Water Remote Sensing of Surface Area and Temperature Measurements of Lake Hartwell

Baylea Gaddis

GISC 3200

September 02, 2020

Abstract

Water is a vital substance on Earth. The water people consume, and use must be monitored to able to ensure good quality. An important source of water for many people come from lakes, such as Lake Hartwell. Monitoring lakes are vital for the population and the environment that uses it. There are many policies and actions in place to ensure the water is healthy. In situ testing provide significant data on the water quality. However, there are other ways to monitor the lake such as remote sensing. The best practice of lake monitoring is using a combination of both remote sensing and in situ measurements. Remote sensing can calculate algae blooms, water level, and temperature. In this study a python toolbox will be created to analyze the surface area and water temperature of Lake Hartwell. This toolbox will use LandSAT 8 data to produce an area shapefile and a mean temperature raster.

Introduction

Lake Hartwell is a man-made lake that was constructed by the U.S. Army Corps of Engineers for flood control, hydropower, and navigation projects. Construction of the lake took place between 1955 and 1963. Lake Hartwell is the largest and most popular lakes in the southeast. The lake provides water supply, recreational use, and fish and wildlife management. Lake Hartwell is between Georgia and South Carolina with the Savannah, Tugaloo, and Seneca Rivers connecting, as shown in Figure 1. The lake is an important source for the community around it. Scientist monitor the water quality to protect the people who use it. The lake can be monitored by remote sensing. Remote sensing scientists study water bodies because of the undeniable link between human societies and water. Research of oceans, freshwater systems, icecaps, and water in the Earth’s atmosphere allow us to locate, quantify, assess, and make decisions regarding water access, water use, and water quality. Water remote sensing is based on the interaction with electromagnetic radiation and water bodies. This project utilizes concepts related to this interaction to quantify surface area and temperature. “Land and water surface temperature is an important aspect in monitoring water quality and is central driver in ecology, biodiversity, and species distribution” (Vanhellemont, 2020). Using remote sensing to calculate water surface temperature allows for a quick and easy way to monitor a large body of water. In situ measurements are useful but are collected at specific points. While remote sensing provides a calculation for the entire body of water. Surface area of water is another aspect that is important to monitor. It is used to study times of drought and flooding. The easiest way to monitor the surface area is by remote sensing. The biggest impact of this data is monitoring lakes over time. The data allows decisions to made for how the water can and will be used, as well as how to maintain the lake.

Figure 1 Study area Lake Hartwell

AL-Fahdawi and colleagues used remote sensing and in situ measurements to monitor water quality of a lake. The study used LandSAT 8 imagery to perform the remote sensing portion. They selected multiple site areas to collect in situ data from to test the physical and chemical properties to calculate temperature, turbidity, TDS, TSS, and chlorophyll-a. For the remote sensing they were studying the same calculations to compare it to in situ data. AL-Fahdawi repeated these data collections for each season to determine the change of water quality throughout a year. The study showed that different bands can monitor the same property at different seasons. Remote sensing provided a general prediction and can a potential cause for error when compared to the in situ calculations. (AL-Fahdawi et al., 2015)

Behera and colleagues used remote sensing to monitor land and water resource developments. The study used LandSAT 8 and Sentinel-2 imagery to monitor the development over time. Behera was looking into the water and vegetation change in check dams that are used for different plantations. The remote sensing data produced NDWI to show the water and moist soil. Behera wanted to see if the water was increasing or decreasing by area. The data also produced EVI, derived from NDVI, to show vegetation intensity. They wanted to see the growth or loss of vegetation in the study area. The study provided useful results to show how different plantations changed based off the water and vegetation health. (Behera 2018)

Tavares and colleagues used remote sensing and water temperature models to generate continuous daily river temperatures. The study was broken into two parts. Part one used LandSAT 7 and 8 to derive river water temperature data. Part two calibrated and validated river temperature models with the temperatures derived. Tavares used multiple methods to find the best way to derive temperatures. Three methods were used for LandSAT 7 and LandSAT 8 and one methods for just LandSAT 8. It was determined that the mix of both LandSAT 7 and 8 was the best approach. Four different models were tested and found two models that worked. Further study is needed to perfect models. (Tavares 2020)

Vanhellemont and colleagues automated water surface temperature retrieval from Landsat 8. The study used in situ water temperatures 3m under water and LandSAT 8 imagery. The surface temperature of the water was retrieved from LandSAT imagery. Land masking was automated from multi-temporal data. The land mask was categorized based of clarity of image. The surface water temperature from land mask were calculated using different algorithms and models. One model was found the best to retrieve surface temperatures. Vanhellemont also found that this study can be used to measure temperatures for other sources besides water. (Vanhellemont 2020)

Objective

The objective of this project is to quantify the surface area of Lake Hartwell, a reservoir located between Georgia and South Carolina that serves as a crucial source for drinking water through the Savanah River Basin. A secondary objective includes making estimation of surface water temperature of the lake utilizing imagery obtained by Landsat 8. The final objective is to automate the process in order to apply it to other water sources.

Methods and Materials

The surface area of Lake Hartwell is calculated by the way that water absorbs light at wavelengths in the near and middle-infrared regions of the electromagnetic spectrum (specifically 740 – 2500 nm). Sensors aboard the Landsat 8 satellite have the spectral resolution available to collect energy in these wavelengths. Lake Hartwell is a geographically large reservoir. For these reasons, Landsat 8 is spatially and spectrally appropriate as a source of data to conduct this research. For this portion three tools will be used to calculate the surface area of the lake: Extract by Mask Tool and Iso Cluster Tool, Raster to Polygon Tool, and Select Tool. The Extract by Mask Tool will be used to extract the study area box from Landsat 8 bands 5, 10, and 11 in order to be processed faster and easier. Band 5 will be used because near-infrared is absorbed first in the water and produces a clearer image for water. Bands 10 and 11 are used because they are the thermal bands and will be used to calculate the water temperature. Band 5 will be imputed into the Iso cluster Tool to be classified into two classes: water and land (Figure 2). The Raster to Polygon Tool is needed to convert the Iso Cluster raster to a polygon. The polygon will be used in the Select Tool to create a water boundary by creating a query to select values that are equal to 1. The 1 value represents water from the Iso Cluster.

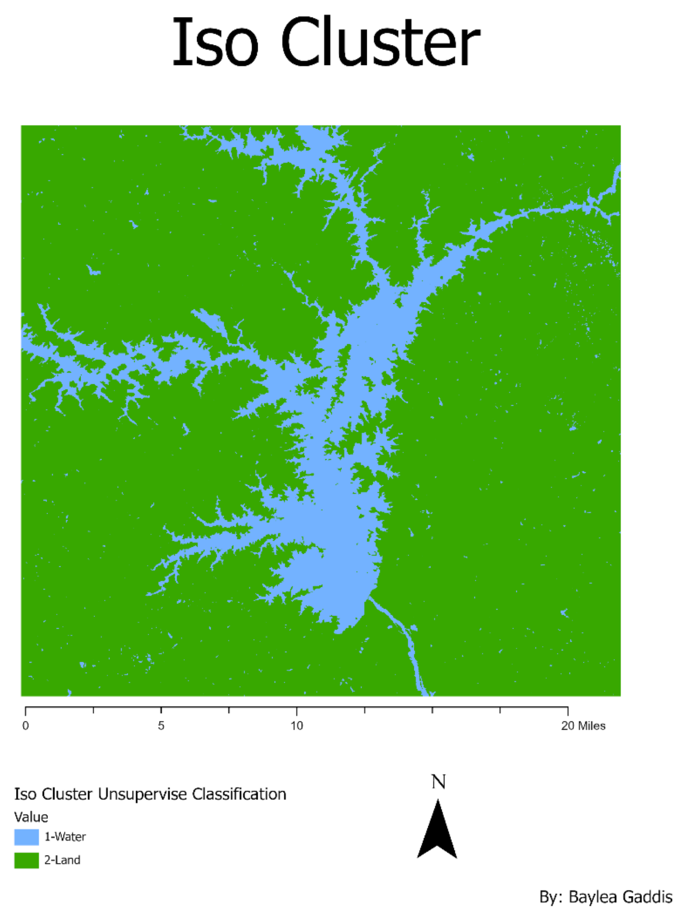


Figure 2 Iso Cluster results

Water surface temperature estimation is calculated by using the thermal band 10 and 11 to convert the data in these bands to temperature at satellite and on the lake surface. This is a two-step process that involves Top of Atmosphere (TOA) radiance calculations and at-satellite brightness temperature calculations. TOA radiance is calculated by converting the digital numbers (DN) in each band to TOA spectral radiance value using the metadata and the formula:

$$L_\lambda = M_L Q_{cal} + A_L$$

Where:

L_λ = TOA spectral radiance (Watts/(m2 * srad * μm))

M_L = Band-specific multiplicative rescaling factor from the metadata (RADIANCE_MULT_BAND_x, where x is the band number)

A_L = Band-specific additive rescaling factor from the metadata (RADIANCE_ADD_BAND_x, where x is the band number)

Q_{cal} = Quantized and calibrated standard product pixel values (DN)

At-satellite brightness temperature is calculated by converting the TOA radiance to at-satellite brightness temperature using the metadata and the formula:

$$T = \frac{K_2}{\ln\left(\frac{K_1}{L_\lambda} + 1\right) - 273.15}$$

Where:
T = At-satellite brightness temperature (K)
L_λ = TOA spectral radiance (Watts/(m2 * srad * μm))
K_1 = Band-specific thermal conversion constant from the metadata (K1_CONSTANT_BAND_x, where x is the thermal band number)
K_2 = Band-specific thermal conversion constant from the metadata (K2_CONSTANT_BAND_x, where x is the thermal band number)
Note: subtract 273.15 to convert to Celsius from Kelvin

For this portion of the project three tools will be used: Raster Calculator Tool, Cell Statistics Tool, and Extract by Mask Tool. The Raster Calculator Tool will be used four times. Two times for TOA radiance and two times for the at-satellite brightness temperature, both for bands 10 and 11. The outputs from the at-satellite brightness temperatures of bands 10 and 11 will be used in the Cell Statistic Tool to find the mean temperature. The raster that is created has the mean land and surface water temperature. Finally, the Extract by Mask Tool will be used to extract the mean temperature raster from the water boundary.

To automate this process a python toolbox is made. Automating this will allow a quick and easy output. The code can be used find the surface area and water surface temperature for any Landsat 8 imagery of bodies of water. The tool will allow the user to input all the data and be outputted the final results. This will allow the user to bypass all the steps mentioned before.

Results and Discussion

The first portion of this project produced the surface area of lake Hartwell (Figure 3). By using band 5 and the Iso Cluster Tool to classify the digital number (DN) values into two categories: water and land. Water is represented as values of 1 and land is represented as values of 2. In Figure 2, the water is shown as blue and land as green. The Iso Cluster identified Lake Hartwell easily, as well as the rivers feeding into and leaving the lake. It also identified other water sources outside of the lake. The Iso Cluster raster is used to create a water boundary. This boundary includes all the water source. The reason being in order to create a code for a python toolbox, using the select tool to find all water will be easier to automate than to locate the polygon for just the lake. Based the Iso Cluster, the area of Lake Hartwell is 64.87 Sq.Mi.

Surface Area

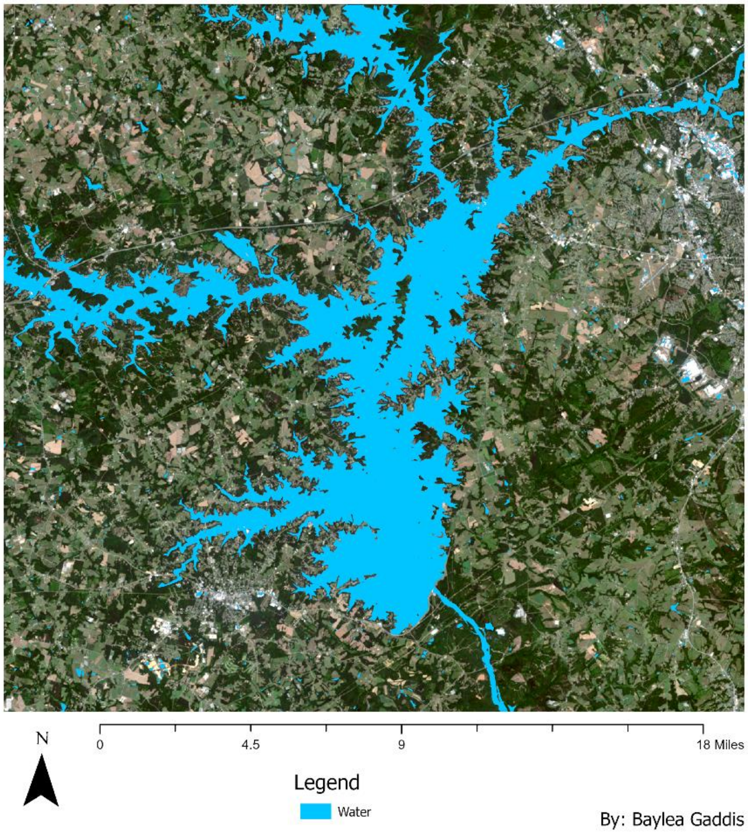


Figure 3 Surface are results

In the second portion of the project, the focus was on finding the water temperature by using bands 10 and 11. For each band the radiance and brightness was calculated in the Raster Calculator tool. The radiance used the DN of each cell and this radiance was used to calculate the brightness of each cell. In order to do these calculations, four values for each band to use in the two equations were located within the metadata provided: RADIANCE_MULT_BAND, RADIANCE_ADD_BAND, K1_CONSTANT_BAND, and K2_CONSTANT_BAND. Once the brightness for each band was calculated, the mean of the two produced the mean land and water temperature. It allows the areas of urbanization to standout since those areas tend have higher temperatures. The land temperatures skew the map to seem like all the water is the same temperature. As seen in Figure 4, extracting the water temperature allows the map to show how the water temperature is distributed and see the major differences.

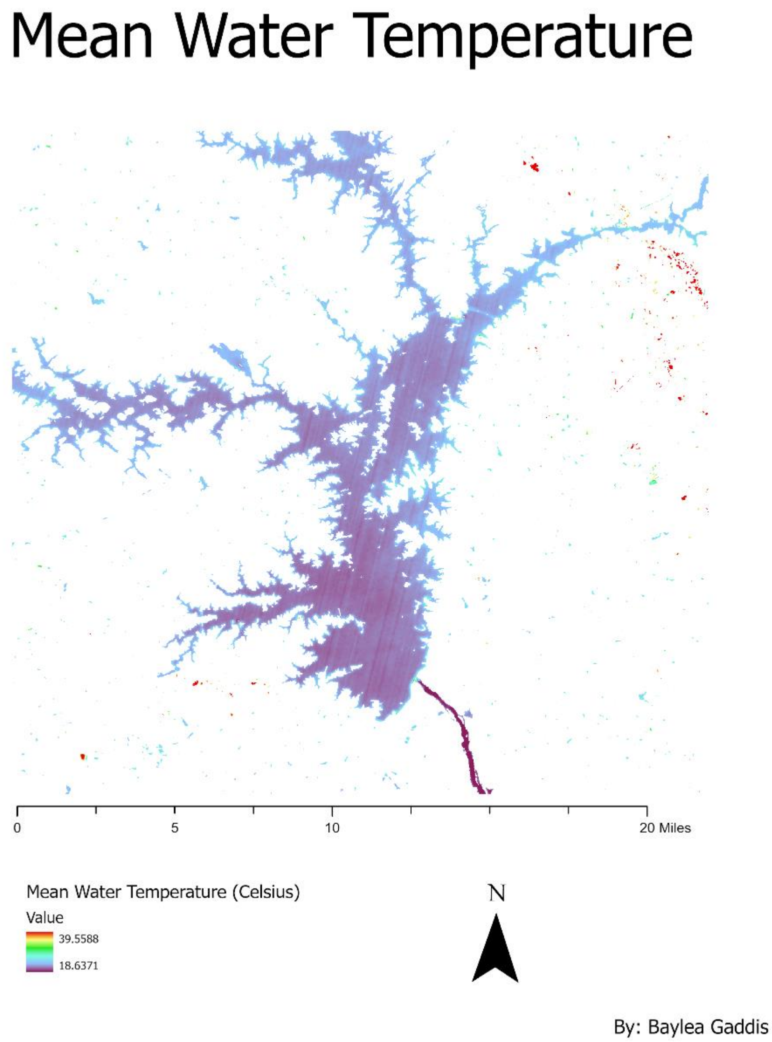
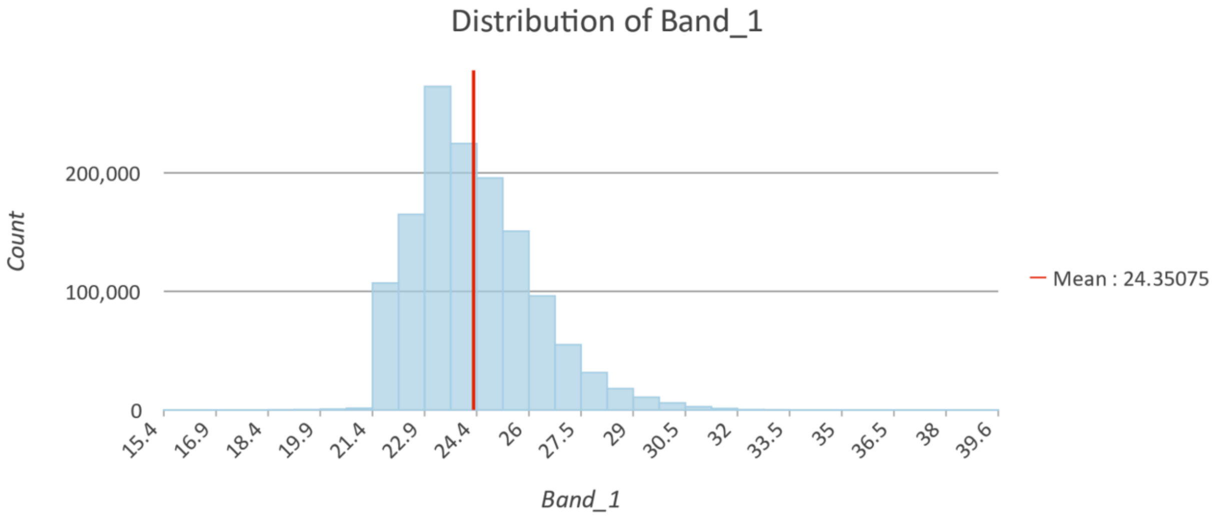


Figure 4 Mean water temperature results

With using the water boundary from the Iso Cluster instead of using just the lake boundary, there is an issue with the water temperature seeming skewed This is because the smaller water bodies will have a higher temperature because they have a smaller surface area and are shallower. Allowing them to become warmer. Figure 5 shows the distribution of temperatures throughout the cells. The mean land and water temperature in Figure 5 states its between 15.38 Celsius and 39.56 Celsius, and the mean water temperature states it's between 18.64 Celsius to 39.56 Celsius. However, this includes all the water bodies found from the surface area polygon. The largest count of cells (the lake body) is between 21.3 Celsius and 25.2 Celsius.

A



B

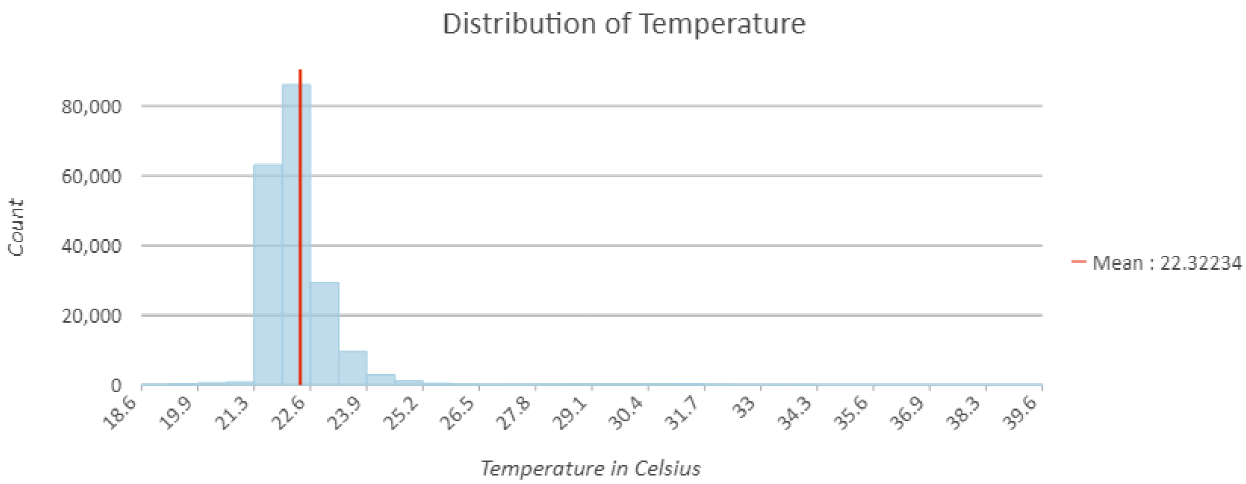


Figure 5 A. Distribution of temperature for mean land and water temperature. B. Distribution of temperature for mean water temperature.

In this project the main goal was to automate this process that most scientist use to monitor the waters temperature and area. This was successful as the same results came out from the automated tool as the manual tools used. However, there were some areas that differ from the different process. In the code the surface area is for all water bodies found by the Iso Cluster Tool. When finding the surface area manually, the lake itself was used. The automated surface area will be skewed because all the other water bodies add to the area. This leads to the mean water temperature to be skewed as well. The smaller water bodies temperature will different from the larger water body.

Conclusion

Remote sensing is a useful tool to monitor water quickly and cheaply. It doesn't replace in situ monitoring though. Remote sensing allows for estimations and predictions. It can provide useful to compare to field data and to provide insight to decision makers. The results for this project can be used to determine areas of hotspots in a lake. This project can also be used for other water sources to be monitored. With modifications to the code it could also be used other temperature related studies, such as heat islands.

Reference

AL-Fahdawi, A., Rabee, A. and Al-Hirmizy, S. (2015) 'Water quality monitoring of Al-Habbaniyah Lake using remote sensing and in situ measurements', *Environmental Monitoring & Assessment*, 187(6), pp. 1–11. doi: 10.1007/s10661-015-4607-2.

Behera, M. D. *et al.* (2018) 'Use of satellite remote sensing as a monitoring tool for land and water resources development activities in an Indian tropical site', *Environmental monitoring and assessment*, 190(7), p. 401. doi: 10.1007/s10661-018-6770-8.

Kumar, V. *et al.* (2016) 'Water quality assessment of river Beas, India, using multivariate and remote sensing techniques', *Environmental monitoring and assessment*, 188(3), p. 137. doi: 10.1007/s10661-016-5141-6.

Nanis, H. and Aly, M. H. (2020) 'Desegregation of remote sensing and GIS to characterize fluctuations in the surface water area of Afar Lakes, Ethiopia', *Geocarto International*, 35(9), pp. 976–990. doi: 10.1080/10106049.2018.1559884.

Tavares, M. H. *et al.* (2020) 'Derivation of consistent, continuous daily river temperature data series by combining remote sensing and water temperature models', *Remote Sensing of Environment*, 241. doi: 10.1016/j.rse.2020.111721.

Vanhellemont, Q. (2020) 'Automated water surface temperature retrieval from Landsat 8/TIRS', *Remote Sensing of Environment*, 237. doi: 10.1016/j.rse.2019.111518.