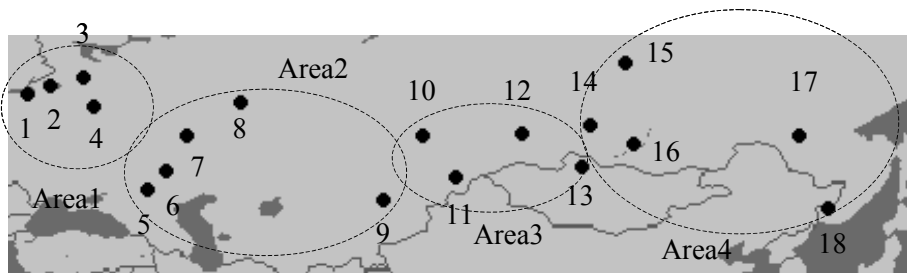


Fig. 3. The location of the study lakes. The each number correspond to the lake in table 1.

3.3 Results

The ice breakup dates on the 18 Eurasian lakes were estimated using the developed method (Fig. 2). The threshold of all of these lakes was assumed to be 2.0 °C, the estimated value for freshwater lakes (in the case of Lake Balkhash, only the western freshwater was selected), and the daily Level 3 mapped SST data from March to June were used for all estimation, and the water temperature trend was evaluated as a quadratic equation (1) for each lake (coefficients a , b , and c of each lake are not reported). Surface temperature was defined as the mean value of 3×3 pixels at the center of each lake.

Fig. 4 shows the ice breakup dates (Julian day) of these lakes for 5 years. The ice breakup dates in 2002 and 2004 are relatively earlier for some of the study lakes, especially lakes in area 1 and area 2). In contrast, the ice breakup date in 2005 is earlier than in 2004 for Lake Chany, Zaisan, Vilyuisk and Zeya in area 3 and 4. Moreover, clear trend of the time series is not observed for lakes at high elevation of area 3, except Lake Khubsugul. We postulate these features are mostly related with the air temperature trend in spring, so the relationships between ice breakup dates and mean air temperature is dealt in the next section.

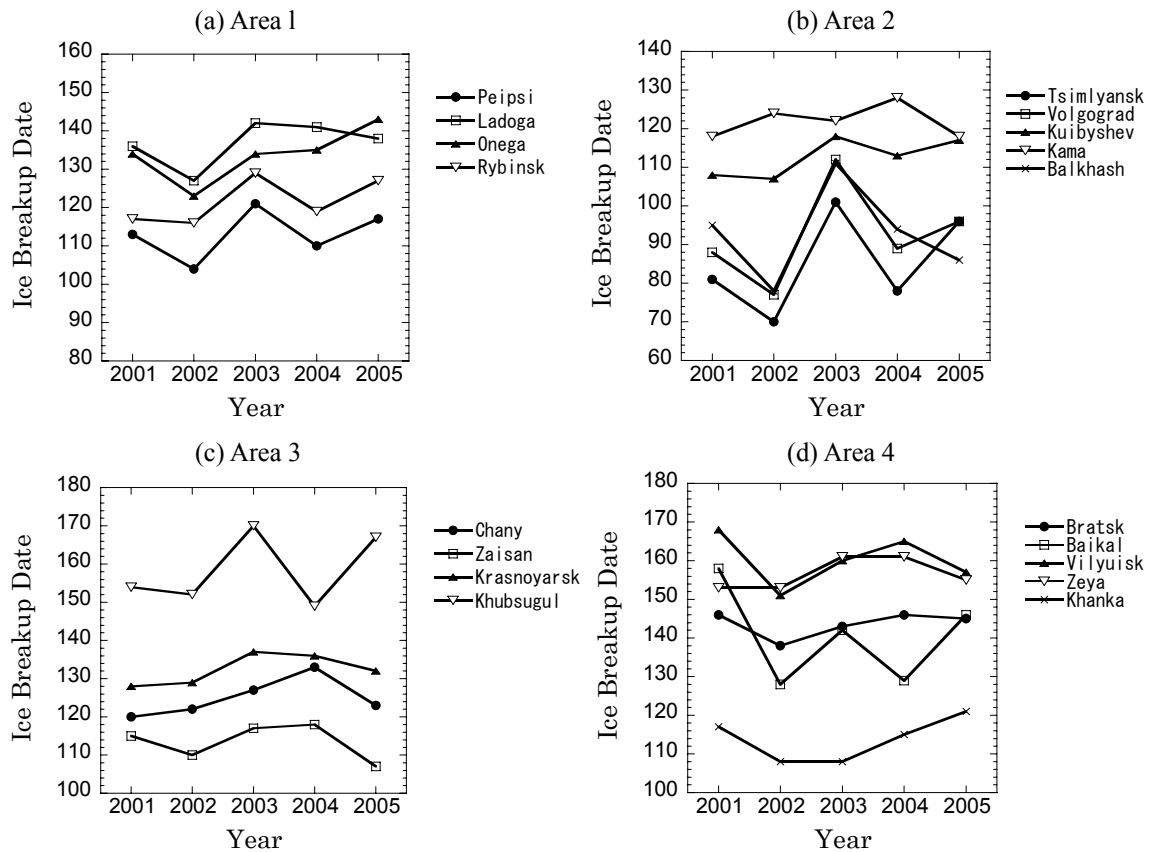


Fig. 4. Ice breakup dates of 18 study lakes on the Eurasian continent from 2001 to 2005.

3.4 Relationships between ice breakup dates and air temperature

The relationships between ice breakup dates and local air temperature are discussed in this section. Air

temperature data were derived from National Center for Environmental Prediction/ National Center for Atmospheric Research (NCEP/NCAR) data set (Kistler *et al.* 2001). It is noted that the effects of air temperature is different by the time of the ice breakup dates. Palecki and Barry (1986) showed that the ice breakup date is correlated most with air temperature in previous month. Accordingly, we used the mean values from March to May in this study taking into consideration of the ice breakup date of study lakes.

Fig. 5 shows the time series of the mean air temperature for each area from 2001 to 2005. The air temperature was averaged for the all lakes of each area. We can see that the air temperature in 2002 and 2004 are relatively higher than other years in area 1, corresponding to the ice breakup dates. Further, the fact that the ice breakup dates in 2005 is earlier than in 2004 for some of the lakes in area 3 and 4 can be explained from the increase the air temperature from 2004 to 2005.

Fig. 6 shows the relationships between ice breakup dates (*IB*) and mean air temperature (*T*). The linear regression equation was expressed as:

$$T = 27.05 - 0.20 IB \quad (2)$$

The correlation coefficients of the equation (2) were -0.93 , and the rms error was about $1.8\text{ }^{\circ}\text{C}$. This equation means that a day change of the ice breakup date corresponded the $0.2\text{ }^{\circ}\text{C}$ changes of the mean air temperature from March to May. These results suggest that annual changes of the ice breakup date mostly can be explained from the mean air temperature.

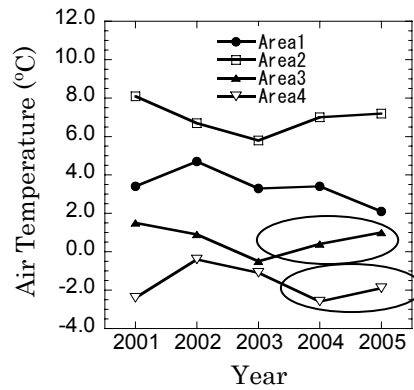


Fig. 5. Time series of the mean air temperature for each area from 2001 to 2005.

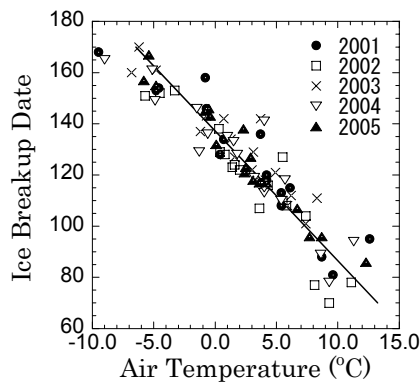


Fig. 6. The relationships between ice breakup date on 18 Eurasian lakes and mean air temperature for each year.

4. Summary

Ice breakup dates on 18 Eurasian lakes from 2001 to 2005 were estimated using water temperature trend derived from MODIS data. The annual changes of the ice breakup dates were different by the location, elevation, local climate, and so on. In the next stage, we evaluated the relationships between ice breakup dates and mean air temperature. The result showed that 1 day change of the ice breakup date represented 0.2 °C changes of the mean air temperature from March to May. We need long term of the ice breakup dates to grasp the relationships between ice breakup dates and local climate more detail, and it is left for future studies.

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