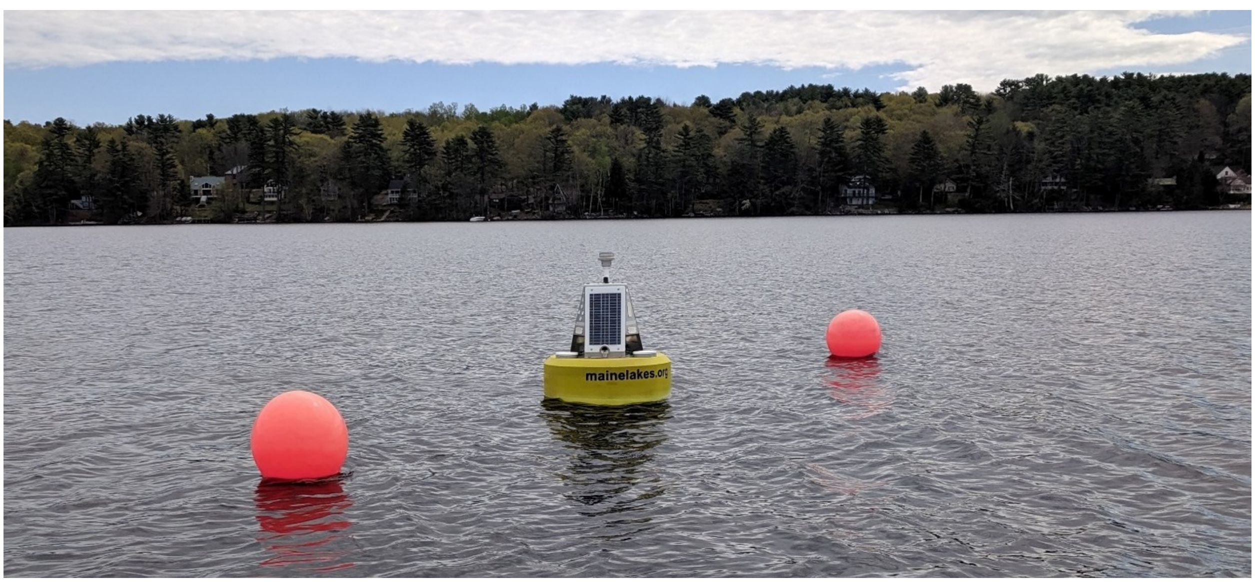
Lakes Environmental Association

2020 Water Testing Report

Chapter 2 – Automated Monitoring Buoys



LEA's Automated Testing Buoys

Highland Lake buoy

Each year, LEA deploys two fully automated monitoring buoys – one on Highland Lake and one on Long Lake. These buoys collect water quality information at 15-minute intervals throughout the spring, summer, and fall. This data is transmitted to us in real time, so we can see conditions change on the lake as they happen. The goals of LEA's testing buoy program are to better under-stand the condition of our lakes, to raise awareness of water quality issues locally, and to contribute to worldwide research and knowledge on lakes.

The Highland Lake buoy was first deployed in 2014 and contains temperature and oxygen sensors at 2-meter intervals from the surface of the lake to near the bottom. It also contains two solar radiation sensors and a single chlorophyll sensor, as well as a small weather station for measuring precipitation, barometric pressure, relative humidity, wind speed and direction, and air temperature. The Long Lake buoy was first deployed in August 2016. Like the Highland Lake buoy, it contains oxygen and temperature sensors at 2-meter intervals. It also measures chlorophyll with three sensors at different depths. Both buoys contain three 10-watt solar panels and a rechargeable battery as their power supply.

The advantages of these buoys are that they automate and enhance the water quality monitoring process. Using traditional (manual) water testing techniques, we are only able to collect data once every two weeks from each lake, usually around the same time of day. In contrast, the buoy automatically collects readings from each sensor at 15-minute intervals, resulting in 96 readings for each parameter every day. We are also able to leave the buoy in the water over a longer period of time than the traditional monitoring season. The wealth of additional data provided gives us a much more detailed picture of what is happening in the lake at any given time.

The information collected by the buoys allows us to better understand lake dynamics throughout the growing season. The combined and simultaneous measurements of water temperature, dissolved oxygen, algae, and weather conditions lets us see the effects of wind and precipitation events in real time, thus allowing us to better interpret how these factors affect lake conditions.

Another aspect of the buoy program is our ability to collaborate with researchers on a larger scale by sharing ideas and methods and contributing to research. Buoys similar to LEA's can be seen in lakes throughout New England and the world. An international organization called GLEON (Global Lake Ecological Observatory Network) helps to connect researchers that collect and use lake data, particularly from automated monitoring buoys, for a variety of projects. GLEON's mission is "to understand, predict, and communicate the impact of natural and anthropogenic influences on lake and reservoir ecosystems".

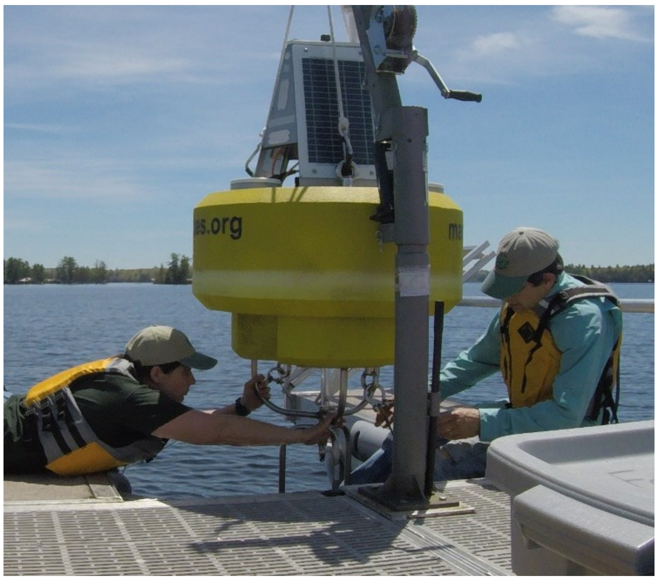
LEA could not have purchased either buoy without a great deal of support from several sources. The Highland buoy was funded by a grant from an anonymous foundation and contributions from landowners around Highland Lake. The Long Lake buoy was funded by a very generous donation from a resident of Long Lake, foundation funding, and contributions from lakefront landowners. LEA worked closely with Colby College professor Dr. Whitney King and Fondriest Environmental to design and set up the buoys.

Long Lake buoy

2020 Results

The presentation of buoy results begins with a general summary of the deployment and findings followed by a summary of weather conditions that help drive the patterns of temperature, oxygen, and algae in each lake in 2020. Those patterns as recorded by the buoys are presented for each lake in the next two sections, followed by an appendix detailing a storm's passage as recorded by the buoys.

Deployment and Results Summary

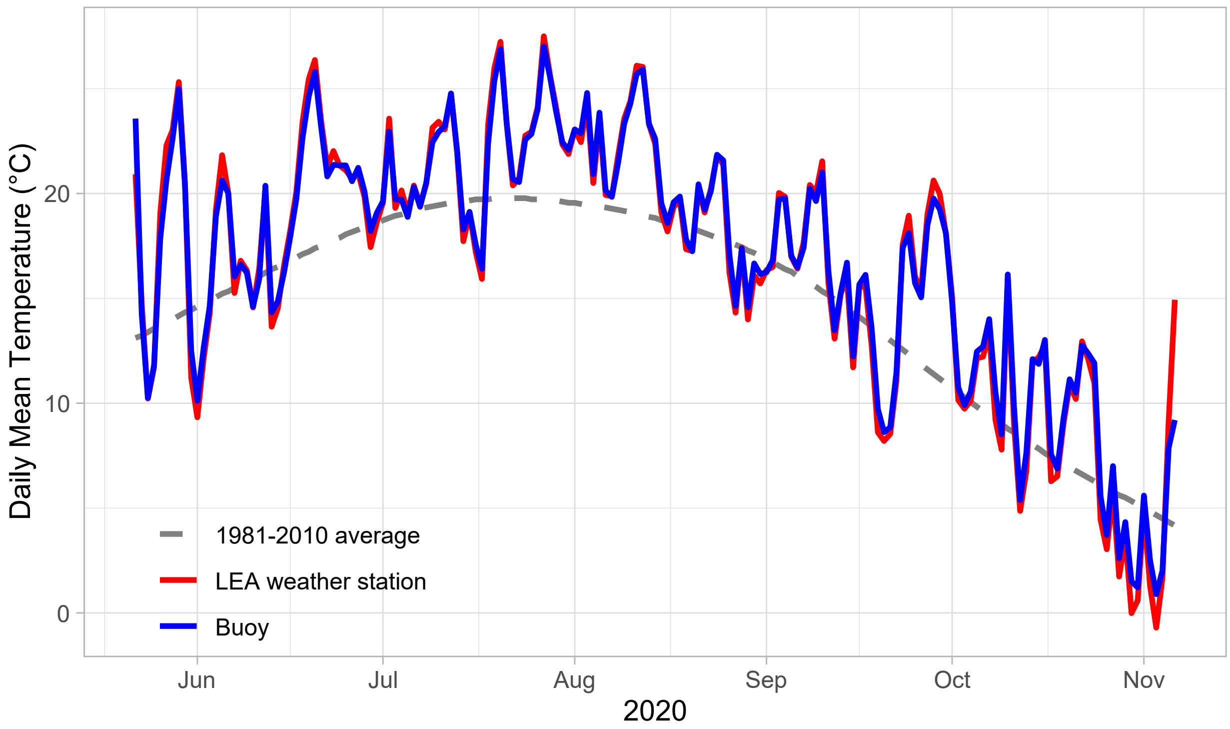


The 2020 deployment of the automated buoys began on May 21 for Long Lake and on May 22 for Highland Lake. Both buoys were in place recording data until November 6th, when they were removed from the lakes. Thermal stratification had already occurred prior to the start of deployment, but we did capture the time point of complete lake mixing (fall turnover) before we retrieved the buoys. During deployment, we performed three to four onsite cleaning and calibration checks for the sensors on each buoy. Two temperature/oxygen sensors on the Highland Lake buoy leaked and had to be replaced with backup sensors. Two chlorophyll sensors on the Long Lake buoy stopped working and were removed. Combined, the buoys collected over 32,000 sets of sensor readings during their time (168 to 169 days) on the water.

General water temperature patterns looked similar in each lake, showing the same basic response to the warmer and drier-than-average conditions of 2020. Stratification and mixing events occurred about the same time, including the strong mixing that occurred in early August after the remnants of Hurricane Isaias passed the area. The water temperature patterns did vary between the two lakes due in large part to contrasting size and shape. For example, the thermocline depth (location in the water column where temperature changes most rapidly) was generally deeper and the temperatures were slightly warmer at the deeper Long Lake site. While complete mixing (lake turnover) occurred on the same date, the deepest layer in Long Lake rapidly cooled and warmed over the next several days. In both lakes, dissolved oxygen declined as temperature increased and as stratification strengthened. Anoxia (absence of dissolved oxygen) occurred in each system in 2020, but as in previous years, Highland Lake's greater oxygen consumption rate meant that it developed anoxia sooner (mid-July as opposed to early September) and lasted longer than Long Lake. Surface chlorophyll fluorescence, which is an estimate of algae concentration, was relatively low in Highland Lake throughout the deployment, but was higher during late August and early September. Long Lake chlorophyll fluorescence at 5 m was elevated in July but lower for the rest of the period. Light sensors on the Highland Lake buoy were used to estimate water clarity, which varied from most clear in June to lower clarity at times in August and September, often in conjunction with higher winds.

Weather Conditions (Highland Lake)

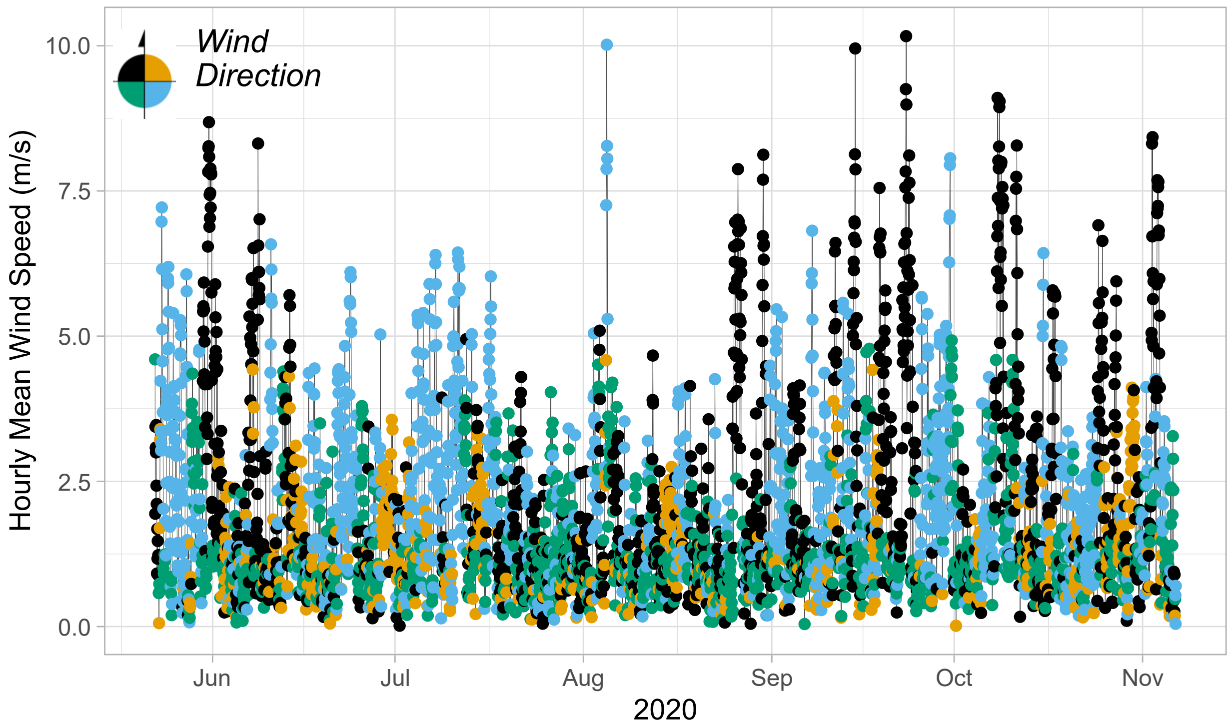
Air Temperature



Local weather conditions (air temperature, wind, rain) play a major role in controlling lake water quality. Sensors on the Highland Lake buoy collect weather and water data simultaneously, and in this section we summarize the weather results. Because the two lakes are geographically close together, the Highland Lake weather data are applicable to Long Lake as well, though the surrounding topography does affect local conditions at each site. Air temperature is important for understanding the heating, cooling, and stability of lake water. The air temperature data (blue line, above) followed a typical seasonal pattern but was warmer than normal for this area (1981-2010, gray dashed line, above) throughout much of the deployment. The latter half of September had a significant warming event and a rapid warm spell made both buoys' retrieval quite pleasant. Air temperature readings on the buoy ranged from -4.5 to 32.2 °C (23.9 to 90.0 °F). Our nearby weather station (red line) near the east shore of Highland Lake recorded almost identical readings, differing only in the extreme values (temperature range -5.1 to 34.1 °C (22.8 to 93.4 °F), which shows how lake water can have a moderating influence on the overlying air temperature.

Weather Conditions (Highland Lake)

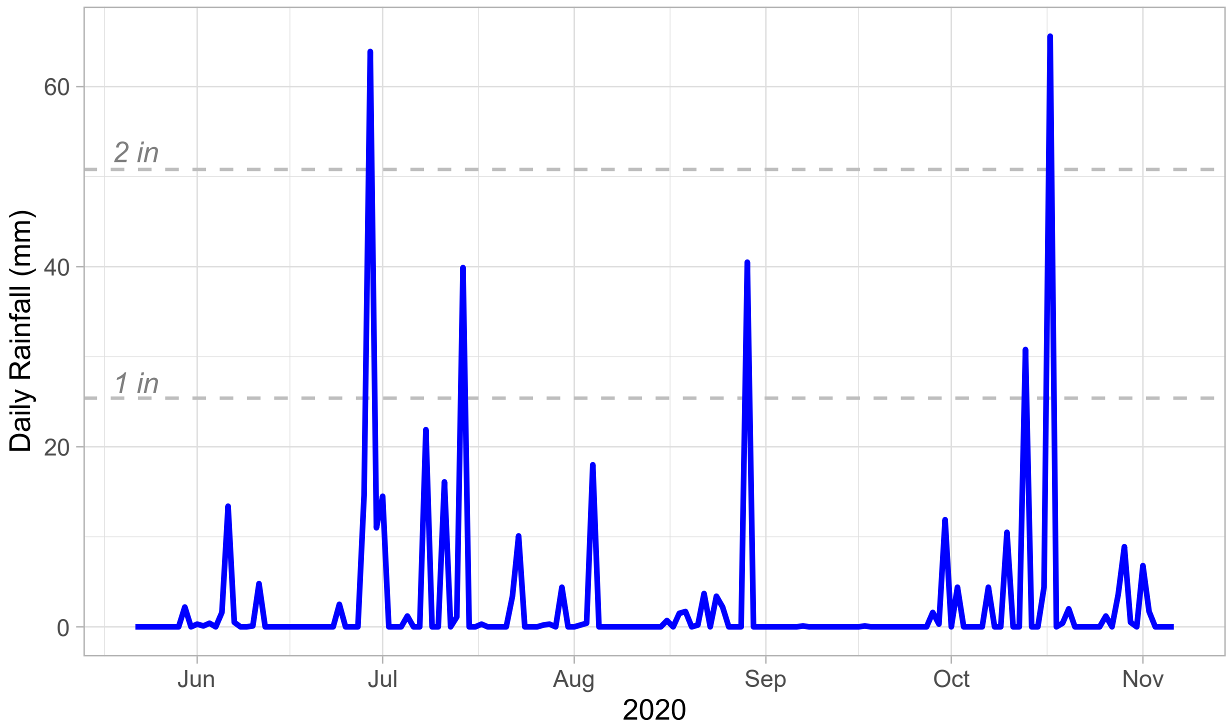
Wind



Wind also has a significant impact on conditions within a lake. Together with temperature, wind can control the physical structure of a lake, like the change from being stratified to being fully mixed. Wind speed and direction measurements recorded by the buoy were quite variable at the 15-minute scale, so broader scale patterns were examined using hourly mean values. In the figures above, the height of the point denotes the mean wind speed and the color indicates the direction from which the wind is blowing (like a weather vane); black means the wind was blowing from anywhere in the north to west (N-W) quadrant, for example. Hourly mean wind speed ranged from 0.01 to 10.2 m/s (0.02 to 22.8 mph), and the buoy recorded a maximum wind speed of 16.2 m/s (36.2 mph) on November 3. Late on August 4, the remnants of Hurricane Isaias passed to the west of the area bringing high winds that impacted the lakes (see Appendix). Other strong winds were noted in late May and August, early June, mid to late September, and early October and November. Wind direction was highly variable, though stronger winds tended to come out of the N-W and S-E quadrants, the prevailing winds for this area. Since the longest lake axis is aligned in those directions, wind measurements at the buoy may be stronger for prevailing winds than other directions because they are unimpeded by local topography.

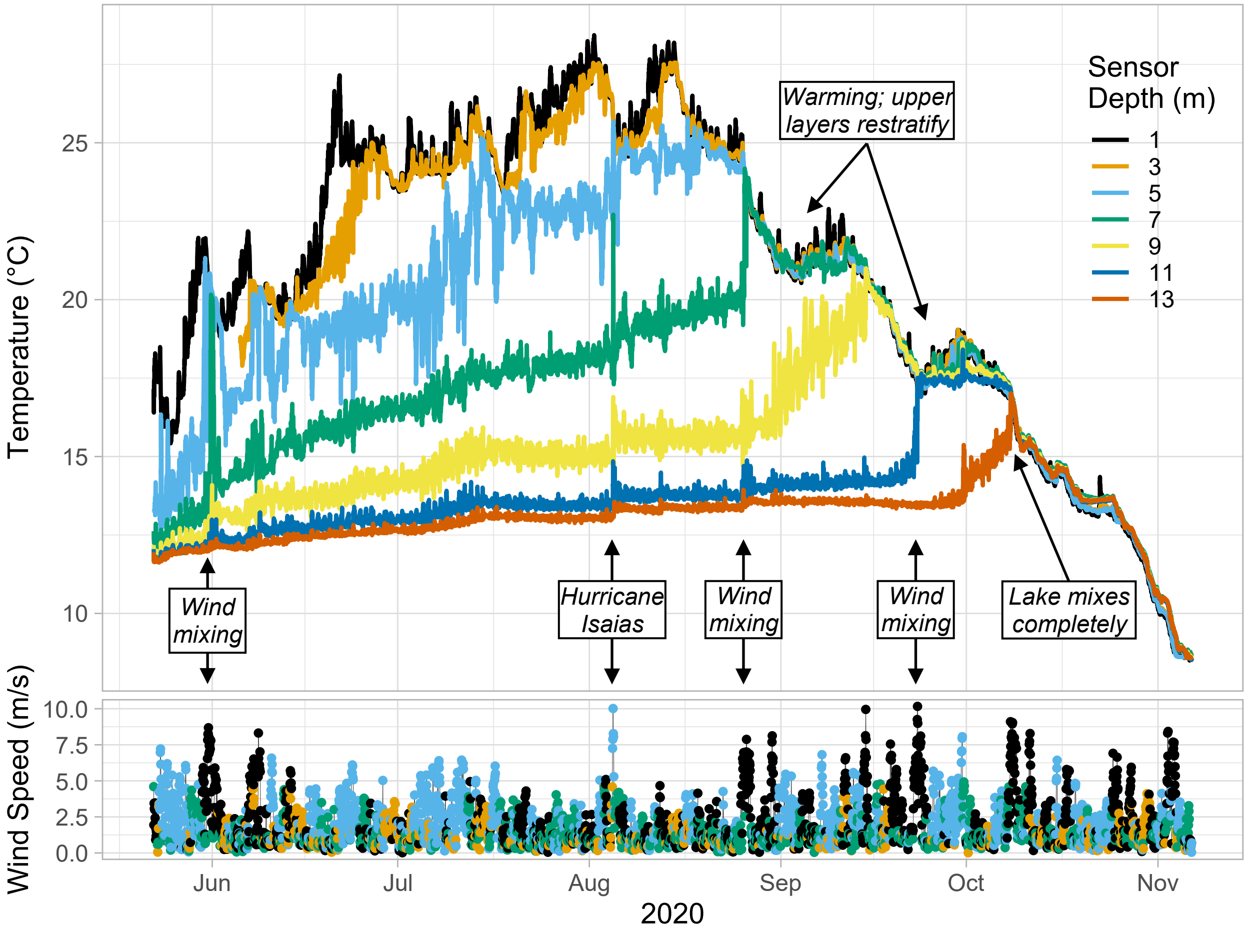
Weather Conditions (Highland Lake)

Rain



Rain adds water directly to a lake and also indirectly through watershed runoff. Rain is important in maintaining lake levels, but sediment and nutrients can be delivered along with it, depending on rain amount and intensity. Total rain recorded by the buoy during the 2020 deployment was about 460.5 mm (18.1 in), less than last year and quite a bit less than the 30-year normal rainfall of 622 mm (24.5 in) for May through October. This came following a lower-than-normal winter snowfall and drought conditions starting in mid-May. In late June through early July, significant rainfall, including two 2+-inch events, helped alleviate the drought conditions. The passage of Hurricane Isaias in early August brought more wind than rain and the buoy recorded only 18 mm (0.71 in) in total. Dry conditions returned in September when there was a period of 29 days without rain. Rains returned in October, which included the highest single day rain total of 65.6 mm (2.58 in) on October 17. High intensity storm events have the most impact on water quality because of the erosion and pollution potential. Most of the time when rain fell, rain intensity was about 3 mm per hour (0.1 in/hr), but the buoy recorded a maximum of 41.9 mm per hour (1.65 in/hr) in late June. This was the highest rainfall rate recorded since August 2017.

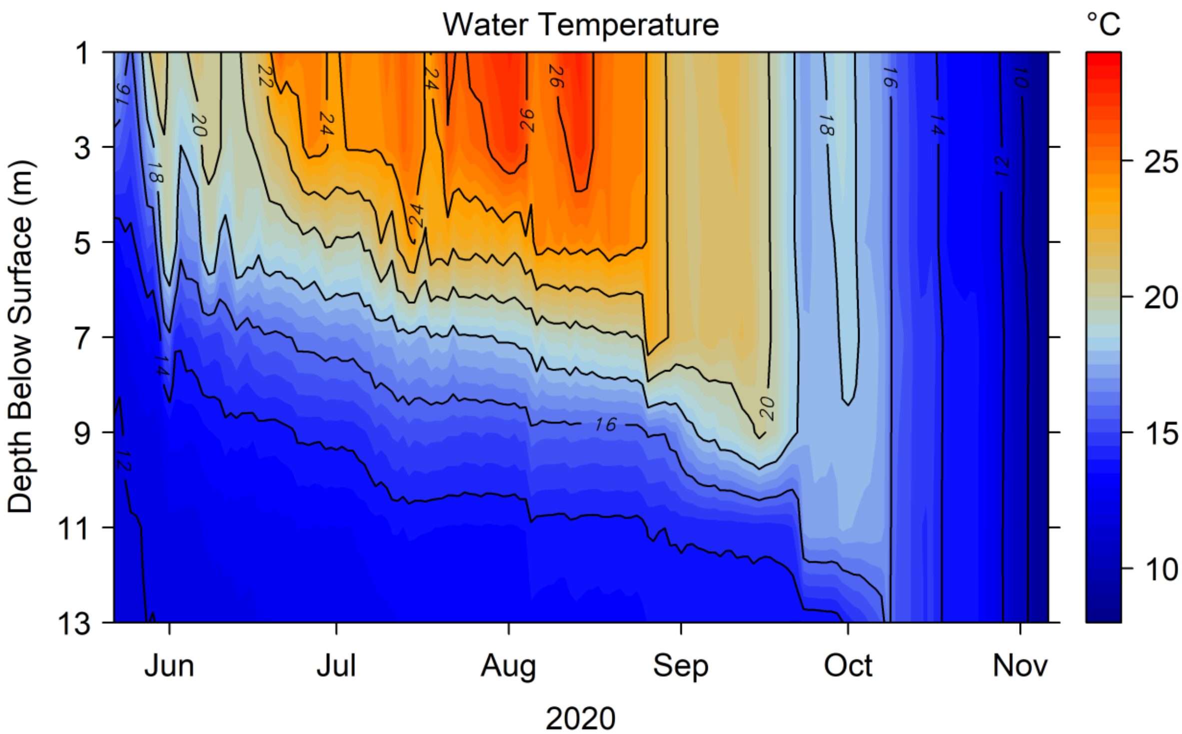
Water Temperature



Water temperature data forms the foundation for most water quality measures and is essential for understanding lake physical dynamics, nutrient cycling, and habitat availability for fish and other aquatic organisms. Data from the individual temperature sensors, along with hourly mean winds, are shown in the above figure. Each colored line represents water temperature at a specific depth below the surface recorded at 15-minute intervals. The maximum recorded temperature on Highland Lake was 28.4 °C (83.1 °F) on August 1, and the minimum temperature was 8.5 °C (47.3 °F) right before the buoy was removed for the season. Daily heating and cooling of the surface water can be seen by the saw-tooth pattern of the 1 m sensor data. Temperature variation was more irregular and sometimes greater in the middle of the water column due to the "sloshing" of internal waves (or seiches) caused by wind energy. Stratification (indicated by wide spaces between lines) had already started before the buoy was deployed and partial mixing (lines getting closer together) happened throughout the season, especially at times of high winds. Good examples of this can be seen on May 30-31, August 26, September 23, and especially on August 4 when winds from the remnants of Hurricane Isaias impacted the entire water column. In September, periods of warming brought on a temporary stratification of the upper water column that had already mixed. Surface waters started cooling in August and September, which reduced the resistance to mixing in the water column. Complete mixing occurred on October 8 following significant wind events that continued through the fall. This turnover date was the earliest yet recorded by the buoy (see table below). By comparison, Long Lake mixed on the same date, but did not stay mixed until several days later.

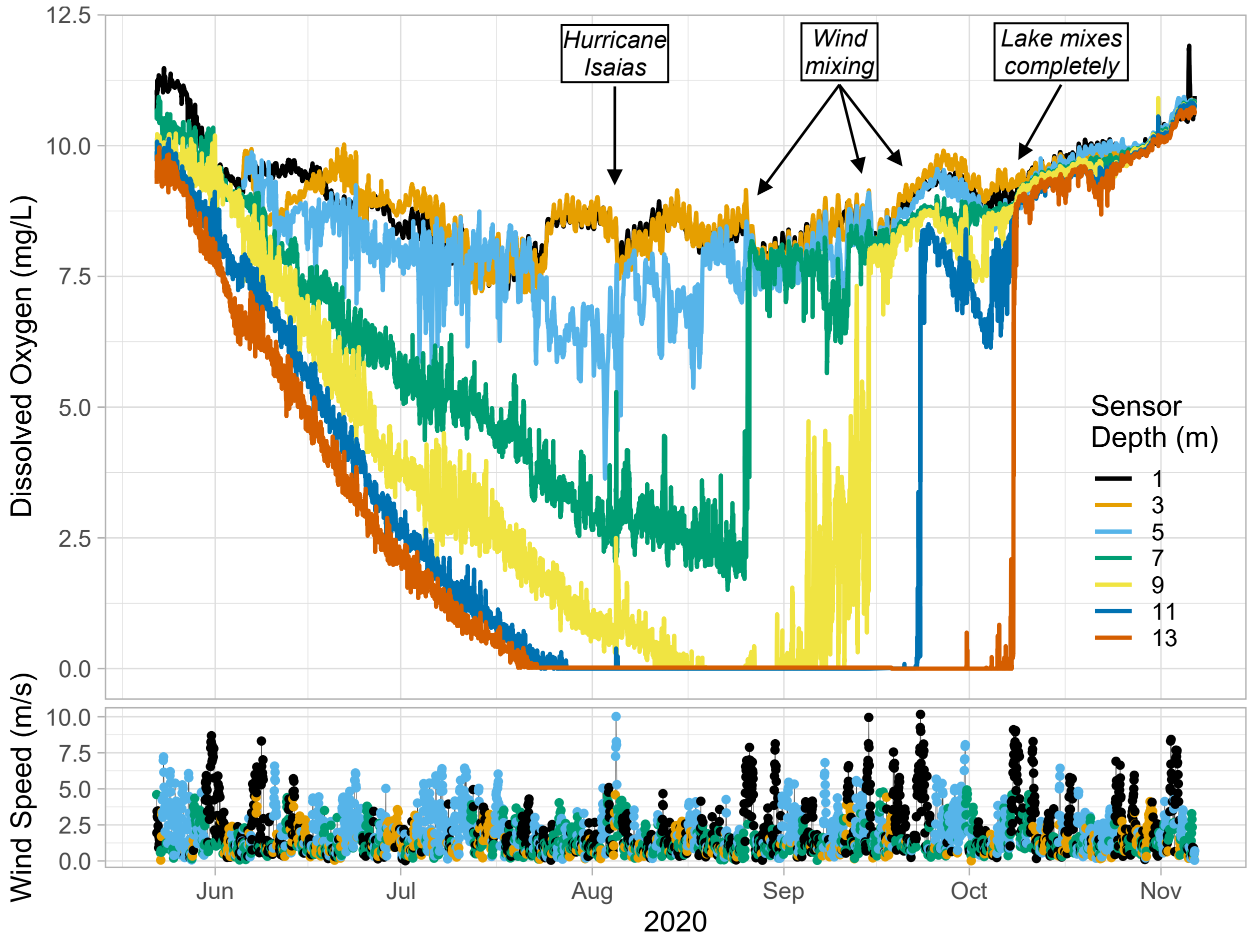
Date of Fall Turnover (Complete Mixing) by Year

YEAR	2013	2014	2015	2016	2017	2018	2019	2020
Turnover Date	after 10/11	10/12	10/11	10/10	11/4?	10/16	10/9	10/8

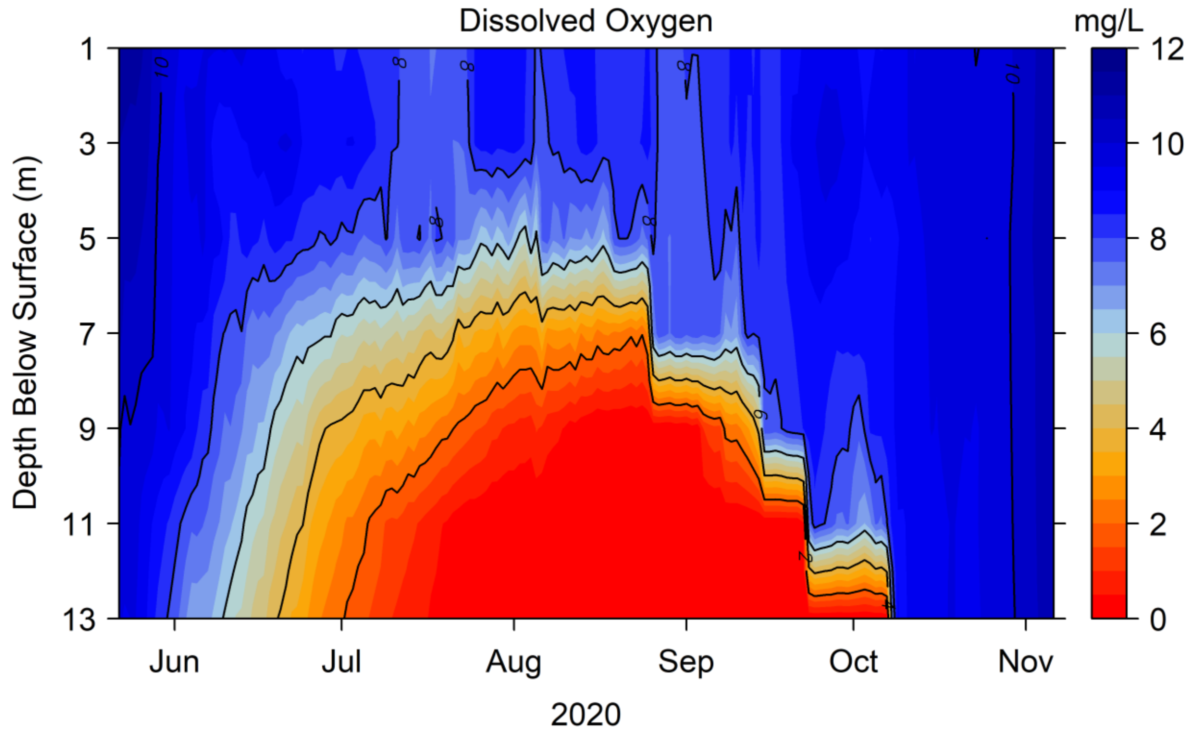


Another, perhaps easier, way to visualize the temperature data is with contour plots (or heat maps). In the above figure, which uses daily mean values to help reduce the noise, temperature across depth and time is represented by colored contours, where the red to blue color range corresponds to a high to low temperature range. Temperature stratification shows up as areas of the plot where colors change in the vertical direction and contour lines are tilted more towards horizontal (from June through early October). The area where contours come closest together (i.e., temperature changes most rapidly with depth) is often referred to as the thermocline. Vertical contour lines indicate mixed conditions, and areas of a single color from top to bottom (such as late-October into November) indicate completely mixed conditions. The effect of wind, like the events previously discussed, can be seen as dips in the contour lines. Warm, stratified conditions stand out as darker red areas in July through August. The downward sloping contours show that the upper layer (epilimnion) and thermocline deepened throughout the summer; thermocline depths ranged from about 3 m in June to 11 m before lake turnover.

Dissolved Oxygen

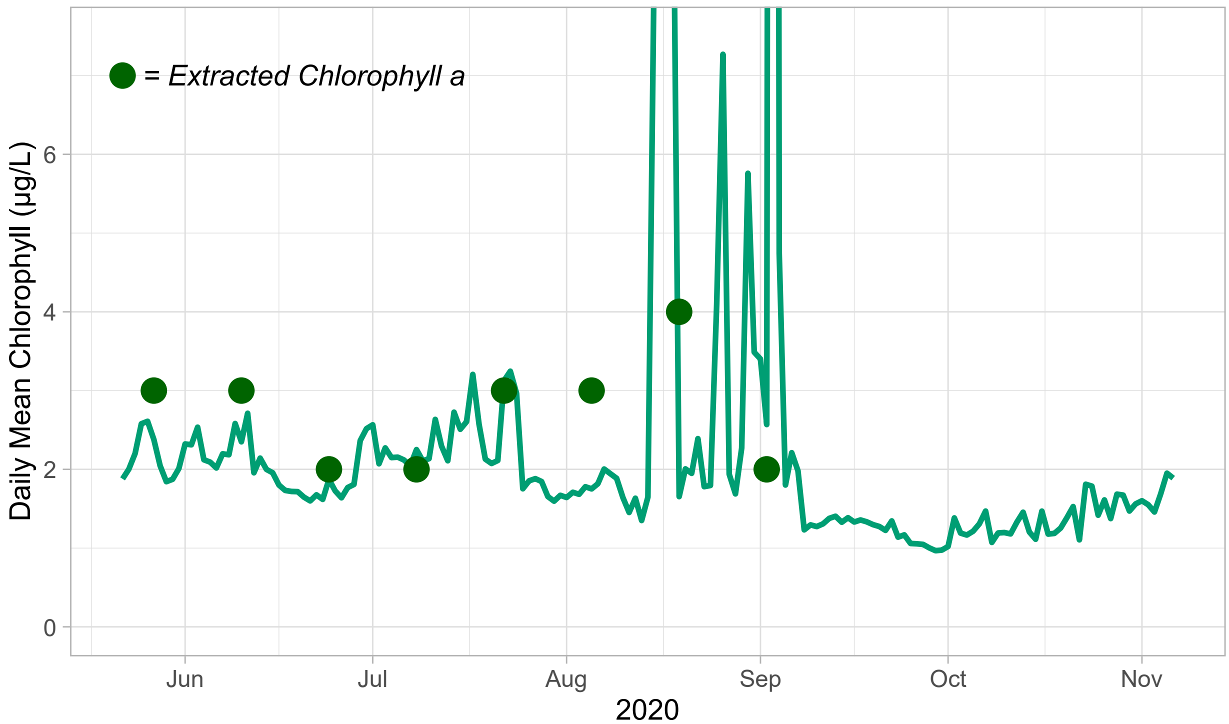


The same types of plots used for temperature can be used to examine the dissolved oxygen (DO) time series data from the buoy. The figure above shows a pattern of generally decreasing DO from the start of the record through early fall. Some of that is simply due to warming water, since cold water can contain more DO than warm water, all else being equal. Oxygen in the deeper waters, however, decreased more rapidly. This is due to biological consumption (animals and bacteria using oxygen) and the reduced aeration (wind mixing) because of stratified conditions; by mid-July deep DO readings reached zero (anoxia). With strong enough winds, however, deeper waters were able to be mixed as evidenced by the rapid and large DO concentration swings during August through October. Even anoxic bottom waters saw a slight DO increase caused by winds from the remnants of Hurricane Isaias in early August, though the effect was short-lived. The daily warming-cooling cycle of the air, the daily cycle of photosynthesis and respiration, and the back and forth rocking of internal waves are responsible for the smaller variations in DO concentration seen in the figure. By early October, the water column was completely saturated with oxygen after temperatures dropped and winds fully mixed the lake.



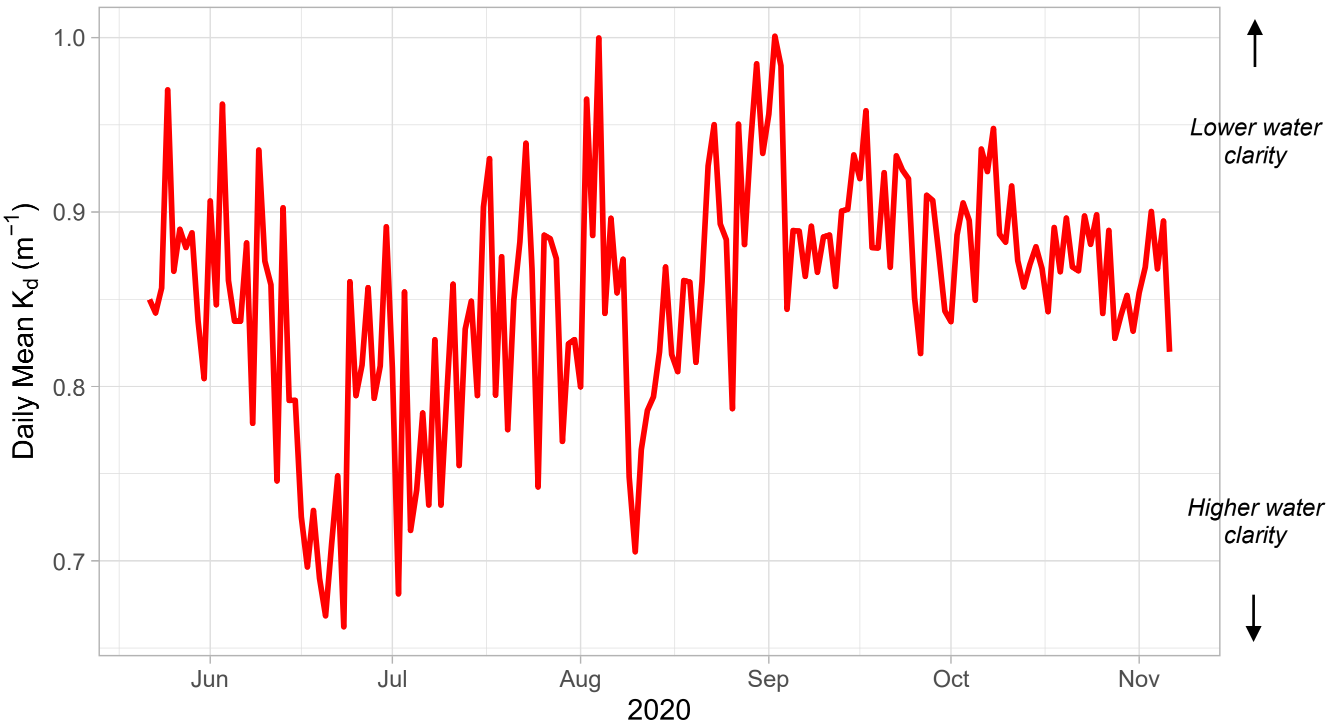
We can also illustrate the buoy dissolved oxygen (DO) data using depth-date contour plots, though in the above figure we have reversed the color scheme used for temperature so that red and blue signify low and high DO, respectively. The contour plot highlights nicely the pattern of lower DO concentrations in summertime deep waters and provides a quick visual gauge of where and when hypoxic (DO < 2 mg/L) conditions occur. As was seen in the previous line plot, Highland Lake bottom water became anoxic (DO = 0 mg/L) starting in mid-July and remained so until early October, when the water column mixed completely. Prior to that, more minor wind mixing events can be seen in the downward dips in the DO contours, such as the August and September events. Besides wind and water temperature, the major control of lake water DO concentrations is biological activity (i.e., respiration and photosynthesis). Oxygen is a byproduct of photosynthesis, so actively growing algae can be an additional source of oxygen in shallow, aerated, well-lit waters. In contrast, deep water DO is reduced when microbes, fish, and plants respire or “breathe” and oxygen cannot be replenished due to thermal stratification. This oxygen consumption eventually leads to hypoxia and anoxia. Fish tend to avoid and are stressed when moving through areas that have DO concentrations below about 4 mg/L, while anoxic bottom waters allow phosphorus trapped in sediments to be released for use by algae; these phenomena highlight the importance of collecting oxygen data.

Chlorophyll or Algae Biomass



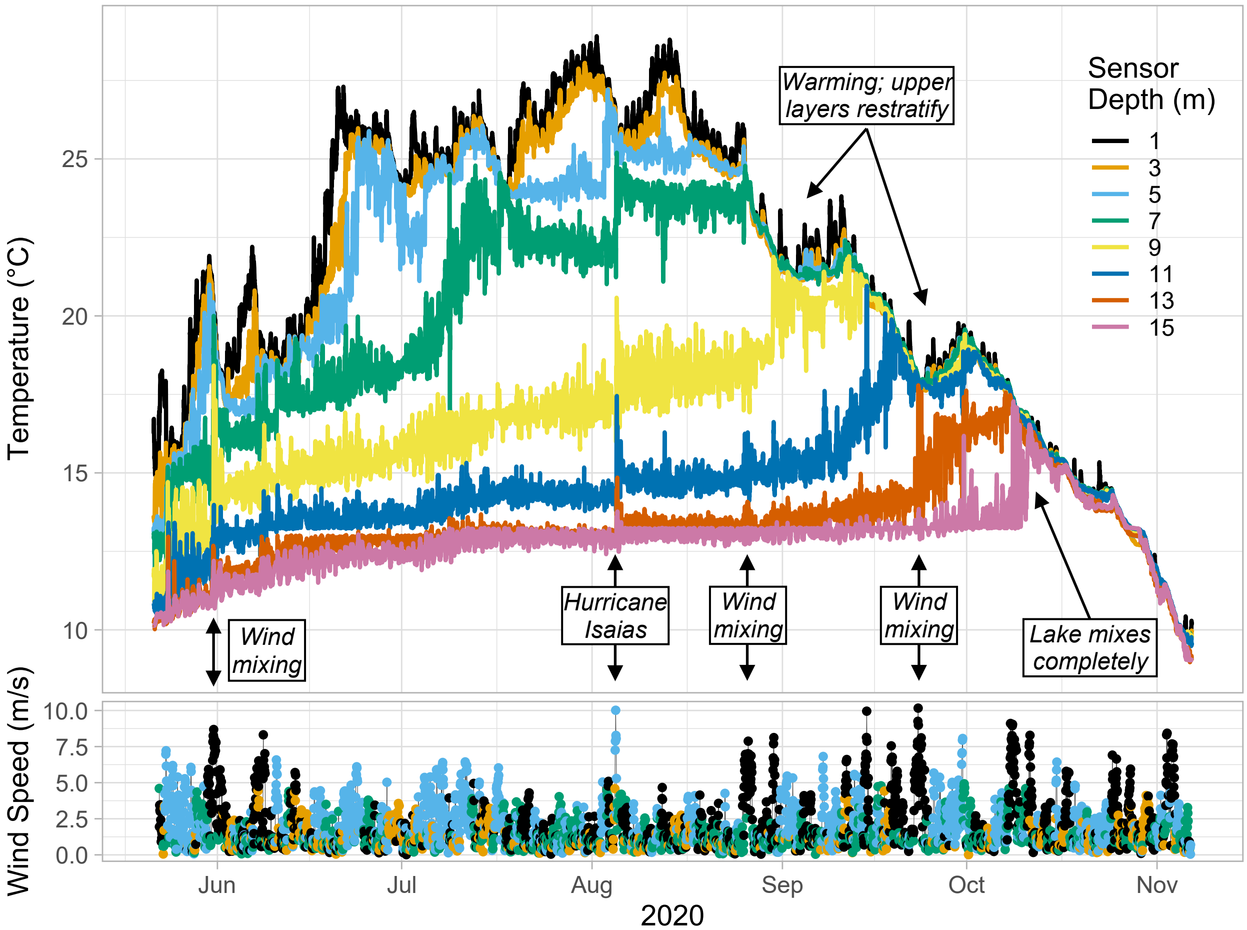
The Highland buoy contains one sensor mounted 1.5 m below the lake surface that measures chlorophyll concentrations using fluorescence (same as the field fluorometer used on regular testing trips and discussed in Chapter 4 of the Water Testing Report). The amount of this pigment (found in all plants and algae) can be used as a proxy for algae biomass and as a measure for the productivity of a lake. It is important to note that field fluorescence is a relative measure and is not as accurate as lab-based chlorophyll measurements. Also, chlorophyll fluorescence often shows variation with depth and the buoy can only measure at a single discrete depth. Still, buoy chlorophyll and extracted chlorophyll *a* concentrations in the epilimnion (upper mixed layer) from our regular testing trips showed a good degree of similarity. Daily mean chlorophyll, shown above, ranged from about 1 to 3 µg/L with minimal variation except for extreme outliers as high as 57 µg/L in mid-August and early September. These outliers were caused by random, high values (10 to > 1000 µg/L) in the raw data, which could be real, but is more likely to be caused by fouling or sensor error. Chlorophyll appears to decrease slightly in September coinciding with the limited rainfall. Concentrations begin to increase in October, which may be tied to increasing rainfall and introduction of nutrients from bottom waters through mixing. There are, of course, other factors that control algae populations, like competition between different species and zooplankton grazing, but those are beyond the capabilities of the buoy.

Light Attenuation (Water Clarity)



The Highland buoy has two light sensors, one mounted on top of the buoy and one mounted at 1.5 m depth below the water surface. Both sensors measure the amount of light at visible wavelengths (400-700 nm) reaching them, but the underwater sensor receives less light because the water and the matter it contains reduces or attenuates the solar energy. That attenuation can be quantified using the light attenuation coefficient, or K_d, which indicates how quickly light decreases with depth and is calculated from the above- and below-water light readings. K_d is one measure of water transparency or clarity similar to Secchi depths, though in this case the relationship is reversed; smaller K_d values indicate clearer water. When K_d equals 1, the photic zone (where there is enough light for algae to grow) is about 4.6 m deep and a K_d of 0.5 means the photic zone is about 9.2 m deep. At the buoy, daily mean K_d varied from about 0.6 to about 1 m^{-1} with an overall mean and standard deviation of 0.86 (± 0.07) m^{-1}. Higher K_d values (lower clarity) occurred in May, early August, and early September, while the lowest K_d values (higher clarity) occurred in June. The high-K_d periods roughly correspond to times with higher wind speeds, suggesting the influence of resuspended particles. Light attenuation is a function of material that absorbs or reflects light like humic and tannic acids, soils and sediments, algae, and even water itself. These same factors influence Secchi depth measurements, so we would expect the two water clarity indicators to be correlated. The comparison between K_d and Secchi depth measured near the buoy (range 5.9 to 7.3 m, data not shown) did suggest the expected relationship, but there was too much variation to make it significant. This is unsurprising given the small range of both values and the fact that the above-water light was uncorrected for reflection by surface disturbances (e.g., waves and ripples).

Water Temperature



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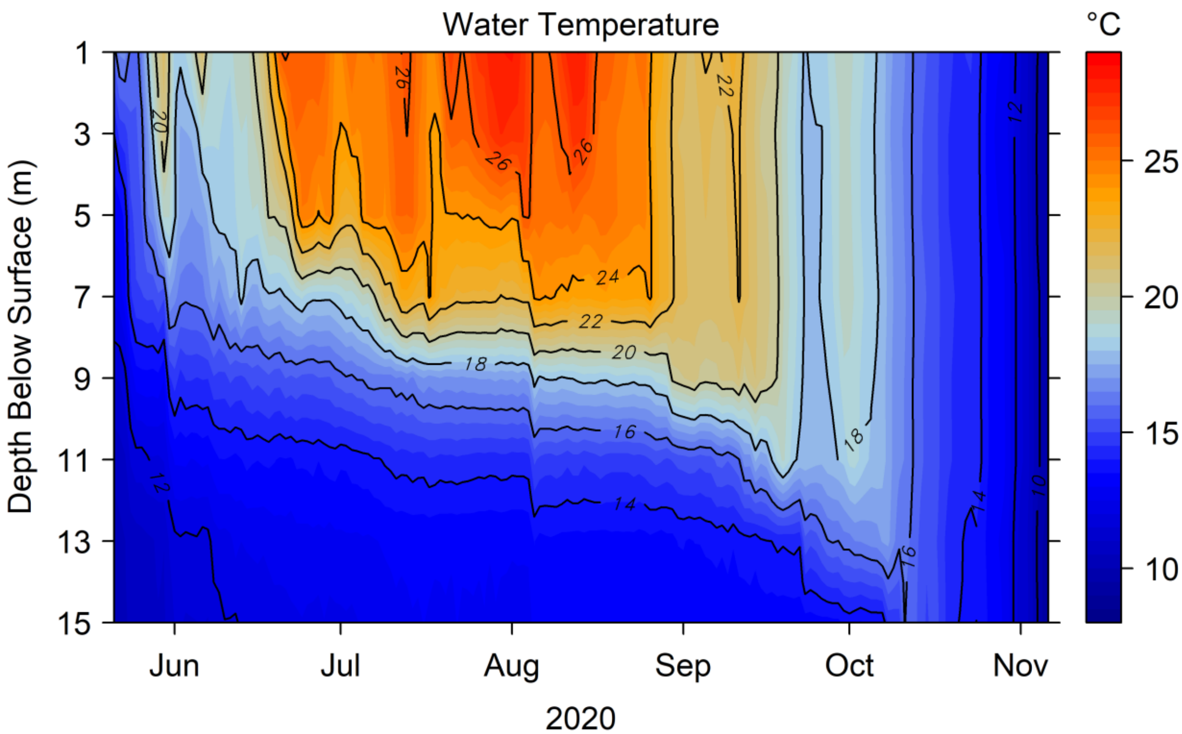
Long Lake Results

This turnover date was the earliest yet recorded by the buoy (see table below). By comparison, Highland Lake mixed on the same date and stayed that way.

Date of Fall Turnover (Complete Mixing) by Year

YEAR	2013	2014	2015	2016	2017	2018	2019	2020
Turnover Date	10/25	10/23	N/A	N/A	11/4	10/18	10/18	10/8



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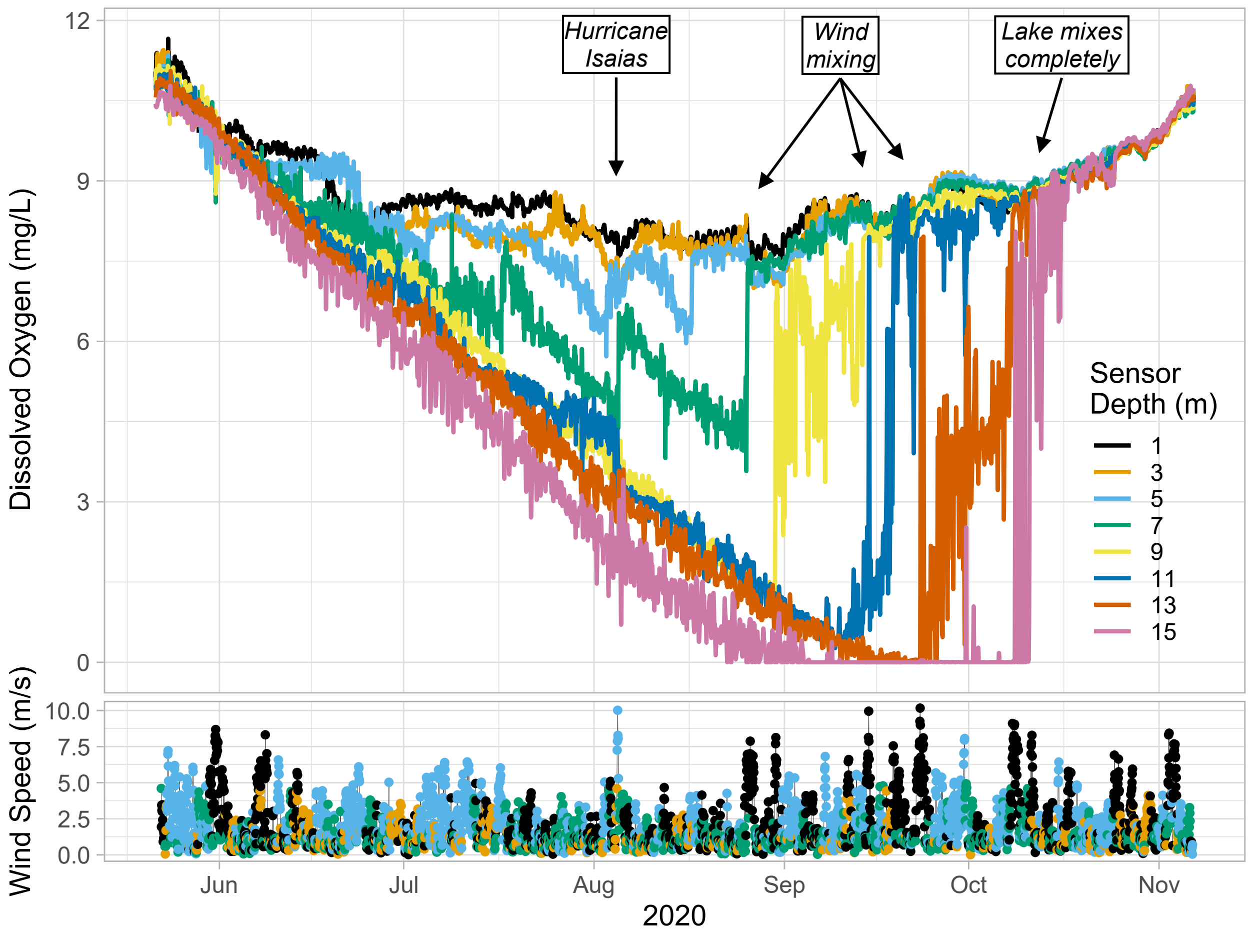
Dissolved Oxygen



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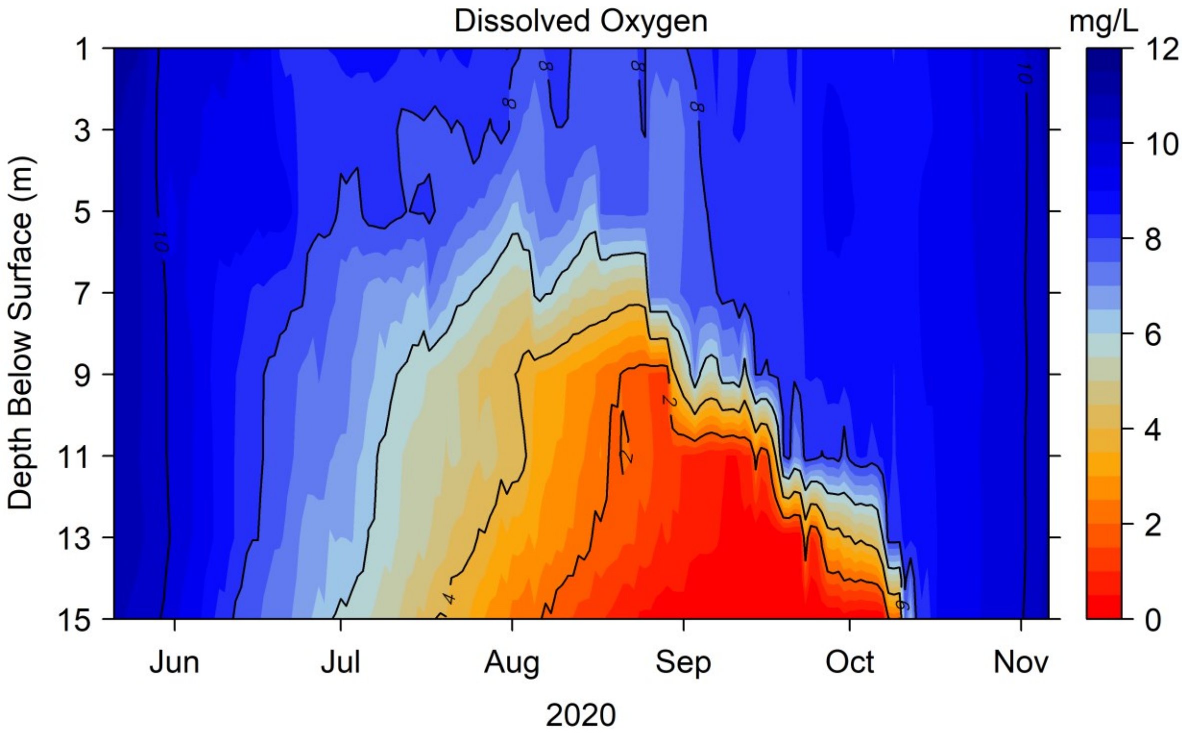

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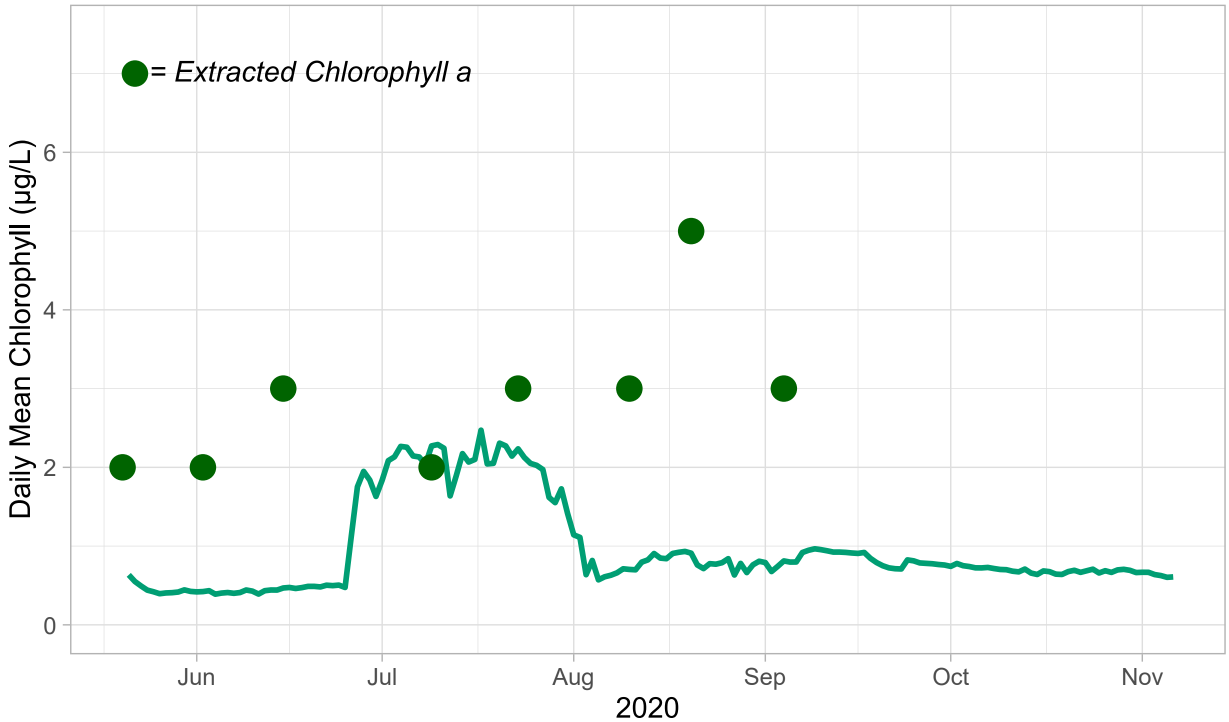
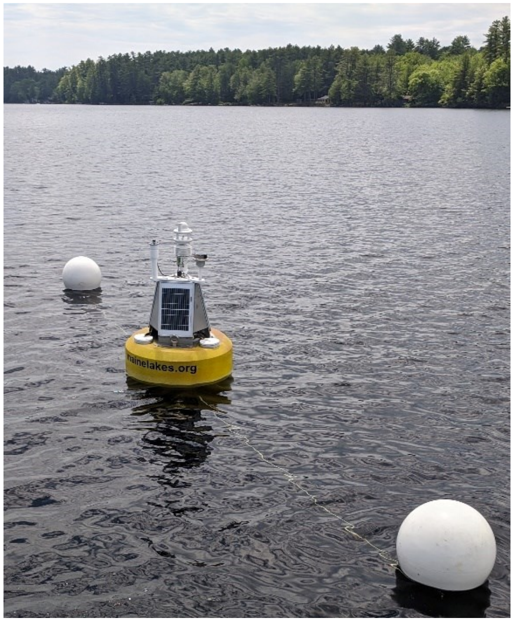
Chlorophyll or Algae Biomass



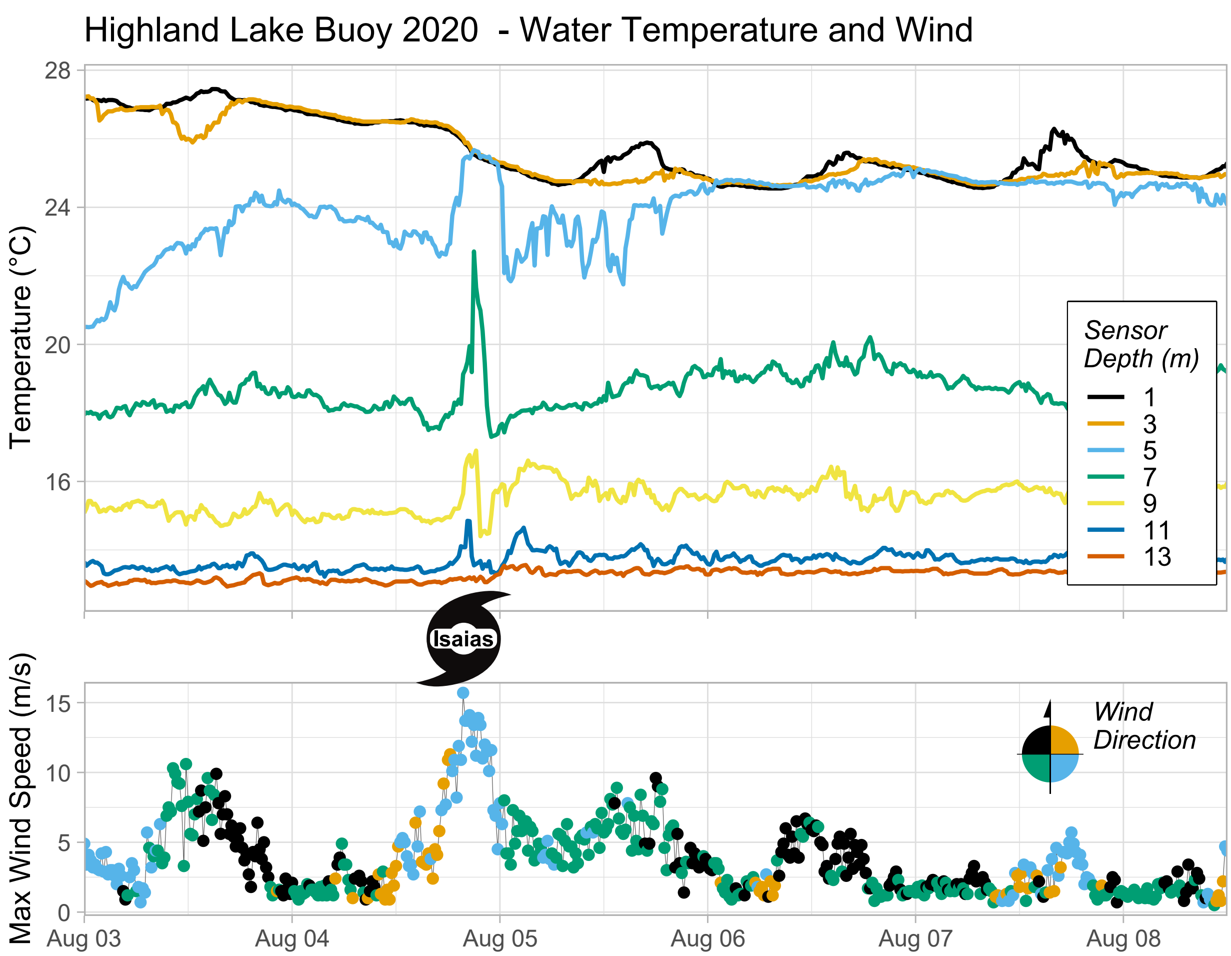
The Long Lake buoy began the season with sensors at three different depths (1, 3, and 5 m below the lake surface) that measure chlorophyll concentrations using fluorescence (same as the field fluorometer used on regular testing trips and discussed in chapter 4). The sensors at 1 and 3 m failed and had to be removed; only the 5 m data is shown. The concentration of chlorophyll (a pigment found in all plants and algae) can be used as a proxy for algae biomass and as a measure for the productivity of a lake. It is important to note that field fluorescence is a relative measure and is not as accurate as lab-based chlorophyll measurements. Also, chlorophyll fluorescence often shows variation with depth and the buoy can only measure at discrete depths. Still, buoy chlorophyll and extracted chlorophyll *a* concentrations from our regular testing trips were of similar magnitude during some of the period. Daily mean chlorophyll, shown above, ranged from near 0.5 to 2 µg/L, with a wide peak in values during July and little variation for the rest of the deployment. The peak values in July do correspond with increased rain, which may have enriched the system with nutrients, like phosphorus and nitrogen. There are, of course, other factors that control algae populations, like competition between different species and zooplankton grazing, but those are beyond the capabilities of the buoy.

Stormy Weather: Impact of Hurricane Isaias on LEA Lakes, August 2020



Maine is accustomed to weathering storms that bring high winds (think nor'easters), but not usually in the summer. Early this past August, we had a drive-by by Hurricane Isaias. Even though the storm had lost strength and was transitioning to extratropical as it moved through New York and Vermont, strong winds pummeled our area for several hours.

Our two automated buoys on Highland Lake and Long Lake captured the event, both from above and below the waterline. The figure below illustrates the water temperature and wind measurements made by the Highland buoy. The top panel shows water temperatures measured at 7 different depths every 15 minutes, and the bottom panel shows maximum wind speed and wind direction at the same time.



Appendix: Hurricane Isaias

Before the storm, the lake was strongly stratified with warmest water in the top 3 m and coldest water at the bottom. On the evening of 4 August, strong southeast winds (up to 15 m/s or 33 mph) pushed lake surface water towards the north forcing warm water downward as shown by the rapid increase in temperature at all depths except the bottom.

By the morning of 5 August, the winds had relaxed some and shifted to the southwest, causing the lake to rock back the other way and deep water to cool down again. By the end of the day, the warm upper layer was now deeper than before (notice how temperatures from 1 to 5 m were the same), a precursor to the annual fall mixing event (i.e., lake turnover).

Since the dog days of August were not over, the effect was short-lived and the water remained warm and stable. In fact, by mid-August, surface waters warmed up and restratified, much like conditions before the storm. The date the lake completely mixed (fall turnover) was the earliest recorded by the buoys. It is possible that the storm mixing event contributed to earlier turnover, though there were several other strong wind events throughout the late summer and fall.

In addition to the two automated buoys, we monitor thirteen lakes in our service area using arrays of HOBO temperature loggers (see Report Chapter 3). High-resolution temperature data from these loggers, much like that reported for the automated buoys, showed wind mixing was evident following the passage of the storm. The effect was most noticeable in lakes that had longer fetch (or unobstructed open water) in the direction of the strongest winds (SE).