Assignment 6: GLMs (Linear Regressios, ANOVA, & t-tests)

Ariel Lam

OVERVIEW

This exercise accompanies the lessons in Environmental Data Analytics on generalized linear models.

Directions

1. Rename this file `<FirstLast>_A06_GLMs.Rmd` (replacing `<FirstLast>` with your first and last name).
2. Change "Student Name" on line 3 (above) with your name.
3. Work through the steps, **creating code and output** that fulfill each instruction.
4. Be sure to **answer the questions** in this assignment document.
5. When you have completed the assignment, **Knit** the text and code into a single PDF file.

Set up your session

1. Set up your session. Check your working directory. Load the tidyverse, agricolae and other needed packages. Import the *raw* NTL-LTER raw data file for chemistry/physics (`NTL-LTER_Lake_ChemistryPhysics_Raw.csv`). Set date columns to date objects.

2. Build a ggplot theme and set it as your default theme.

```
# 1
library(tidyverse)
```

```
## -- Attaching packages --------------------------------------- tidyverse 1.3.2 --
## v ggplot2 3.3.6      v purrr   0.3.4
## v tibble  3.1.8      v dplyr   1.0.10
## v tidyr   1.2.1      v stringr 1.4.1
## v readr   2.1.2      v forcats 0.5.2
## -- Conflicts ------------------------------------------ tidyverse_conflicts() --
## x dplyr::filter() masks stats::filter()
## x dplyr::lag()    masks stats::lag()
```

```
library(agricolae)
library(ggplot2)
library(lubridate)
```

```
##
## Attaching package: 'lubridate'
##
## The following objects are masked from 'package:base':
##
##     date, intersect, setdiff, union
```

```
getwd()
```

```
## [1] "/Users/ariellam/Desktop/EDA-Fall2022/Assignments"
```

```r
setwd("/Users/ariellam/Desktop/EDA-Fall2022")
NTL_LTER <- read.csv("./Data/Raw/NTL-LTER_Lake_ChemistryPhysics_Raw.csv",
    stringsAsFactors = TRUE)
NTL_LTER$sampledate <- as.Date(NTL_LTER$sampledate,
    format = "%m/%d/%y")
NTL_LTER$Year4 <- month(NTL_LTER$sampledate)

# 2
assignment_theme <- theme_light(base_size = 12) +
    theme(axis.text = element_text(color = "black"))

theme_set(assignment_theme)
```

Simple regression

Our first research question is: Does mean lake temperature recorded during July change with depth across all lakes?

3. State the null and alternative hypotheses for this question: > Answer: H0: change in temp = 0 Ha: 0 < change in temp > 0

4. Wrangle your NTL-LTER dataset with a pipe function so that the records meet the following criteria:

- Only dates in July.
- Only the columns: `lakename`, `year4`, `daynum`, `depth`, `temperature_C`
- Only complete cases (i.e., remove NAs)

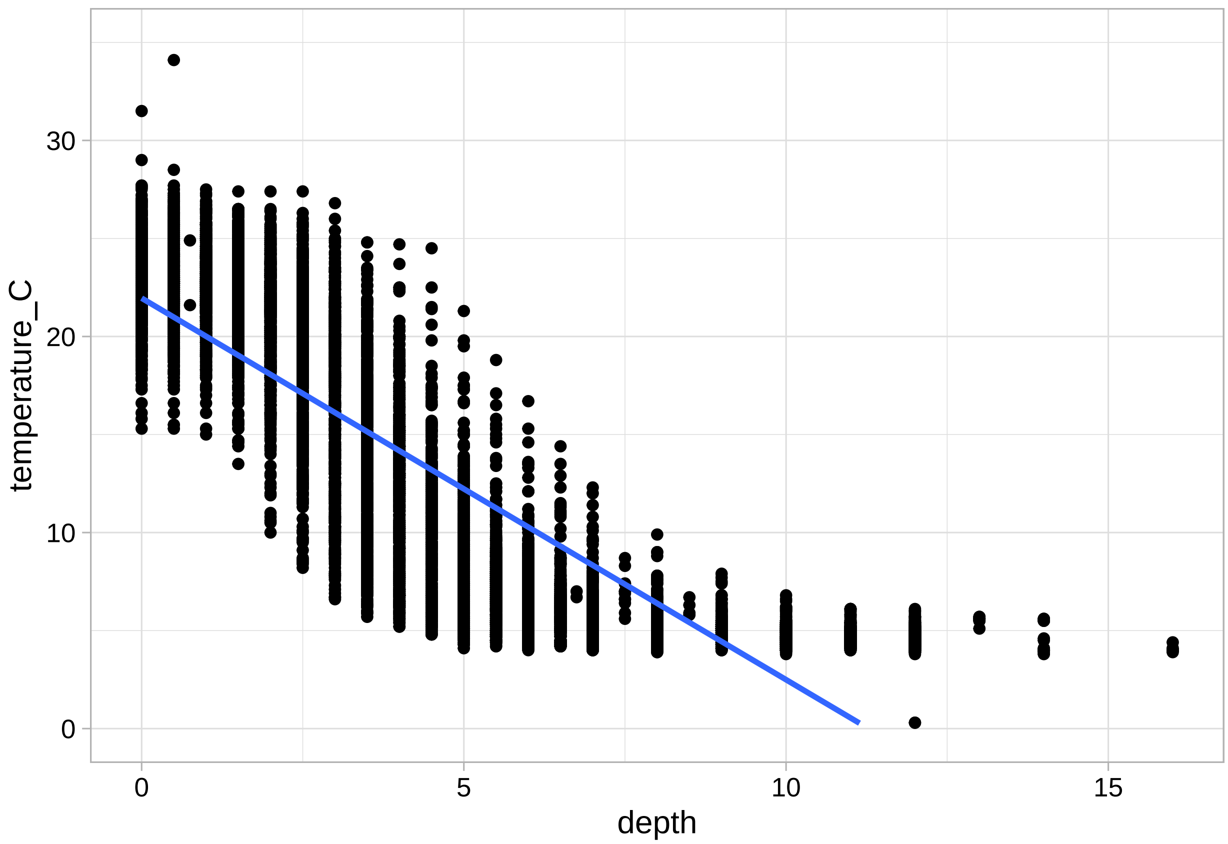
5. Visualize the relationship among the two continuous variables with a scatter plot of temperature by depth. Add a smoothed line showing the linear model, and limit temperature values from 0 to 35 °C. Make this plot look pretty and easy to read.

```r
# 4
NTL_LTER_TempDepth <- NTL_LTER %>%
    filter(month(NTL_LTER$sampledate) == "7") %>%
    select(lakename, year4, daynum, depth, temperature_C) %>%
    drop_na()

# 5
ggplot(NTL_LTER_TempDepth, aes(x = depth, y = temperature_C)) +
    geom_point() + geom_smooth(method = lm, se = FALSE) +
    ylim(c(0, 35))
```

```
## `geom_smooth()` using formula 'y ~ x'

## Warning: Removed 24 rows containing missing values (geom_smooth).
```



6. Interpret the figure. What does it suggest with regards to the response of temperature to depth? Do the distribution of points suggest about anything about the linearity of this trend?

   Answer: As depth increases, the temperature seems to decrease until a certain threshold. The distribution of points suggest a linear trend with a large spread because the points seem to disperse from the line.

7. Perform a linear regression to test the relationship and display the results

```
# 7
temp_depth_regression <- lm(data = NTL_LTER_TempDepth,
    temperature_C ~ depth)
summary(temp_depth_regression)
```

```
##
## Call:
## lm(formula = temperature_C ~ depth, data = NTL_LTER_TempDepth)
##
## Residuals:
##     Min      1Q  Median      3Q     Max
## -9.5173 -3.0192  0.0633  2.9365 13.5834
##
## Coefficients:
##             Estimate Std. Error t value Pr(>|t|)
## (Intercept) 21.95597    0.06792   323.3   <2e-16 ***
## depth       -1.94621    0.01174  -165.8   <2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
```

```
## Residual standard error: 3.835 on 9726 degrees of freedom
## Multiple R-squared:  0.7387, Adjusted R-squared:  0.7387
## F-statistic: 2.75e+04 on 1 and 9726 DF,  p-value: < 2.2e-16
```

8. Interpret your model results in words. Include how much of the variability in temperature is explained by changes in depth, the degrees of freedom on which this finding is based, and the statistical significance of the result. Also mention how much temperature is predicted to change for every 1m change in depth.

   Answer: The linear model is based on 9726 degrees of freedom. The p-value of 2.2e-16 indicates that the relationship is significant as it is less than the significance value of 0.05. The low p-value indicates that the null hypothesis is false and it is possible to accept the alternative that the change in depth does correlate with a change in temperature. The multiple R-squared value of .7387 indicates an acceptable goodness of fit for the linear model and states that 73.87% of variability is accounted for by this model. . The linear model indidcates that for every change in 1m of depth, the temperature will change by a magnitude of 1.9 degrees celcius. Because they are negatively correlated, an increase in depth leads to a decrease in temp and vice versa.

Multiple regression

Let's tackle a similar question from a different approach. Here, we want to explore what might the best set of predictors for lake temperature in July across the monitoring period at the North Temperate Lakes LTER.

9. Run an AIC to determine what set of explanatory variables (year4, daynum, depth) is best suited to predict temperature.

10. Run a multiple regression on the recommended set of variables.

```r
# 9

temp_depth_model <- lm(data = NTL_LTER_TempDepth,
    temperature_C ~ year4 + daynum + depth)
step(temp_depth_model)
```

```
## Start:  AIC=26065.53
## temperature_C ~ year4 + daynum + depth
##
##          Df Sum of Sq    RSS   AIC
## <none>                141687 26066
## - year4   1       101 141788 26070
## - daynum  1      1237 142924 26148
## - depth   1    404475 546161 39189

##
## Call:
## lm(formula = temperature_C ~ year4 + daynum + depth, data = NTL_LTER_TempDepth)
##
## Coefficients:
## (Intercept)        year4       daynum        depth
##    -8.57556      0.01134      0.03978     -1.94644
```

```r
# 10

temp_depth_multi_regression <- lm(data = NTL_LTER_TempDepth,
    temperature_C ~ year4 + daynum + depth)
summary(temp_depth_multi_regression)
```

```
##
```

```
## Call:
## lm(formula = temperature_C ~ year4 + daynum + depth, data = NTL_LTER_TempDepth)
##
## Residuals:
##     Min      1Q  Median      3Q     Max
## -9.6536 -3.0000  0.0902  2.9658 13.6123
##
## Coefficients:
##              Estimate Std. Error  t value Pr(>|t|)
## (Intercept) -8.575564   8.630715   -0.994  0.32044
## year4        0.011345   0.004299    2.639  0.00833 **
## daynum       0.039780   0.004317    9.215  < 2e-16 ***
## depth       -1.946437   0.011683 -166.611  < 2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 3.817 on 9724 degrees of freedom
## Multiple R-squared:  0.7412, Adjusted R-squared:  0.7411
## F-statistic:  9283 on 3 and 9724 DF,  p-value: < 2.2e-16
```

11. What is the final set of explanatory variables that the AIC method suggests we use to predict temperature in our multiple regression? How much of the observed variance does this model explain? Is this an improvement over the model using only depth as the explanatory variable?

    Answer: AIC method suggests that all three variables: year4, daynum, and depth should be used to predict temperature in the multiple regression. 74.11% of the observed variance is accounted for by this model. This is only a slightly improvement over the model using only depth as the explanatory variable.

Analysis of Variance

12. Now we want to see whether the different lakes have, on average, different temperatures in the month of July. Run an ANOVA test to complete this analysis. (No need to test assumptions of normality or similar variances.) Create two sets of models: one expressed as an ANOVA models and another expressed as a linear model (as done in our lessons).

```
# 12 unique(NTL_LTER_TempDepth$lakename)
Temp_ANOVA <- aov(data = NTL_LTER_TempDepth, temperature_C ~
    lakename)
summary(Temp_ANOVA)
```

```
##               Df Sum Sq Mean Sq F value Pr(>F)
## lakename       8  21642  2705.2      50 <2e-16 ***
## Residuals   9719 525813    54.1
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
ANOVA_lm <- lm(data = NTL_LTER_TempDepth, temperature_C ~
    lakename)
summary(ANOVA_lm)
```

```
##
## Call:
## lm(formula = temperature_C ~ lakename, data = NTL_LTER_TempDepth)
##
```

```
## Residuals:
##     Min      1Q  Median      3Q     Max
## -10.769  -6.614  -2.679   7.684  23.832
##
## Coefficients:
##                           Estimate Std. Error t value Pr(>|t|)
## (Intercept)                17.6664     0.6501  27.174  < 2e-16 ***
## lakenameCrampton Lake      -2.3145     0.7699  -3.006 0.002653 **
## lakenameEast Long Lake     -7.3987     0.6918 -10.695  < 2e-16 ***
## lakenameHummingbird Lake  -6.8931     0.9429  -7.311 2.87e-13 ***
## lakenamePaul Lake          -3.8522     0.6656  -5.788 7.36e-09 ***
## lakenamePeter Lake         -4.3501     0.6645  -6.547 6.17e-11 ***
## lakenameTuesday Lake       -6.5972     0.6769  -9.746  < 2e-16 ***
## lakenameWard Lake          -3.2078     0.9429  -3.402 0.000672 ***
## lakenameWest Long Lake     -6.0878     0.6895  -8.829  < 2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 7.355 on 9719 degrees of freedom
## Multiple R-squared:  0.03953,    Adjusted R-squared:  0.03874
## F-statistic:    50 on 8 and 9719 DF,  p-value: < 2.2e-16
```

13. Is there a significant difference in mean temperature among the lakes? Report your findings.

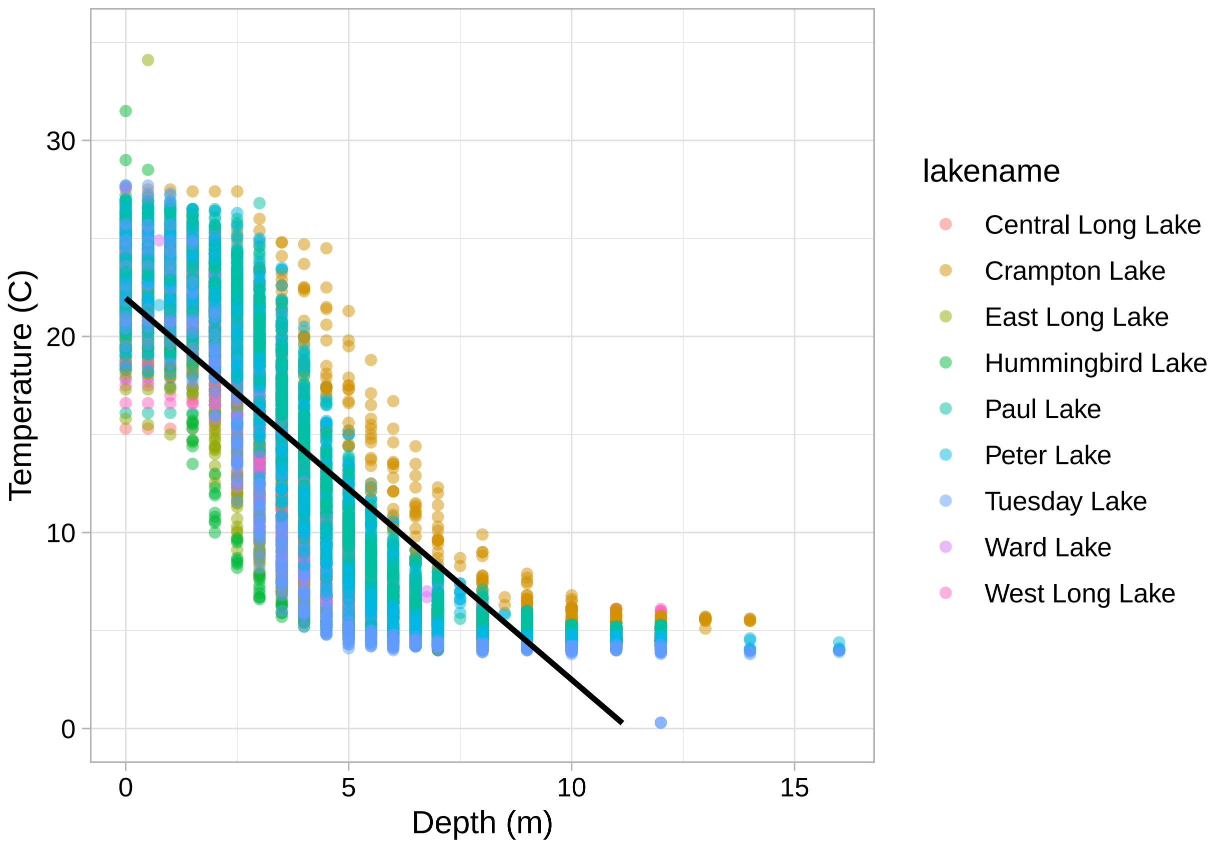
    Answer: From the aov, the df value of 9719 and the overall p-value of less than 2e-16 show that there is a significant difference in the means of the lakes. The anova lm function set the baseline comparison against Central Long Lake. The deviations of the means of the different lakes are all statistically significant as they are all less than 0.05. This signifies that the lakes are significantly colder than Central Long Lake, and some are colder than others.

14. Create a graph that depicts temperature by depth, with a separate color for each lake. Add a geom_smooth (method = "lm", se = FALSE) for each lake. Make your points 50 % transparent. Adjust your y axis limits to go from 0 to 35 degrees. Clean up your graph to make it pretty.

```
# 14.
graph_temp_depth <- ggplot(NTL_LTER_TempDepth,
    aes(x = depth, y = temperature_C)) + geom_point(aes(color = lakename),
    alpha = 0.5) + geom_smooth(method = "lm",
    color = "black", se = FALSE) + ylim(c(0, 35)) +
    xlab("Depth (m)") + ylab("Temperature (C)")
print(graph_temp_depth)
```

```
## `geom_smooth()` using formula 'y ~ x'
```

```
## Warning: Removed 24 rows containing missing values (geom_smooth).
```



15. Use the Tukey's HSD test to determine which lakes have different means.

```
# 15

TukeyHSD(Temp_ANOVA)
```

```
##   Tukey multiple comparisons of means
##     95% family-wise confidence level
##
## Fit: aov(formula = temperature_C ~ lakename, data = NTL_LTER_TempDepth)
##
## $lakename
##                                           diff        lwr        upr     p adj
## Crampton Lake-Central Long Lake    -2.3145195 -4.7031913  0.0741524 0.0661566
## East Long Lake-Central Long Lake   -7.3987410 -9.5449411 -5.2525408 0.0000000
## Hummingbird Lake-Central Long Lake -6.8931304 -9.8184178 -3.9678430 0.0000000
## Paul Lake-Central Long Lake        -3.8521506 -5.9170942 -1.7872070 0.0000003
## Peter Lake-Central Long Lake       -4.3501458 -6.4115874 -2.2887042 0.0000000
## Tuesday Lake-Central Long Lake     -6.5971805 -8.6971605 -4.4972005 0.0000000
## Ward Lake-Central Long Lake        -3.2077856 -6.1330730 -0.2824982 0.0193405
## West Long Lake-Central Long Lake   -6.0877513 -8.2268550 -3.9486475 0.0000000
## East Long Lake-Crampton Lake       -5.0842215 -6.5591700 -3.6092730 0.0000000
## Hummingbird Lake-Crampton Lake     -4.5786109 -7.0538088 -2.1034131 0.0000004
## Paul Lake-Crampton Lake            -1.5376312 -2.8916215 -0.1836408 0.0127491
## Peter Lake-Crampton Lake           -2.0356263 -3.3842699 -0.6869828 0.0000999
## Tuesday Lake-Crampton Lake         -4.2826611 -5.6895065 -2.8758157 0.0000000
## Ward Lake-Crampton Lake            -0.8932661 -3.3684639  1.5819317 0.9714459
## West Long Lake-Crampton Lake       -3.7732318 -5.2378351 -2.3086285 0.0000000
```

```
## Hummingbird Lake-East Long Lake     0.5056106 -1.7364925  2.7477137 0.9988050
## Paul Lake-East Long Lake            3.5465903  2.6900206  4.4031601 0.0000000
## Peter Lake-East Long Lake           3.0485952  2.2005025  3.8966879 0.0000000
## Tuesday Lake-East Long Lake         0.8015604 -0.1363286  1.7394495 0.1657485
## Ward Lake-East Long Lake            4.1909554  1.9488523  6.4330585 0.0000002
## West Long Lake-East Long Lake       1.3109897  0.2885003  2.3334791 0.0022805
## Paul Lake-Hummingbird Lake          3.0409798  0.8765299  5.2054296 0.0004495
## Peter Lake-Hummingbird Lake         2.5429846  0.3818755  4.7040937 0.0080666
## Tuesday Lake-Hummingbird Lake       0.2959499 -1.9019508  2.4938505 0.9999752
## Ward Lake-Hummingbird Lake          3.6853448  0.6889874  6.6817022 0.0043297
## West Long Lake-Hummingbird Lake     0.8053791 -1.4299320  3.0406903 0.9717297
## Peter Lake-Paul Lake               -0.4979952 -1.1120620  0.1160717 0.2241586
## Tuesday Lake-Paul Lake             -2.7450299 -3.4781416 -2.0119182 0.0000000
## Ward Lake-Paul Lake                 0.6443651 -1.5200848  2.8088149 0.9916978
## West Long Lake-Paul Lake           -2.2356007 -3.0742314 -1.3969699 0.0000000
## Tuesday Lake-Peter Lake            -2.2470347 -2.9702236 -1.5238458 0.0000000
## Ward Lake-Peter Lake                1.1423602 -1.0187489  3.3034693 0.7827037
## West Long Lake-Peter Lake          -1.7376055 -2.5675759 -0.9076350 0.0000000
## Ward Lake-Tuesday Lake              3.3893950  1.1914943  5.5872956 0.0000609
## West Long Lake-Tuesday Lake         0.5094292 -0.4121051  1.4309636 0.7374387
## West Long Lake-Ward Lake           -2.8799657 -5.1152769 -0.6446546 0.0021080
```

```r
# Extract groupings for pairwise
# relationships
TukeyHSDTest <- HSD.test(Temp_ANOVA, "lakename",
    group = TRUE)
TukeyHSDTest
```

```
## $statistics
##   MSerror   Df     Mean       CV
##   54.1016 9719 12.72087 57.82135
##
## $parameters
##    test   name.t ntr StudentizedRange alpha
##   Tukey lakename   9         4.387504  0.05
##
## $means
##                    temperature_C      std    r Min  Max    Q25   Q50    Q75
## Central Long Lake       17.66641 4.196292  128 8.9 26.8 14.400 18.40 21.000
## Crampton Lake           15.35189 7.244773  318 5.0 27.5  7.525 16.90 22.300
## East Long Lake          10.26767 6.766804  968 4.2 34.1  4.975  6.50 15.925
## Hummingbird Lake        10.77328 7.017845  116 4.0 31.5  5.200  7.00 15.625
## Paul Lake               13.81426 7.296928 2660 4.7 27.7  6.500 12.40 21.400
## Peter Lake              13.31626 7.669758 2872 4.0 27.0  5.600 11.40 21.500
## Tuesday Lake            11.06923 7.698687 1524 0.3 27.7  4.400  6.80 19.400
## Ward Lake               14.45862 7.409079  116 5.7 27.6  7.200 12.55 23.200
## West Long Lake          11.57865 6.980789 1026 4.0 25.7  5.400  8.00 18.800
##
## $comparison
## NULL
##
## $groups
##                    temperature_C groups
## Central Long Lake       17.66641      a
## Crampton Lake           15.35189     ab
```

```
## Ward Lake              14.45862     bc
## Paul Lake              13.81426      c
## Peter Lake             13.31626      c
## West Long Lake         11.57865      d
## Tuesday Lake           11.06923     de
## Hummingbird Lake       10.77328     de
## East Long Lake         10.26767      e
##
## attr(,"class")
## [1] "group"
```

16.From the findings above, which lakes have the same mean temperature, statistically speaking, as Peter Lake? Does any lake have a mean temperature that is statistically distinct from all the other lakes?

> Answer: Paul Lake and Ward Lake seem to have the same mean temperature as Peter Lake. The p-values for their differences against Peter Lake are not statistically significant as the they are above .05 which indicate that they don't vary in terms of mean temperature. Central Long lake does seem to have a large difference in mean from the other lakes as the mean difference magnitudes appear much higher in comparison to the other lakes.

17. If we were just looking at Peter Lake and Paul Lake. What's another test we might explore to see whether they have distinct mean temperatures?

    > Answer: If we were just looking at peter and paul lake, we could use a t-test because that test tests for one categorical explanatory (temperature) against two categories (peter and paul lake)

18. Wrangle the July data to include only records for Crampton Lake and Ward Lake. Run the two-sample T-test on these data to determine whether their July temperature are same or different. What does the test say? Are the mean temperatures for the lakes equal? Does that match you answer for part 16?

```r
crampton_ward <- NTL_LTER_TempDepth %>%
    filter(lakename %in% c("Crampton Lake", "Ward Lake"))

crampton_ward_t_test <- t.test(crampton_ward$temperature_C ~
    crampton_ward$lakename)
crampton_ward_t_test
```

```
##
##  Welch Two Sample t-test
##
## data:  crampton_ward$temperature_C by crampton_ward$lakename
## t = 1.1181, df = 200.37, p-value = 0.2649
## alternative hypothesis: true difference in means between group Crampton Lake and group Ward Lake is n
## 95 percent confidence interval:
##  -0.6821129  2.4686451
## sample estimates:
## mean in group Crampton Lake     mean in group Ward Lake
##                    15.35189                    14.45862
```

> Answer: The test gives a non significant p-value and therefore must accept the null hypothesis that the difference in means between the two lakes is equal to 0. The mean temperatures are pretty close to each other as the mean for Crampton Lake is 15.4 and the mean for Ward lake is 14.5. The tukey test in question 16 between Crampton and Ward give a high p value that isn't siginicant indicating that their mean temperatures are similar and therefore match the t-test results.