# Environmental Systems and Societies
# Internal Assessment

How does the distance between a location and its nearby water bodies influence the atmospheric temperature of that location?

# 1 Background

In 2017, the total residential electricity consumption in the United States of America was about 1.38 kilowatt hours, sharing 37 % of the total national energy consumptions. Among them, cooling accounted for "the largest share of annual U.S. residential sector electricity consumption".(*Use of Electricity*, 2018)

Air conditioners, as an effective cooling devices, can cool down the high room temperature in a sunny day during summer. A large proportion of electricity energy is consumed by these air conditioners (*Use of Electricity*, 2018), whose production depends greatly on coals and natural gases, which accounts for 66.2 % of the total electricity generated. (Dr. Kat, 2016) These coals and natural gases are not only non-renewable energy, but also emits huge amount of carbon dioxide in their combustion, significantly leading to global warmings.(*Overview of Greenhouse Gases*, 2018)

However, alternative house cooling methods, which consume less or no electricity, could be sought, in order to reduce the emission of greenhouse gases. As water has higher specific heat capacity than soil, the temperature of natural water bodies inside a city may increase less than its surrounding soils in the daytime under intense solar radiations, thus absorb the heat in its surrounding locations.

This investigation provides an analysis of how the water bodies in cities cools down its surroundings in a hot day in summer.

# 2 Hypothesis

## 2.1 Hypothesis of Research Question

The atmospheric temperature of a location is positively related to its distance to a nearby water body.

## 2.2 Variables and Assumptions of the Hypothesis

The independent variable in this hypothesis is a location's distance to a nearby water body, measured in centimeters. The dependent variable is the atmospheric temperature at that location, measured in degrees Celsius.

This hypothesis applies only: (these are the controlled variables)

- on the location in a city on a plain,
- on a pedestrian road,
- near the surface of the ground, (altitude less than 10 meters)
- where the wind blows less than 5 meter per second, (Huler, 2007)
- of the water body of lake,
- at noon in a hot sunny day in summer (around 12 p.m., 35 degrees Celsius).

## 2.3 Rationale of the Hypothesis

Since the specific heat capacity of water is about 5 times the specific heat capacity of soil, the water is much cooler than its surrounding soil under same solar radiation in a hot sunny day in summer. As a result, the cooler air above water cools down the hotter air above soil by convection.

Since the atmospheric temperature changes smoothly, there should be a relationship that the nearer a location is to a nearby water body, the cooler its atmospheric temperature shall be.

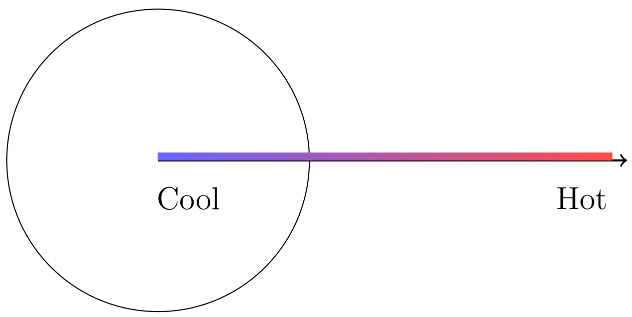


Figure 1: The temperature of a location is positively related to the distance to its nearby water body

# 3 Experiments

## 3.1 Experiment Design

This experiment is designed as a simulative experiment, since the position of a natural water body cannot be moved in order to measure its effect on a location's atmospheric temperature. In this experiment, a basin of water is used to simulate a water body, and it is put in a garden to effect the atmospheric temperature of its surrounding environments. For the convenience of the experiment, a water basin with diameter of 30 centimeters are used, since it is widely accessible. A photo of the experiment environment is provided in figure 2.

Figure 2: Experiment environments

The garden simulates a city on a plain; the stool simulates the pedestrian road; the water basin and the thermometer are next to the ground; the basin of water simulates a lake instead of a river or a sea; and finally, it was 1 p.m. at a hot sunny day, according to figure 3.

## 3.2 Experiment Procedures

A mercury thermometer is used to measure the atmospheric temperature around that basin of water, and a triangular ruler in a set square is used to measure the distance from the center of that basin of water.

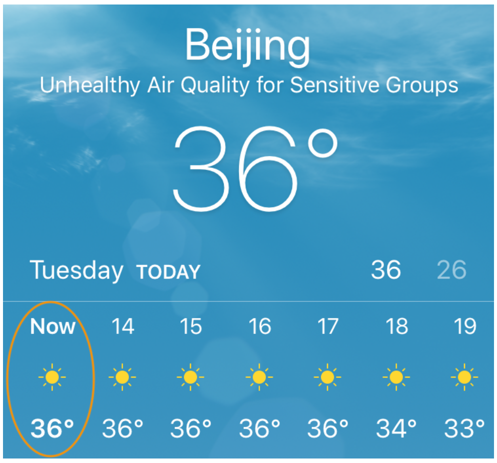


Figure 3: Weather report on experiment day

Half a basin of water is collected from a water tap in a nearby washroom, and put on a stool in a garden. Five minutes is given for the atmospheric temperature in the new microclimate around the basin to change.

A test trial of data recording is given to verify the feasibility of the planned experiment steps. Then the real data are measured.

Figure 4: Measuring under direct sunlight

There are totally four sets of data to be measured in this experiment. The first two sets of data measures the relationship between a location's temperature and its distance to the center of the water basin under **direct sunlight**, shown in figure 4, while the last two sets of data measures the relationship in **shade**, shown in figure 5.

Figure 5: Measuring in shade

The temperatures at the locations with the distance of five centimeters are measured, in order to obtain 8 readings which was enough to conduct linear regression afterwards.

Two sets of data are measured and an average value is calculated for the relationships of each sunlight situation to be measured. However, to prevent the influence from which the water in basin was heated too much during the time of measurement (since temperatures can't be measured instantaneously using a mercury thermometer), the temperatures at different locations are measured in different order. To be specific, in the first trial, the temperature from the center of the water basin is measured first and then the samples more further away from the center are measured. The order is reversed in the second trial.

The temperature of the environment and the temperature of the water body are also recorded, in different orders as well. The environment temperature is measured first, before measuring the atmospheric temperatures at different locations. Then the measuring order is reversed in the following trial.

## 3.3 Safety Precautions

Do not break the thermometer as it contains mercury inside.

# 4 Result Analysis

The data is analyzed by calculating average temperatures for each of the two sets of experiment both under direct sunlight and in shade, scattering those temperatures on graphs with respect to the distance between its measured location and the water body and regressing for a line of best fit.

Table 1 provides the original data from the experiment.

| Distance to water (centimeter) | 0 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | Environment | Water |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Test trial (degrees Celsius) | 39 | 38 | 39 | 40 | 40 | 41 | 41 | 40 | 40 | 45 | 28 |
| Temperature under sunlight (degrees Celsius) | 39.2 | 40.1 | 40.5 | 40.9 | 41.2 | 41.2 | 42.1 | 42.8 | 42.1 | 40 | 27 |
| Temperature under sunlight (degrees Celsius) | 40.9 | 41.0 | 41.5 | 42 | 41.7 | 41.7 | 41.7 | 41.5 | 41.0 | 40 | 29 |
| Temperature in shade (degrees Celsius) | 34.5 | 34.8 | 34.5 | 35.0 | 36.0 | 36.7 | 37.1 | 37.1 | 37.2 | 36.8 | 27 |
| Temperature in shade (degrees Celsius) | 38.9 | 39.5 | 38.5 | 39.1 | 40.2 | 39.9 | 39.0 | 37.3 | 38.0 | 37.4 | 27.5 |

Table 1: Data recording table

## 4.1 Relationships under Sunlight

According to figure 6, a location's temperature is positively correlated to its distance to the center of its nearby water basin, under direct sunlight. The atmospheric temperature is 40.1 degrees Celsius at the center of that water basin, while the atmospheric temperature rises towards 41.5 degrees Celsius at 40 centimeters from the center of that water basin. The water temperature is 28 degrees Celsius.

The r-squared value of the regression is 0.773, indicating that the location's distance to the water basin is pretty linearly related to its atmospheric tem-

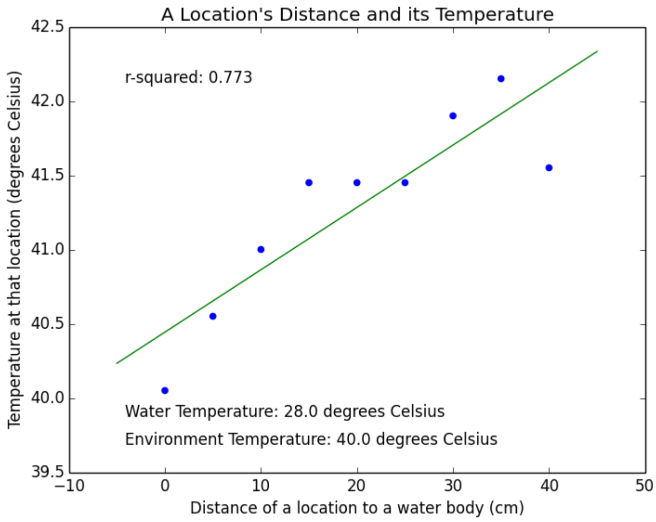


Figure 6: The relationship between a location's distance to the center of a water basin and its atmospheric temperature, **under direct sunlight**

perature. The scattered points also shows a clear tendency on that relationship.

## 4.2 Relationships in Shade

A location's temperature is not clearly correlated to its distance to the center of its nearby water basin, in the shade, according to figure 7.

In these two sets of experiments, the average water temperature is 27.8 degrees Celsius. The environment temperature is 37.1 degrees Celsius, which is lower than more than half of the atmospheric temperatures above the locations near that water basin or the water basin itself.

Since this group of experiment is conducted in shade, the range of temperatures at the y-axis is about 4 degrees Celsius lower than that in the previous graph in figure 6.

The r-squared value of the regression is 0.333, indicating that there is no strong correlations between a location's distance to the water basin and its atmospheric temperature.

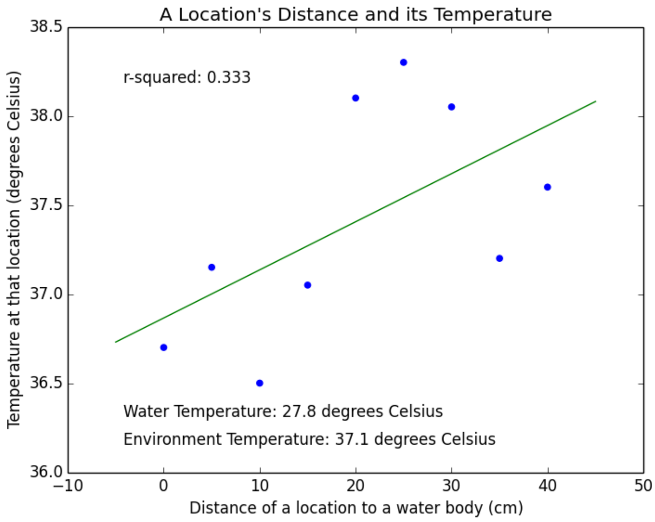


Figure 7: The relationship between a location's distance to the center of a water basin and its atmospheric temperature, **in shade**

# 5 Conclusions and Evaluations

## 5.1 Conclusions

According to the results of this experiments, the atmospheric temperature of a location is positively related to its distance to a nearby water body only when that location is under **direct sunlight**.

## 5.2 Discussions

In figure 7, contrary to the expected cooling effect on the nearby locations, the measured atmospheric temperature is even higher than the original environment temperature, both above the center of the water basin and the locations 40 centimeters away from the center of the water basin. A possible error could be because of the underestimated environment temperature due to the fact that some water is spilled on the stool in the garden which lead to a decreased temporary environment temperature.

## 5.3 Hypothesis Testing

Linear regression t test is performed on the obtained data, in order to determine whether the correlation between the distance of a location to a water body and the temperature at that location is statistically significant. The significant level $\alpha$, is set to be 5%.

$H_0$: There is **no** correlation between the distance of a location to a water body and the temperature at that location, $\rho = 0$.

$H_1$: There **is** correlation between the distance of a location to a water body and the temperature at that location, $\rho \neq 0$.

The p-value of the first group of data is 0.18%, which is less than $\alpha$, suggesting $H_0$ is true, that there **is** significant correlation between the the two sets of data measured **under direct sunlight**. However, the p-value of the second group of data is 10.4%, which is more than $\alpha$, suggesting $H_0$ is true, that there is **no** significant correlation between the two sets of data measured **in shade**.

## 5.4 Error Analysis

Since this experiment is limited to be a simulative experiment, its errors are mainly caused by the scales and simplifications of the simulative model and the inaccurate measurings of the meters.

### 5.4.1 Scale of Experiment

A water basin is used to simulate a natural water body, but the difference of scale affects the water's atmosphere cooling effect. Since a tiny amount of wind could blow the cooled atmosphere above the water basin, which has a radius of only 15 centimeters, away, the cooling effect of the atmospheric temperature by water may not be detected or recorded by the thermometer.

Moreover, a natural water body is not only longer or wider, but also deeper than a water basin, such that it absorbs the amount of heat proportional to its length **cubed**, while controlling the atmospheric temperature of its surrounding area proportional to its length **squared**. So the small water basin has less ability to control the atmospheric temperature of its surrounding area than a big natural water body, which further weakens the air cooling effect in the simulative experiment.

Finally, the temperature of such small water basin rises much faster than a large natural water body. Under direct sunlight, the temperature of the water basin was 27 degrees Celsius after it was left in the experiment environment for 5 minutes at the first trial, but raised to 29 degrees Celsius after the measurement of the second trial is finished, even though the water in the basin was replaced before the second trial.

#### 5.4.2 Simplification of Model

The atmospheric convection of a natural water body could be much more complex. There could be more turbulent air flows, and even blustering ocean waves and river flows, rubbing the air, influencing its movement. The transpirations of vegetations and their heat absorptions could also add disturbances to the water body model.

#### 5.4.3 Inaccurate Measurements

A mercury thermometer is used to measure the atmospheric temperature above the water basin and its surrounding locations. However, the sunlight radiation at the metal tip of the thermometer heats up its temperatures and increase the readings of the thermometer.

## 6 Applications and Further Investigations

### 6.1 Applications

This investigation provides a solid evidence on the cooling effect of a water body on its nearby locations in a hot sunny day in summer. As the heat capacity of water is higher than that of the soil, the water bodies could absorb more heat in the daytime to cool down its surroundings. As a result, enough proportion of water body area is suggested to include in the planning of the construction of a city.

### 6.2 Further Investigations

In an arbitrary location, there could be multiple nearby water bodies of it in different form. There could be lakes of different surface shapes, river of different width and curve shapes, and oceans with different coastline shapes, even a combination of all three. A further investigation should consider these influences.

Moreover, the change of temperatures of locations which is further away from a water body should be recorded, in order to determine a potential range of the cooling effect of a water body, and possibly with respect to the size of that water body.

# References


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# A Data Analysis Programs

```
import numpy as np
import matplotlib.pyplot as plt

distance = [i * 5 for i in range(9)] + [-2, -1]
sun1 = [39.2, 40.1, 40.5, 40.9, 41.2, 41.2, 42.1, 42.8, 42.1, 40, 28]
sun2 = [40.9, 41.0, 41.5, 42, 41.7, 41.7, 41.7, 41.5, 41.0, 40, 29]
shade1 = [34.5, 34.8, 34.5, 35.0, 36.0, 36.7, 37.1, 37.1, 37.2, 36.8, 28]
shade2 = [38.9, 39.5, 38.5, 39.1, 40.2, 39.9, 39.0, 37.3, 38.0, 37.4, 27.5]

sun = [(a + b) / 2 for (a, b) in zip(sun1, sun2)]
sunParameters = np.polyfit(distance[:9], sun[:9], 1)
sunEquation = np.poly1d(sunParameters)
sunCorrMatrix = np.corrcoef(distance[:9], sun[:9])
sunR2 = sunCorrMatrix[0, 1] ** 2

shade = [(a + b) / 2 for (a, b) in zip(shade1, shade2)]
shadeParameters = np.polyfit(distance[:9], shade[:9], 1)
shadeEquation = np.poly1d(shadeParameters)
shadeCorrMatrix = np.corrcoef(distance[:9], shade[:9])
shadeR2 = shadeCorrMatrix[0, 1] ** 2


plt.scatter(distance[:9], sun[:9], color = 'blue')
plt.plot((-5, 45), (sunEquation(-5), sunEquation(45)),
color = 'green')
plt.figtext(0.2, 0.2, 'Water Temperature: {} \
degrees Celsius'.format(round(sun[-1], 1)))
plt.figtext(0.2, 0.15, 'Environment Temperature: {} \
degrees Celsius'.format(round(sun[-2], 1)))
plt.figtext(0.2, 0.8, 'r-squared: {}'.format(round(sunR2, 3)))
plt.title("A Location's Distance and its Temperature")
plt.xlabel('Distance of a location to a water body (cm)')
plt.ylabel('Temperature at that location (degrees Celsius)')
plt.savefig('sunlightgraph', bbox_inches = 'tight')
plt.clf()

plt.scatter(distance[:9], shade[:9], color = 'blue')
plt.plot((-5, 45), (shadeEquation(-5), shadeEquation(45)),
```

```
color = 'green')
plt.figtext(0.2, 0.2, 'Water Temperature: {} \
degrees Celsius'.format(round(shade[-1], 1)))
plt.figtext(0.2, 0.15, 'Environment Temperature: {} \
degrees Celsius'.format(round(shade[-2], 1)))
plt.figtext(0.2, 0.8, 'r-squared: {}'.format(round(shadeR2, 3)))
plt.title("A Location's Distance and its Temperature")
plt.xlabel('Distance of a location to a water body (cm)')
plt.ylabel('Temperature at that location (degrees Celsius)')
plt.savefig('shadegraph', bbox_inches = 'tight')
plt.clf()


print(sun)
print(shade)
```