Solar-induced Thermal Activity and Stratification in Pond Water

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***Abstract*-Ponds are universally used to store water for a large number of uses. With the increasing demand for more fresh water, ponds, lakes and reservoirs are likely to be constructed on a larger scale. We must understand the effects of environmental changes on fresh water if we are to most efficiently utilize this resource. This study undertakes to increase our understanding of the rate of thermal response of ponds and other bodies of water to every-day environmental changes. The central research agenda is to investigate how the temperature of pond water from top to bottom responds to the day/night cycle, changes in air temperature just above the surface, cloud conditions, and other sudden environmental changes. Data collection for this study spanned October 2007 to June 2011 and had a continuous time resolution of 50 seconds.**

Keywords- Pond Water; Pond Stratification; Water Temperature; Thermal Activity

I. INTRODUCTION

With a growing worldwide human population and a finite amount of fresh water available, the increasing occurrence of water shortages is a major global concern. One common way to increase water resources available for human use is to build dams, reservoirs and ponds. Of course, such construction has and will continue to have major effects on natural ecosystems, a problem not addressed in this study. This paper presents the high-resolution thermal activity of a pond, whereby the temperature was continuously measured every 50 seconds throughout the water column. Ruochuan Gu, et al., (1996) [1] employed a resolution of 20 minutes in a similar study, whereas other studies by Abis, Karen L., et al., (2006) [3], Escobar, Jaime, et al., (2009) [4] and Moss, Brian (1969) [5] observed much longer times between data collections. There appears to be no literature on long- term year round data collection.

With time intervals between data points of less than 20 minutes, the purpose of this study was to analyze thermal activity in pond water in response to rapid changes in the environment above the surface of the water. The data presented in this paper is presented in a graphic format to allow the reader to graphically visualize and interpret the data.

II. METHOD

Temperature probes (PASCO Model PS-2135 thermistors) sealed in glass test tubes with waterproof silicone were positioned ~50 cm apart from top to bottom near the center of the pond. The test tubes were inverted and secured to a weighted drop line to minimize water seepage into the tube, which would damage the thermistor. The top thermistor was placed approximately 10 cm below the surface of the water and held in place by a float and tie line across the pond, as shown in Figures 1 and 2.The system was designed to collect continuous data for approximately three years. The pond was oval in shape and ~107 meters long, ~38 meters wide and 3 meters deep at the site of the temperature probes. The top temperature probe was within ~10 cm of the surface of the water, and the bottom probe was placed in sediment at the bottom of the pond. The air temperature just above the surface of the water was recorded with a probe placed on top of the float. A solar cell was located at the edge of the pond, and its output was used to record sunrise, sunset, and cloud conditions. Data from each sensor was collected once per second for 50 seconds and then averaged and saved as a single data point. Data was collected continuously using two PASCO plorer GLX Data loggers. (http://www.pasco.com/) The pond is located near the city of Binghamton, New York, USA, at Latitude 42.030564 N and Longitude -75.882511 W. Water flows into the pond from a meadow and a spring that flow year round, as shown in Fig. 1. A typical illustration sensor response during daylight is shown in Fig. 3.

At the beginning of the experiment during an equipment test run, it was noted that on clear days the air temperature began rising before the solar cell indicated the sunrise; therefore, the increase in air temperature was used as “time zero” when describing events in Fig. 3. The solar cell responded to sunrise approximately 91 minutes after the air temperature responded (began to rise). The temperature of the water began rising approximately 351 minutes after the initial rise in air temperature. Approximately 658 minutes after “time zero,” a dark cloud moved between the sun and the pond. The cloud blocked direct sunlight from entering the water for approximately 73 minutes. Maximum blockage of direct sunlight occurred at (c), approximately 28 minutes after the cloud first appeared between the sun and the pond. The air temperature fell to its lowest point at (d), after 18 minutes, and the temperature of the water at all levels in the pond fell to lowest temperatures 12 minutes later. After the cloud passed and direct sunlight re-entered the water, the rise in temperatures followed a similar pattern. Daylight on August 3, 2008 officially lasted for 14.3 hours, and the solar cell recorded daylight as lasting 14.7 hours.

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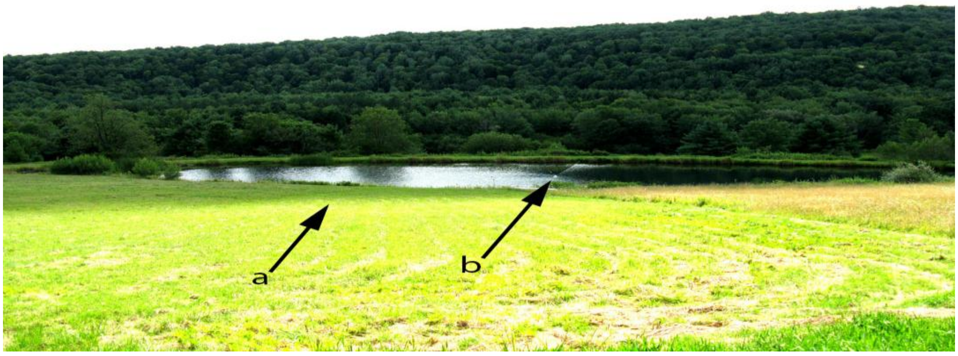

Fig. 1 Photograph of the pond in late summer as a dense cloud passed between the sun and the pond. Arrows (a) and (b) point to the location of the passing shadow and the temperature sensors. Photograph brightness enhanced for effect

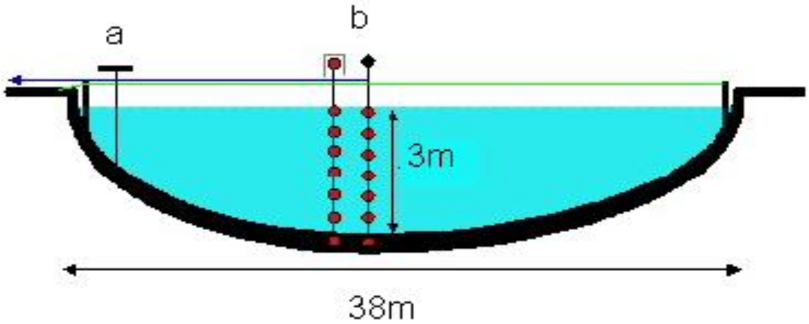

Fig. 2 Schematic diagram of the pond and sensors, (a) Solar cell used to monitor sunrise, sunset and cloud conditions. (b) Temperatures probes used to monitor water and air temperatures

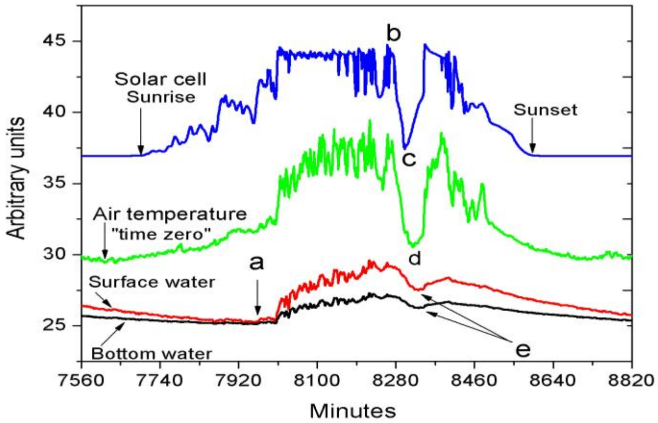

Fig. 3 Four of the sensors that best illustrate how the system responds to a major event

(a) Temperature of water starting to rise. (b) Cloud began blocking direct sunlight. (c) Maximum direct sunlight blockage. (d) Minimum air temperature during blockage. Other sensors are not shown here for clarity

III. SPRING AND SUMMER

First, thermal activity in the water over a period totalling more than a year will be looked at broadly. Fig. 4 illustrates thermal activity from mid-spring to early fall in the year 2008 is shown. Fig. 5 shows, thermal activity from fall to spring in 2009 and 2010. As expected, many weather events occurred during this time period, several of which will be examined and discussed in detail.

Each spike at the top of the graph in Fig. 4 corresponds to one day; the height of the spike represents the maximum water temperature at the surface of the pond on that day. The graph indicates the water temperature at ~50 cm intervals from the bottom to the top of the pond; the lowest trace represents the temperature of the sediment at the bottom of the pond.

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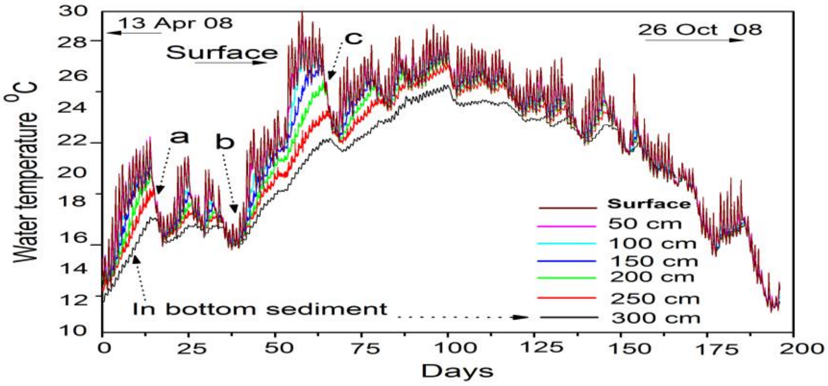

Fig. 4 Continuous temperature profile of the 3 m deep pond beginning in the spring on April the 13th 2008 and ending in the fall on October the 26th 2008

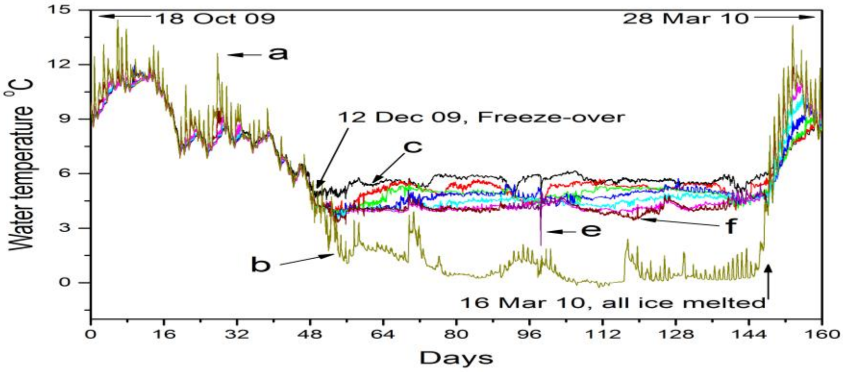

Fig. 5 Continuous temperature profile of the 3 m deep pond beginning in the fall on October the 18th 2009 and ending in the spring on March the 28th 2010. Note that on the 12th of December, the pond froze over and the bottom became warmer than the top and remained so for the rest of the winter

April 23, 2008 began as a partly sunny morning, with heavier clouds moving in by noon and dark clouds rolling in by early afternoon; this resulted in a sudden drop in air temperature just above the surface of the water and a corresponding drop in surface water temperature, as shown at (a) in Fig. 6. Notably, at (b) the temperature of the water 50 cm below the surface stopped increasing and remained nearly constant for the remainder of the day, until after sunset (c). In contrast, the following day had a clear sky, and the temperature of the water at 50 cm continued to rise from just after sunrise until late afternoon. The weather on April 25th was similar to April 23rd. In the early spring during the late afternoon when the sun was low on the horizon and setting, the air temperature began to drop, resulting in decreasing surface water temperatures which fell below the temperature of the water ~1 meter deep, as shown at (c) in Fig. 6 (the probe measuring the temperature at the bottom of the pond was omitted for clarity in Fig. 6). The trace marked (2) in Fig. 6 is the record of the temperature at 2.5 meters deep, and the trace marked (7) represents the temperature at the water surface.

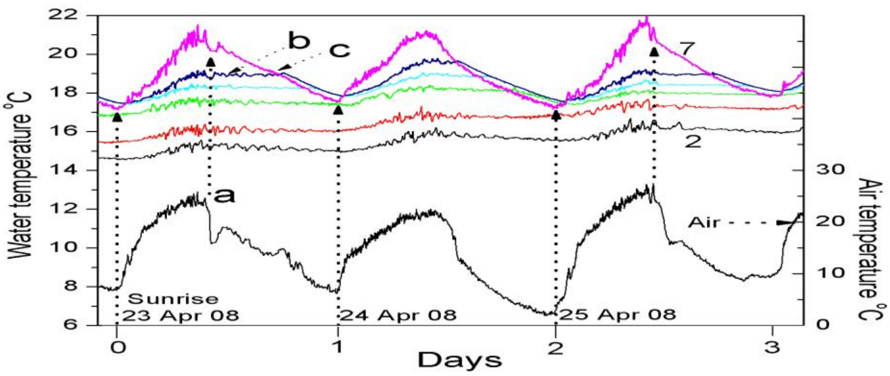

Fig. 6 Variation in water temperature at various depths in response to day/night cycles and changing weather conditions. From the top, (7) was the probe at the surface, next, probe (6) was 50 cm down, then (5) was 100 cm down, (4) was at 150 cm, (3) was at 200 cm, and (2) was 250 cm deep

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August 19, 2008 was a rainy day; August 20 was a bright, partly cloudy day; and August 21, the last day shown in Fig. 7, was a very clear blue sky day.

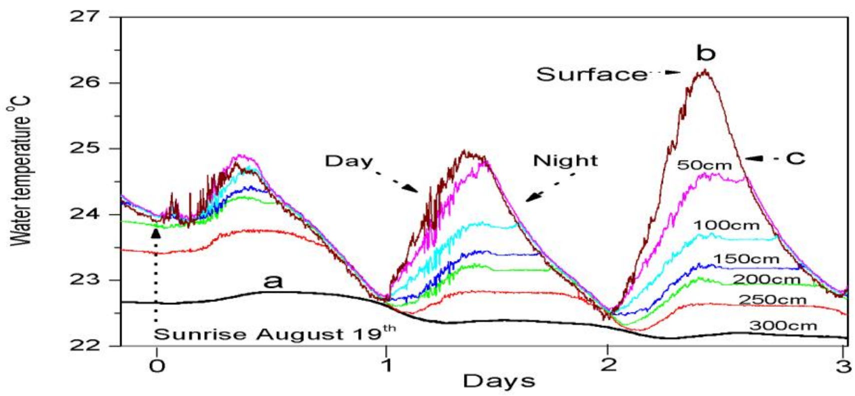

Fig. 7 Water temperature at various depths in response to day/night cycles and changing eather conditions

There was no noticeable wind during this period of data collection, August 19, 2008 through August 21, 2008. During this unique three-day period, the effect of clouds on the thermal activity of the water at every depth in the pond was clearly demonstrated. Fig. 7(a) demonstrates that the pond was slowly cooling; this was evident from the temperature data collected by the probe located in the sediment at the bottom of the pond. The pond had reached maximum temperature in late July (see Fig. 4, approximately day 100). August 21, 2008, was a clear day with no wind (Fig. 7(b)). These conditions created a temporary thermal stratification that quickly collapsed after sunset, as seen at (c) in Fig. 7. Long-term pond thermal stratification occurred in a step fashion beginning at sunrise each day and continuing over many days, as shown in Fig. 8; however, it collapsed within 24 hours when direct sunlight was blocked by clouds during daylight hours. This effect was dramatic when the air temperature during the night fell significantly below that of the water temperature (see (a) and (c) in Fig. 4 and (a) in Fig. 8). During this study, there were two long periods observed in the early spring when thermal stratification extended from top to bottom for more than two or three days. For most of the summer, thermal stratification was observed at the bottom of the pond, and lasted several months.

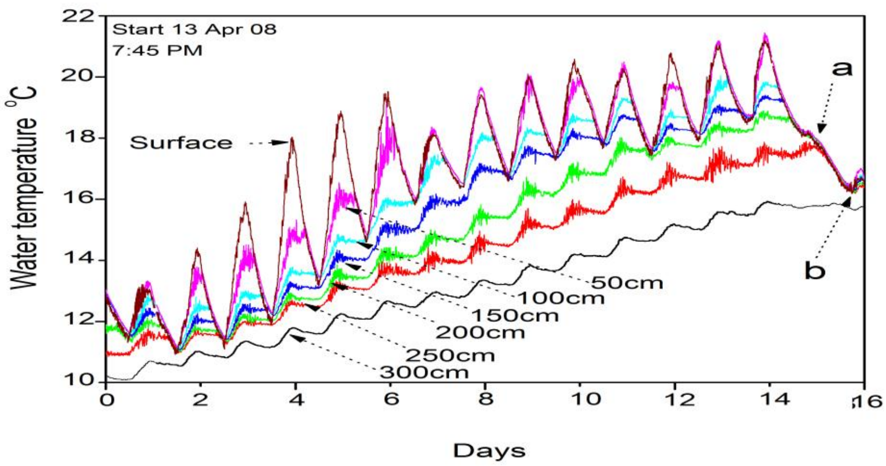

Fig. 8 Day-by-day step stratification of the pond in early spring and the collapse in one day at (a)

In the spring and summer, there were more variable, short-term reversals in the direction of temperature changes, with variability times ranging from several minutes to one hour. There was little variability in the temperature signals at night. This was true on the calmest, sunniest days (see Figs. 7 and 9).

However, there was one significant period in May 2008 when the temperature reversal continued after sundown, as is shown on day 3 in Fig. 10. On partly cloudy days, clouds passing between the sun and the pond produced most of the variations. On windy days, waves produced by the wind reflected sunlight away from the pond that would otherwise have been absorbed by the water; therefore, less solar energy reached the water. On days when the sky was clear and the wind was calm, a nearly constant temperature increase was observed throughout the water column during daylight, in addition to a nearly constant fall in temperature at night (see (b) in Fig. 7).

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We began to investigate how much of the variations and reversals in temperature was caused by wind and how much was caused by interrupted solar energy input from cloud coverage. Fig. 9 illustrates data collected on June 9 and June 10, 2008. Both days were mostly clear in the morning and mostly cloudy in the afternoon, with intermittent clouds passing between the sun and the pond with light wind gusts. On June 10th at ~6:25 PM, a fast-moving thunderstorm passed over the pond with wind gusts of 50 mph. By 7:45 PM, the storm had passed and the sun had re-emerged. The frequent wavering seen in trace (2) attributed to the storm. The effect was much stronger near the bottom of the pond than nearer to the surface. We see a similar response in Fig. 6 during changing weather conditions. Why the response is sometimes greater at the bottom of the pond than it is in the center is not clear. The trace labeled (0) represents the air temperature and the trace labeled (1) represents the temperature probe located in the sediment.

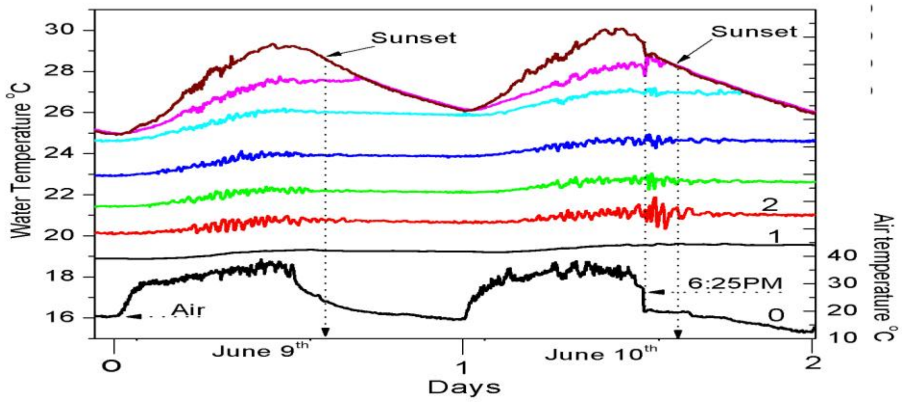

Fig. 9 Effect of a fast-moving storm

On June 10, 2008, a fast-moving thunderstorm passed over the pond at 6:25 PM, with rain and wind gust up to 50 mph. The turbidity rose to ~5.2 NTU in early June 2008 and fell to near 0.1 NTU for the rest of the summer.

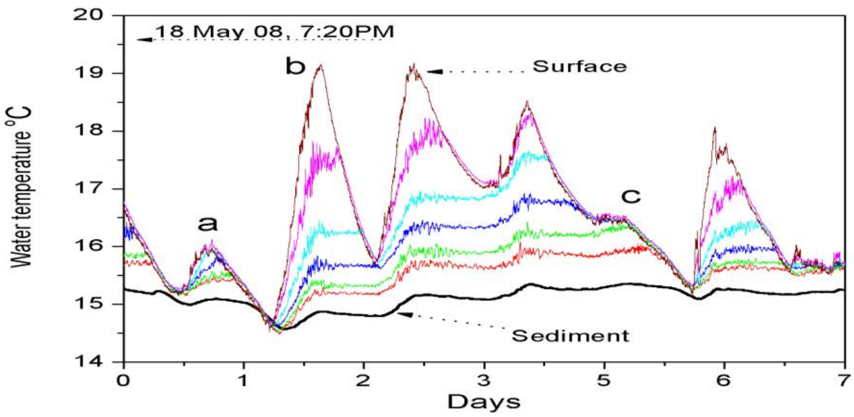

Fig. 10 Mostly cloudy day (a), clear sky sunny day (b) and (c) a rainy day all day

IV. FALL AND WINTER

Once the pond began cooling in late summer, thermal stratification became a single-day event that occurred on bright sunny days, as shown in Fig. 11. Note that for most of this period, the night-time temperature of the surface water cooled to below the temperature at the bottom, regardless of the daytime temperature. During an overcast rainy day, the pond was nearly the same temperature at all depths (a) and continued cooling day and night, as shown in Fig. 11 at (a) and (b).

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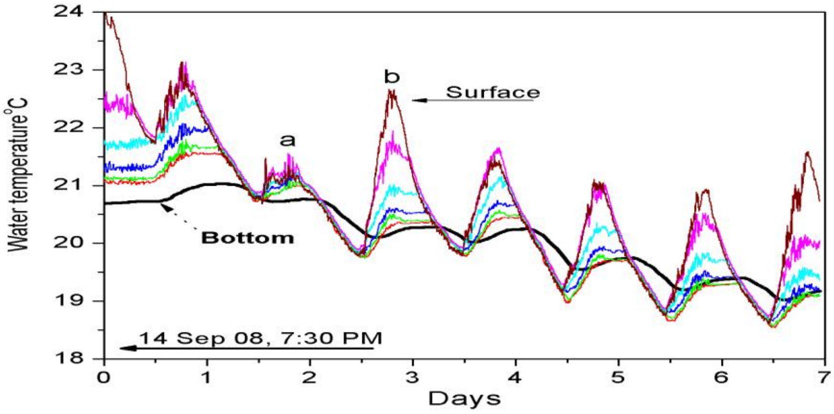

Fig. 11 Day/night cycles when the warmest water is at the bottom of the pond at night

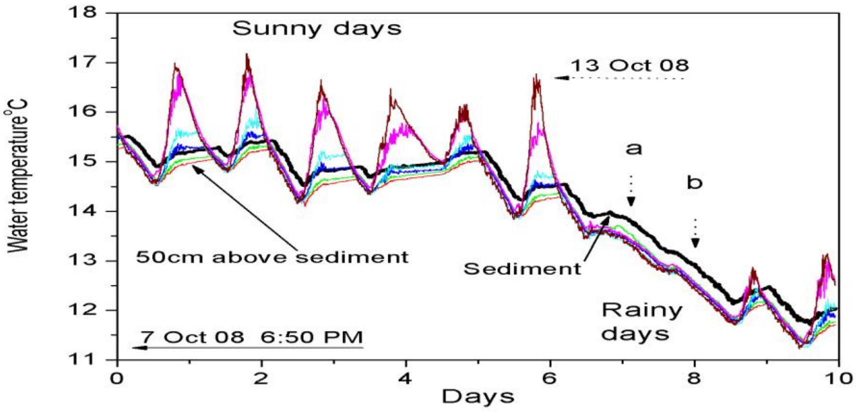

Fig. 12 Thermal activities in the water prior to pond freeze-over

During the fall prior to freezing, thermal stratification developed in the water near the bottom of the pond and remained stratified for several days. Simultaneously, the water in the upper part of the pond cycled through day/night periods of stratification during the day which collapsed at night, as shown on the sunny days in Fig. 12. On rainy days, the water above approximately 50 cm from the bottom of the pond was approximately the same temperature and showed a cooling trend, as shown at (a) and (b) in Fig. 12. Additionally, the coldest water during days 6-8 was at all levels above 50 cm from the bottom of the pond.

The pond freezing process often took several days; however, when surface freezing was completed, the pond became thermally active primarily near the surface, as shown in Figure 13. The effect of the day/night cycle in deeper water was also apparent in the water just under the ice after surface freezing, as shown in Fig. 14(a). Fig. 14(b) represents the air temperature and the solar cell response to dally cloud conditions.

As shown in Fig. 14, day 1 was mildly overcast, day 2 was heavily overcast, and days 3 and 4 had scattered cloud coverage. Day 13 was a clear day, as shown in Fig. 14(b). The solar cell output reflected the type of weather on a particular day. The general decrease in temperature of the surface water was an indication that the ice sheet was thickening and had almost reached the depth of the topmost temperature probe by day 14. The temperature of the water under the ice sheet rose with each sunrise on partly cloudy or sunny days; a temperature increase concurrent with sunrise was not as clear on cloudy days. During the spring and summer and before freezing, a consistent rise in air temperature before sunrise on partly cloudy or sunny days was observed. The effect of sunrise on the air temperature during winter was not as consistent or dramatic as it was during summer, as demonstrated by Fig. 14(b). The single observance of long-term stable pond thermal stratification occurred in mid-winter when the air temperature remained near or below 0 ℃ for an extended period of time, as shown in Fig. 15.

On the night of January 20, 2010, a warm front passed through the atmosphere, producing ~5 cm of rain in less than 24 hours. The pond was covered with a sheet of ice > than 8 cm.

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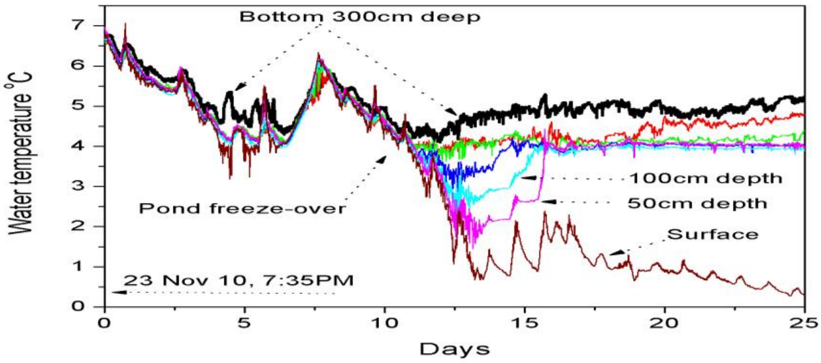

Fig. 13 Pond freeze-over followed by winter thermal stratification

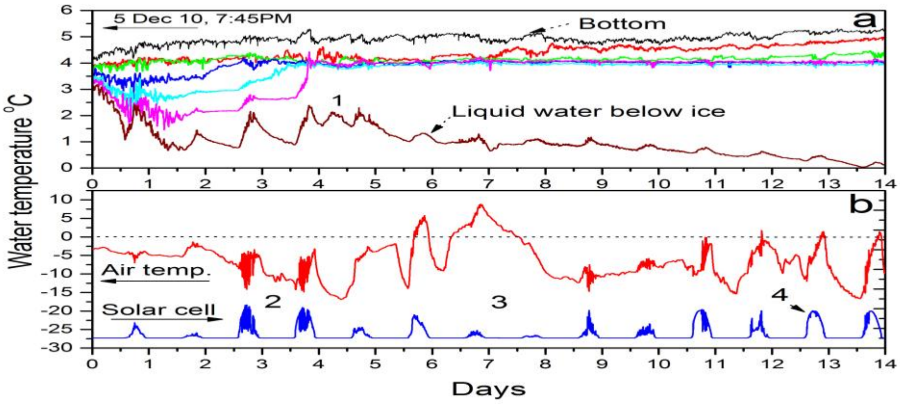

Fig. 14 Days after freeze-over when the pond was covered with a thin sheet of ice. (A) Sensors in the water. (B) Air temperature and solar cell response to interruptions in direct sunlight

Cold runoff from the frozen meadow above the pond (shown in Fig. 1) flowed to the pond and then over and under the ice sheet. The temperature of the water flowing into the pond was close to 0 ℃ due to the snow in the meadow before the onset of the rain. Because this incoming water was colder and heavier than the water currently at the bottom of the pond, it sank to the bottom, thereby temporarily lowering the temperature of the water near the bottom, as shown in Fig. 16. This unique rain event produced the only major thermal event in the water during the freeze.

Water just below the ice sheet demonstrated a smooth rise in temperature following the sunrise every day, with the single exception of the day of the rainstorm. As the ice sheet began melting in late winter, the rise in water temperature just beneath the ice was constant and dramatic on sunny days, illustrated by (a) in Fig. 17. The water temperature at the bottom began to respond to the day/night cycle once the ice thinned and snow on the ice had been eliminated. When the pond was free of ice on the morning of March 16, 2010, the daily thermal stratification resumed, and the pond thermally inverted.

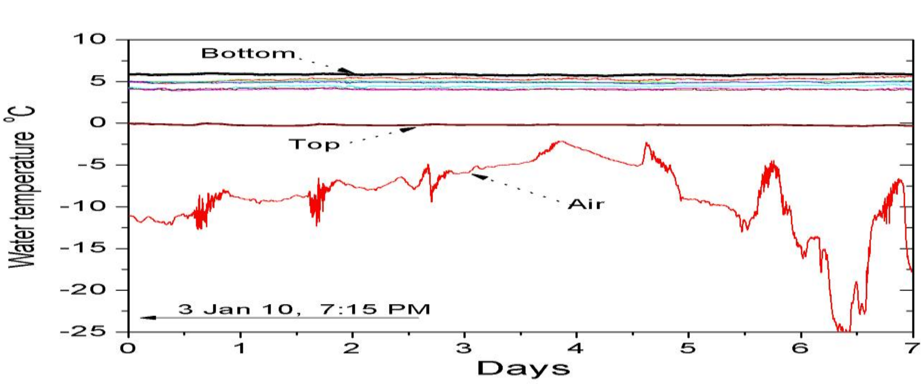

Fig. 15 Stable pond stratification under a sheet of ice covered with snow

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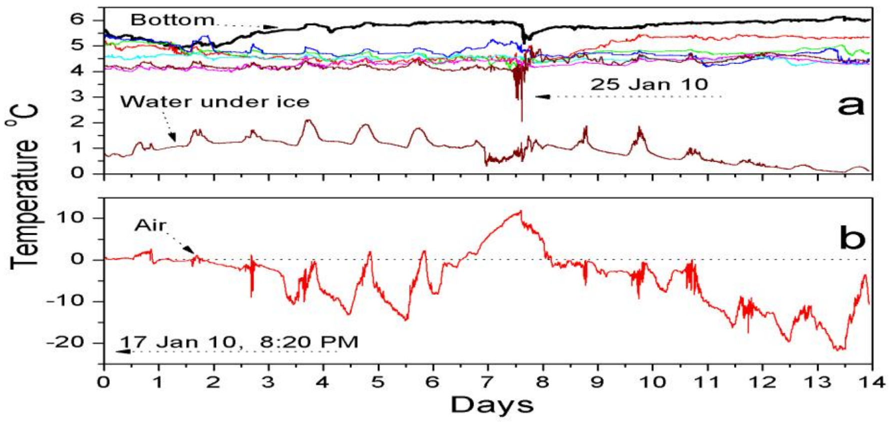

Fig. 16 Effect of a 20 ℃ temperature rise beginning on the night of January 23rd and a 5 cm rainfall January 25, 2010

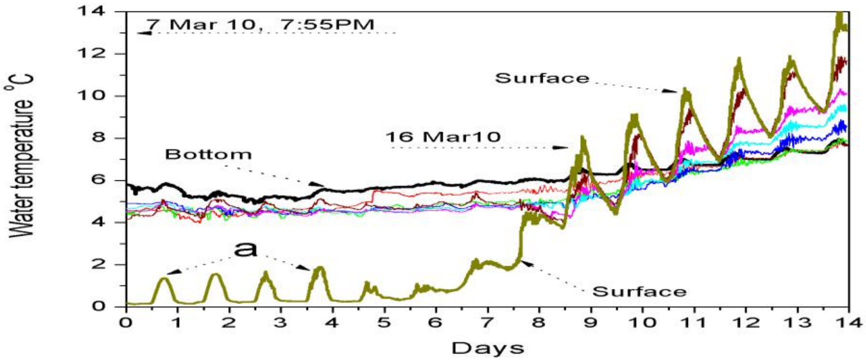

Fig. 17 Transitioning from winter to spring

V. CONCLUSION

Direct sunlight on a small body of water is a major factor affecting the daily and intraday changes in the temperature of the water throughout the water column. A succession of bright, sunny days produced thermal stratification in a step-wise fashion, cascading from the top down, as long as sunlight remained uninterrupted during daylight hours. One cloudy day could cause thermal stratification to collapse, and two successive cloudy days caused a complete collapse of thermal stratification. Turbulence at the surface or waves produced by wind reduced the amount of solar energy entering the pond by continuously altering the reflective properties of the surface, creating a net effect of lower energy input on windy days, more variation and temperature reversals, a smaller overall daily temperature increase and more thermal activity in the water column. Temperature variation and reversals were always present, i.e. thermal activity during the daylight affected temperature traces because of cloud coverage and surface turbulence, whereas during the night time traces were generally constant on both windy and calm nights.

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