Estimation of Lake Ice Thickness Using Measured Temperature Profile in Ice and Water

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ABSTRACT

Ice thickness is an important parameter in studies on engineering and climate change, and it is also difficult to obtain even by present methods of field investigation and remote sensing. Retrieval of ice thickness from measurement of ice temperature profile from buoy data is a potential method, but the retrieval method is still not so robust to different situations. To solve this problem, ice temperature profiles obtained by the temperature chain in Ulansuhai Lake from January to March 2016 were employed. The temperature profiles in ice were summarized into 6 typical types by analyzing the data and fitting the curve with different equations, such as the one or three order polynomial and the cubic spline function. Ice-water interface was estimated by the location of the 0 degrees Celsius on the temperature profile. Comparing the ice thickness obtained from the different fitting equations with that obtained from field measurements, it is showed that the difference between the ice thickness that estimated by the temperature profile and the measured data is less than the interval of temperature probe on the profile, namely, 5cm.

KEY WORDS: Ice thickness, Ice-water temperature profile, Fitting equation

INTRODUCTION

The sea-ice thickness distribution in the polar region has been shown to respond sensitively to global climate change (Mitchell et al., 1990). The ice hinders exchanges between the ocean and atmosphere, reflects solar radiation back to space, is an obstacle to ship travel, and has numerous impacts on plant and animal species (Haas et al., 2008; Parkinson, 2004). Recent years, the arctic sea ice extent in summer has famous reduced (Parkinson at al., 2008). The ice cover, extent and ice thickness are the most important parameters for the ice research. For these parameters, we can use different methods to obtain. The remote sensing can offer the highest spatial resolution for extraction of daily available, global sea ice concentration data (Spreen et al, 2008). It can also offer the ice thickness, but the accuracy of the result from remote sensing need to be further investigated (Laxon at el., 2013). Drilling is the most accuracy method to measure the ice thickness, but it can't be continue measurement in Arctic. The buoy is more and more widely used in Arctic research. We can get the ice-water temperature profile from the buoy data (Cheng at el., 2014). Retrieval of ice thickness from measurement of the ice-water temperature profile is a potential method, but the retrieval method is still not so robust to different situations .

In this paper, we measured ice-water temperature on Ulansuhai Lake, in Inner Mongolia China. We applied the temperature chain to measure ice-wate temperature and the underwater ultrasonic range finder to monitor the ice thickness. Our objectives are to: (1) Class the cure of the ice-water temperature profile by analyzing of the temperature profile data; (2) Use different equations to fit the temperature profile and retrieval of ice thickness; (3) Compare the ice thickness that estimated and measured data.

MEASUREMENT PLACE AND OBSERVATIONS

Measurement Place

Ulansuhai Lake is a freshwater lake in China, it is located in southwest of Inner Mongolia, situated in the north bank of the middle reaches of Yellow River (Figure 1). The lake is 233 km^2. The ice season lasts 4 months (from Dec. to Mar.), and the maximum ice thickness usually reaches more than 40 cm in late Junary, just before the onset of ice melt. We measured ice temperature profiles from January 12th to March 10th. The water depth of measurement place was 2.2 meters.

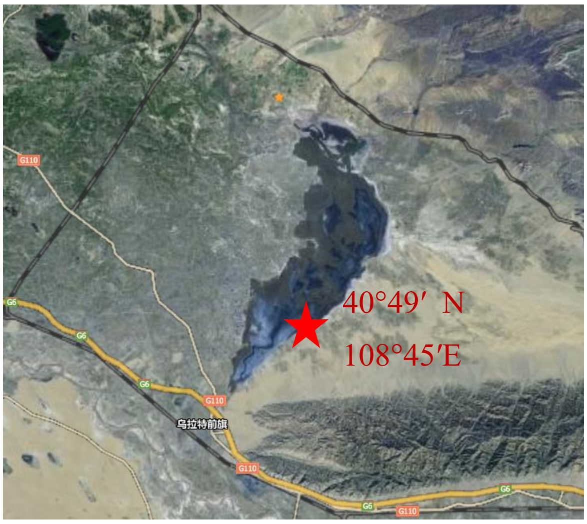

Figure 1. The Ulansuhai Lake and the measurement place

Measurement Method and Equipment

The temperature profile was measured by the platinum resistance temperature chain made by Dalian University and Technology. The interval of sensor is 5cm in the first 60cm, 40cm in the last 160cm. The accuracy of the temperature sensor is 0.01° C and the sampling interval is 1 min. The color map of temperature profiles are shown in Figure 2.

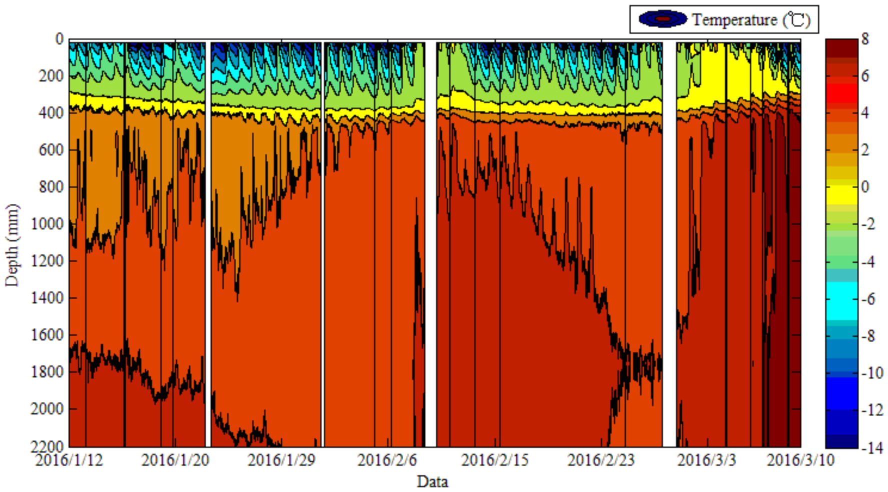

Figure 2. The color map of temperature profiles

The ice thickness was measured by an acoustic sensor in the interval 10 min. The measuring accuracy of the acoustic sensor is 0.1 mm. For recognizing the acoustic correction, there was thermal line method and drill method to measure ice thickness in random time. The three methods got fitted well data, see Figure 3.

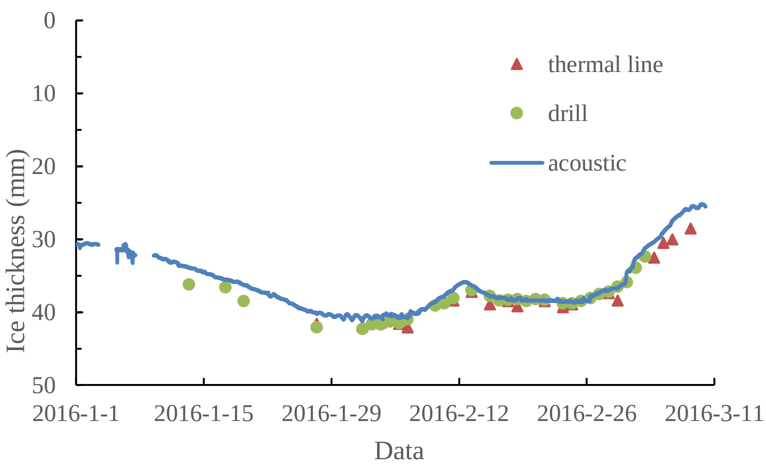

Figure 3. Ice thickness

DATA ANALYSIS

6 Typical Types of Temperature Profiles

By analyzing the data of the temperature profiles, we get the 6 typical types of temperature profiles (Figure 4). Type 1 and 5 always happened at the beginning freezing period. Type 2, 3, 4 always happened at the stable freezing period. Type 6 happened at the melting period.

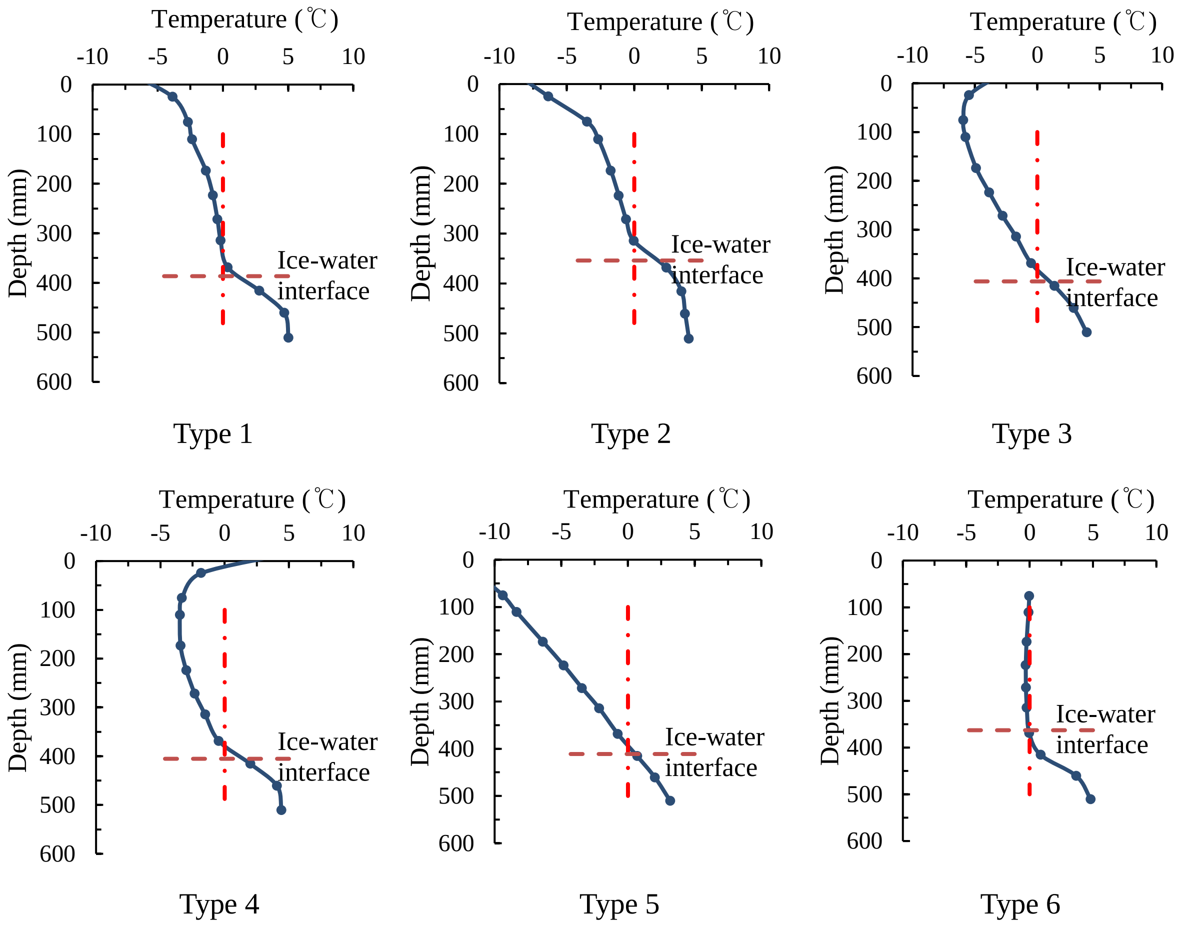

Figure 4. 6 typical types temperature profiles

Estimate Ice Thickness

First, we defined the location of 0° C for the ice-water interface. The shape of the temperature profiles of ice- water interface is different. Type 5 is nearly linear, the other are nearly the "S". We choose four points (two points in the ice and two points in the water) that different equations are used to fit, in order to obtain the location of the 0℃. Respectively using one or three order polynomial and the cubic spline function to fit these four points. The results that compare the ice thickness that estimated by the temperature profile and the measured data are shown in Tab. 1.

Table 1. Measure and estimate ice thickness

Type	Measure ice thickness (mm)	One order polynomial		Three order polynomial		Cubic spline function	
		Estimate ice thickness (mm)	Difference (mm)	Estimate ice thickness (mm)	Difference (mm)	Estimate ice thickness (mm)	Difference (mm)
1	386.63	318.53	-68.10	338.84	-47.79	338.82	-47.81
2	354.32	301.19	-53.13	316.11	-38.21	316.21	-38.12

3	406.20	374.17	-32.03	383.70	-22.50	384.22	-21.98
4	405.30	364.95	-40.35	383.42	-21.88	384.19	-21.11
5	411.20	391.64	-19.56	393.75	-17.45	393.84	-17.36
6	362.96	357	-5.96	375.83	12.87	375.99	13.03

CONCLUSIONS AND DISSCIONS

From the Tab. 1, we can see that different equations are applicable to different types of the ice-water temperature profiles. For the type 1, the difference of three order polynomial is the smallest. For the type 2 to 5, the applicable equation is cubic spline function. The one order polynomial is applicable to the type 6. The difference between the ice thickness that estimated by the temperature profile and the measured data is less than the interval of temperature sensor on the profile, namely, 5cm.

The temperature profile of sea ice is different from the fresh water ice. We will study the applicability for the sea ice-water temperature profiles in the next work, and look for other equation that is more suitable for fitting these points.

ACKNOWLEDGEMENTS

The in suit measurements on Ulansuhai Lake were supported by the Global Change Research National Major Scientific Research Projects (2015CB953901), National Natural Science Foundation of China (51579028, 41428603) and the Open Foundation of the State Key Laboratory of Frozen Soil Engineering (SKLFSE201604).

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