Temperature Fluctuations underneath the Ice in Diamond Lake, Minnesota

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Material

Autonomous temperature sensors, data loggers, have been placed in the Diamond Lake in Minnesota, Minneapolis, USA. The depth was shallow (<1 m) at the measurement site. Temperature sensors were about 1-2 inches apart attached to the plastic rope tied to the floater on one side and anchored with the piece of metal on the other side of the rope.

Results

Hourly measurements revealed the temperature changes of the ice frozen over the lake as well as the temperature record of the water under the ice. The ice that formed over the lake was soon covered with the snow. Snow isolated the ice from the daily air temperature changes. Sensors that were frozen deeper within the ice showed dumped and delayed thermal fluctuation from the surface. The sensors that were frozen at the bottom within the ice showed continuous, almost constant, temperature near freezing. However, all of the sensors that were within the liquid water below the ice showed thermal variation indicating significant 12 and 24 hour periods.Fig.1

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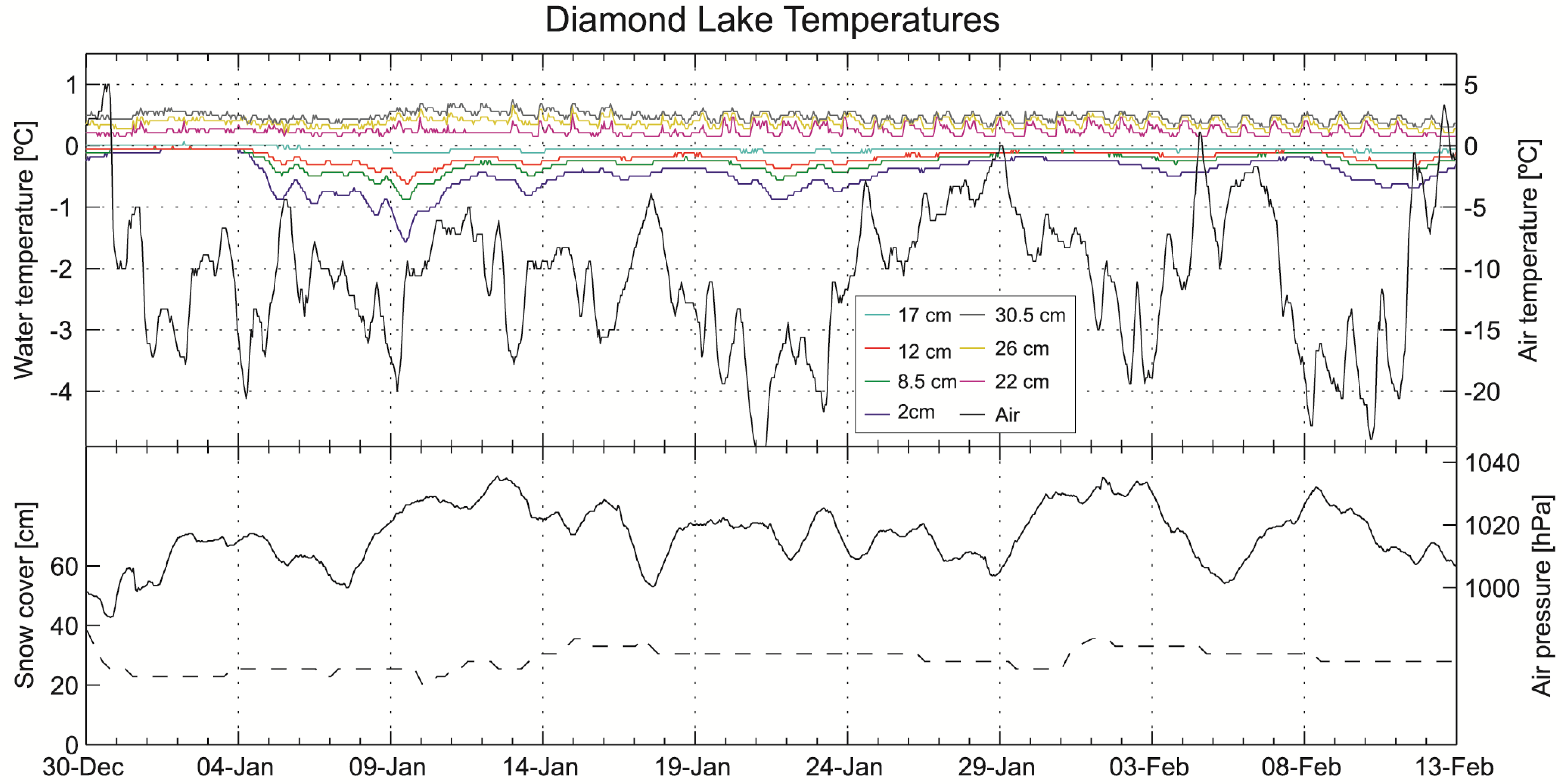

Fig. 1: Overall record of temperatures (top), snow cover and barometric pressure (bottom) from the Diamond Lake, Minnesota, over the period of 50 days in winter 2011. In the upper section the ice (lower set of four curves) and water (upper set of three curves) temperatures were measured by iButton sensors in the lake in depths from 2 to 30.5 cm; the air temperature curve (the lower most curve in upper panel), snow cover and barometric pressure records (two curves in the lower panel) were obtained from the station KMST, 40 km south east apart. Curves for data loggers at 5.5 cm and 28.5 cm were removed for simplicity.

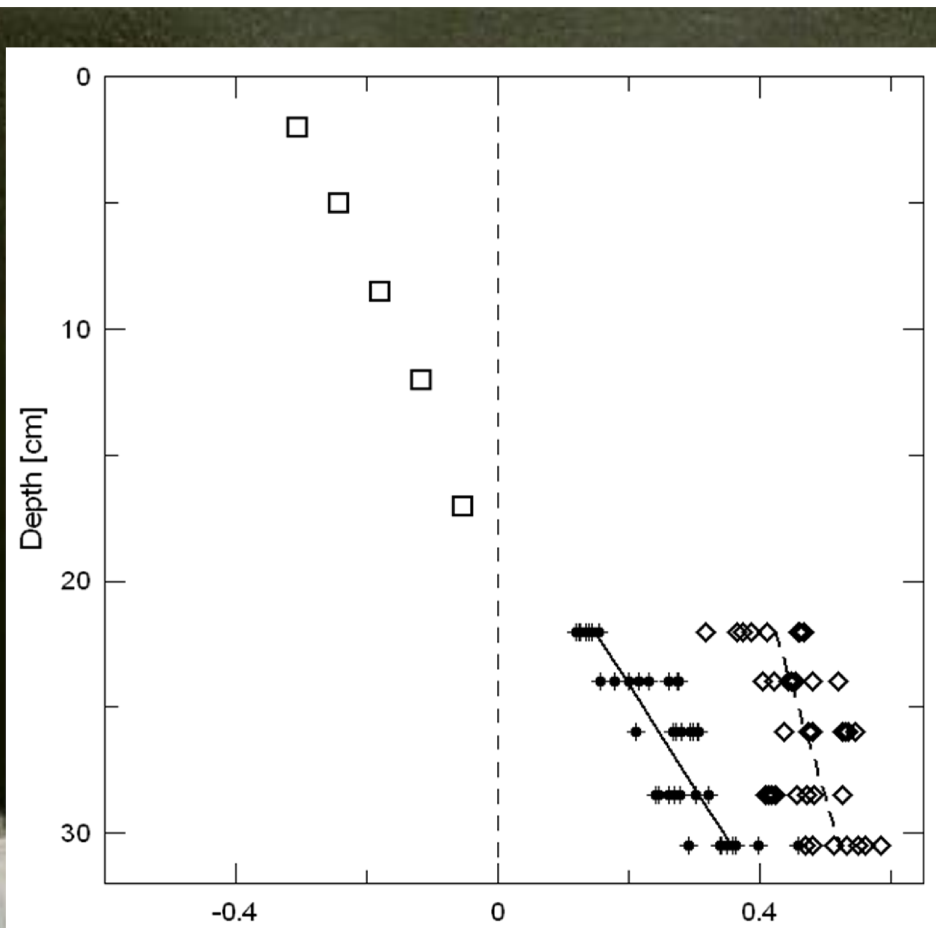

Fig. 2: Temperature profile is shown along the thermometer array from January 29 till February 6. Squares: mean temperatures in the ice cover, filled diamonds: minimum daily temperatures, open diamonds: maximum daily temperatures. Lines show the least-squares fit with temperature gradients 2.4 °C/m for daily minima and 1.2 °C/m for daily maxima.

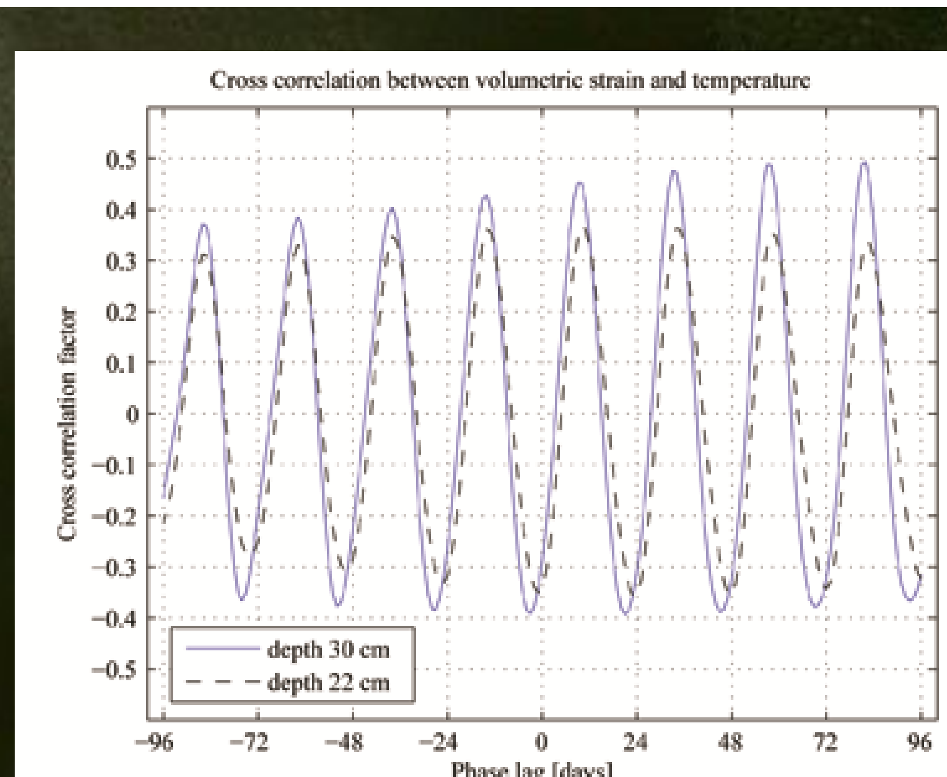

Fig. 3: Cross correlation function between volumetric strain and temperatures. Positive phase corresponds to delay of temperature after earth tides. The maximum correlation occurs for phase delay of 11 h and maximum anticorrelation for delay -3h; both for the 30.5 cm sensor depth.

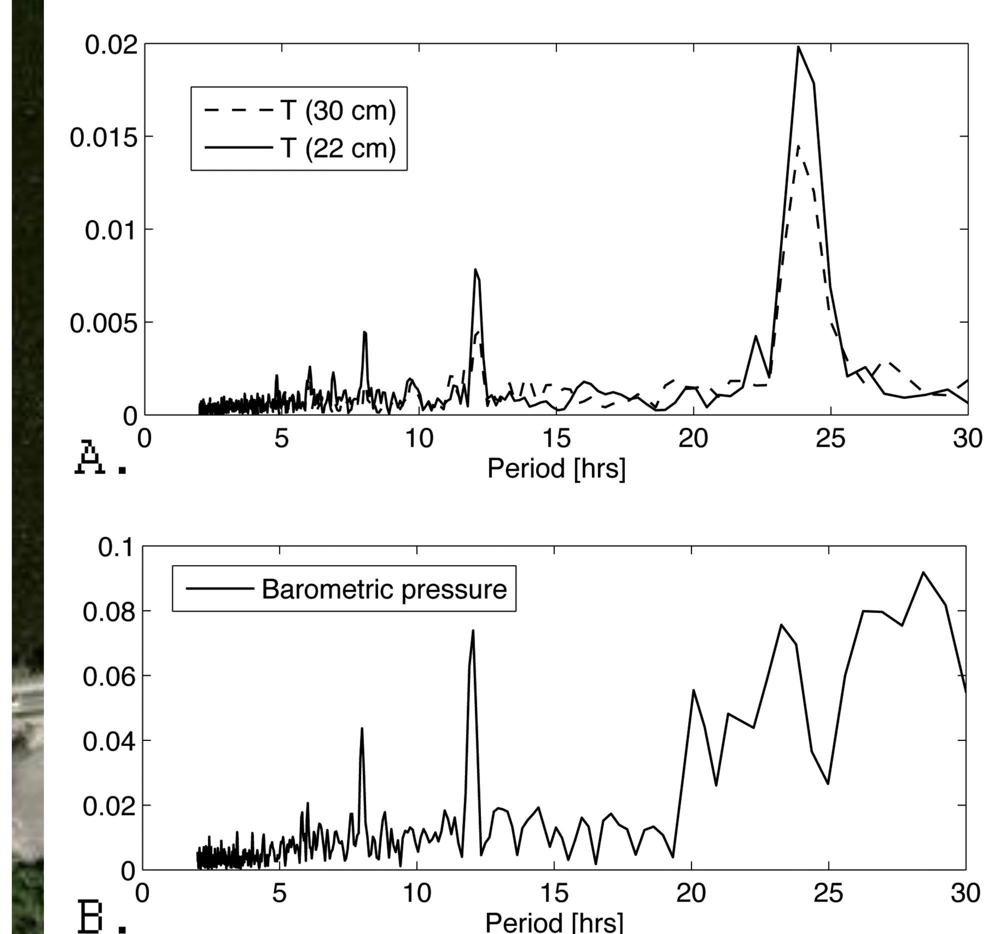

Fig. 4:. Amplitude spectra show temperature (A.) and barometric (B.) records for the period January 20 to February 10, 2011 at depths of 22 and 30 cm.

Discussion and Conclusions

The heating is more efficient than cooling indicating that the heat source is coming from the ground below (Fig. 2). We have correlated these variations with the tidal forces from the solar system bodies and found that during the maximum of the tidal gravity forces, when both the Moon and the Sun gravity forces were additive, the variation of the temperature correlated with the daily tides (Fig 3). If the tidal forces are responsible for the thermal fluctuations measured, the lake must be connected to a large fault system whose ridged blocks cause water to circulate and transfer the heat from below.

The amplitude spectrum (Fig 4) shows maxima at 24.0, 12.1 and 8.0 h. The relevance of the 8 and 12 h periods questionable due to its the spiky character due to insufficient amplitude resolution of the digitized temperature. Spectrum resolution of only 1.5 h at 24 h period (0.7 h at 12 period) does not allow to distinguish among the tidal components, whose periods differ by fractions of hour.

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