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

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OVERVIEW

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

Directions

1. Change "Student Name" on line 3 (above) with your name.
2. Work through the steps, **creating code and output** that fulfill each instruction.
3. Be sure to **answer the questions** in this assignment document.
4. When you have completed the assignment, **Knit** the text and code into a single PDF file.
5. After Knitting, submit the completed exercise (PDF file) to the dropbox in Sakai. Add your last name into the file name (e.g., "Fay_A06_GLMs.Rmd") prior to submission.

The completed exercise is due on Monday, February 28 at 7:00 pm.

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
getwd()
```

```
## [1] "C:/Users/av241/Documents/Environmental_Data_Analytics_2022/Assignments"
```

```
Chemistry_Data_Raw <- read.csv("../Data/Raw/NTL-LTER_Lake_ChemistryPhysics_Raw.csv",
                               stringsAsFactors = FALSE)
#importing the raw dataset

library(lubridate) # loading lubridate to set date
```

```
##
## Attaching package: 'lubridate'

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

```
library(tidyverse) #loading tidyverse to set theme, etc.
```

```
## -- Attaching packages --------------------------------------- tidyverse 1.3.1 --

## v ggplot2 3.3.5     v purrr   0.3.4
## v tibble  3.1.6     v dplyr   1.0.7
## v tidyr   1.1.4     v stringr 1.4.0
```

```
## v readr   2.1.1     v forcats 0.5.1

## -- Conflicts ------------------------------------------ tidyverse_conflicts() --
## x lubridate::as.difftime() masks base::as.difftime()
## x lubridate::date()        masks base::date()
## x dplyr::filter()          masks stats::filter()
## x lubridate::intersect()   masks base::intersect()
## x dplyr::lag()             masks stats::lag()
## x lubridate::setdiff()     masks base::setdiff()
## x lubridate::union()       masks base::union()
```

```
library(agricolae)# for HSD.test, etc.

Chemistry_Data_Raw$sampledate <- mdy(Chemistry_Data_Raw$sampledate)

class(Chemistry_Data_Raw$sampledate)
```

```
## [1] "Date"
```

```
#2

mytheme <- theme_gray(base_size = 10) +
  theme(axis.text = element_text(color = "darkgrey"),
        legend.position = "bottom")

theme_set(mytheme)
```

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: The mean lake temperature does not change with depth across all lakes Ha: The mean lake temperature changes with depth across all lakes

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.

```
#4
NTL_Wrangled_July <- Chemistry_Data_Raw %>%
  mutate(month= month(Chemistry_Data_Raw$sampledate))%>%
  filter(month=="7") %>%
  select(lakename, year4, daynum, depth, temperature_C)%>%
  filter(!is.na(temperature_C))

summary(NTL_Wrangled_July) # no NAs!
```

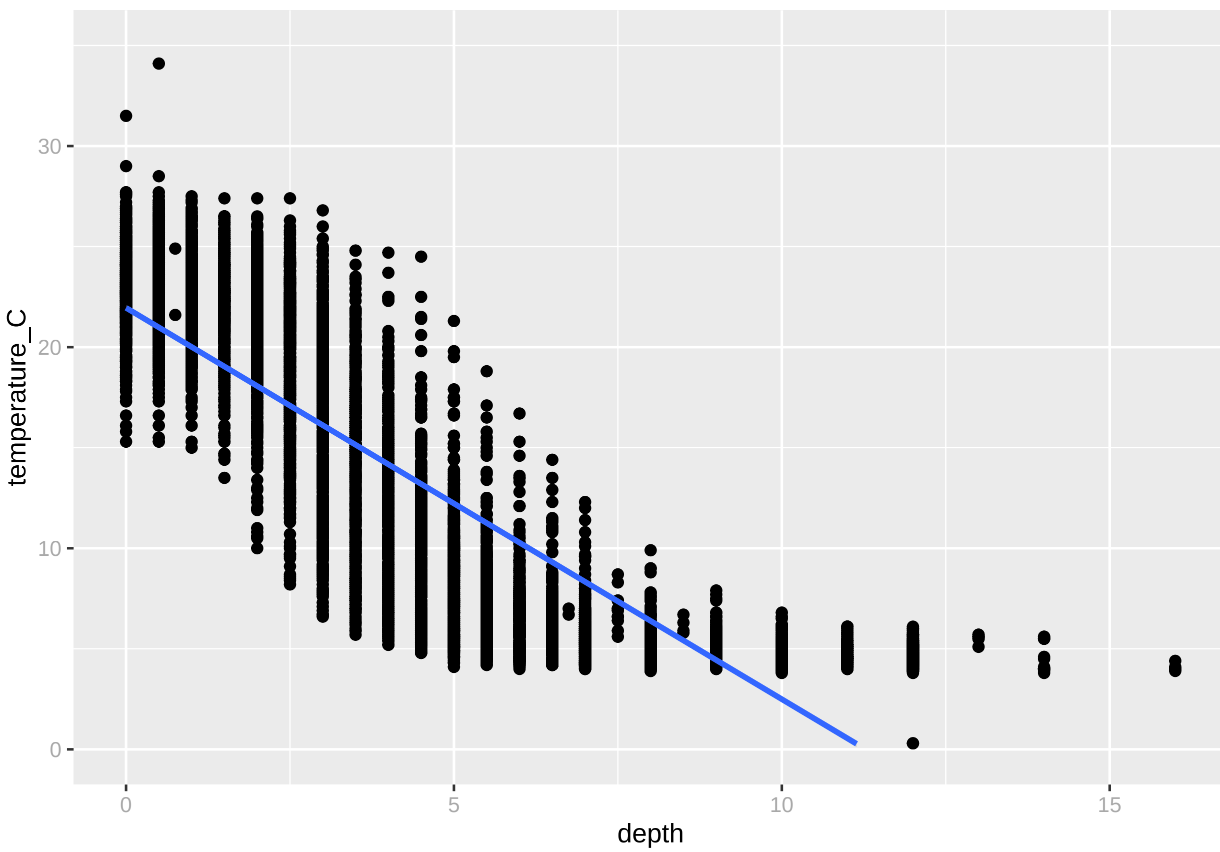
```
##    lakename             year4          daynum          depth
##  Length:9728        Min.   :1984   Min.   :182.0   Min.   : 0.000
##  Class :character   1st Qu.:1992   1st Qu.:190.0   1st Qu.: 2.000
```

```
##   Mode  :character   Median :1998   Median :198.0   Median : 4.500
##                      Mean   :1999   Mean   :197.5   Mean   : 4.745
##                      3rd Qu.:2006   3rd Qu.:205.0   3rd Qu.: 7.000
##                      Max.   :2016   Max.   :213.0   Max.   :16.000
##   temperature_C
##   Min.   : 0.30
##   1st Qu.: 5.50
##   Median :10.10
##   Mean   :12.72
##   3rd Qu.:20.80
##   Max.   :34.10
```

```
#5
NTL_regression_print <-
  ggplot(NTL_Wrangled_July, aes(x = depth, y = temperature_C)) +
  geom_point() +
  geom_smooth(method = "lm", se=TRUE)+
  ylim(0,35)
print(NTL_regression_print)
```

```
## `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: Temperature appears to reduce until a certain depth, where it starts to level off, at about

8 meters. The correlation between depth and temperature is apparent

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

```
#7
NTL_regression <- lm(data = NTL_Wrangled_July, temperature_C ~ depth)
summary(NTL_regression)
```

```
##
## Call:
## lm(formula = temperature_C ~ depth, data = NTL_Wrangled_July)
##
## 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
```

```
#The R-squared is 0.7387, and p-value is < 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: These results are based on 392 degrees of freedom. Depth explains about 73.8% of the variability in temperature. The result is statistically significant with a p-value of <2.2e-16, substantially lower than 0.05.

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.

```
#9

LTER_AIC <- lm(data = NTL_Wrangled_July, temperature_C ~ year4 + daynum +
              depth)

#Choose a model by AIC in a Stepwise Algorithm
step(LTER_AIC)
```

```
## 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_Wrangled_July)
##
## Coefficients:
## (Intercept)        year4       daynum        depth
##    -8.57556      0.01134      0.03978     -1.94644
```

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

```
##
## Call:
## lm(formula = temperature_C ~ year4 + daynum + depth, data = NTL_Wrangled_July)
##
## 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
```

```
#the AIC indicates that all the explanatory variables are significant

#10
NTL_regression2 <- lm(data = NTL_Wrangled_July, temperature_C ~ year4+ daynum + depth)
summary(NTL_regression2)
```

```
##
## Call:
## lm(formula = temperature_C ~ year4 + daynum + depth, data = NTL_Wrangled_July)
##
## 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: The AIC suggests that the variables to consider are year4, depth and daynum. These variables explain 74.12% of the variability in temperatures. The p-value remains the same, so the results are significant. Considering we have additional insight on variability without an increase in p-value, this is an improved model.

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

# null hypothesis: there is no difference in means

Lake_Temp_anova <- aov(data = NTL_Wrangled_July,  temperature_C ~ lakename)
summary(Lake_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
```

```
# P-value of <2e-16 indicates null hypothesis is invalid.

# Next, formatting ANOVA as lm
Lake_Temp_anova2 <- lm(data = NTL_Wrangled_July,  temperature_C ~ lakename)
summary(Lake_Temp_anova2)
```

```
##
## Call:
## lm(formula = temperature_C ~ lakename, data = NTL_Wrangled_July)
##
## 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: Based on this analysis, there is a significant difference in means between lakes, evidenced from the p-value of on <2e-16.The lm-based analysis also indicates a substantial difference in means as compared to the intercept term.

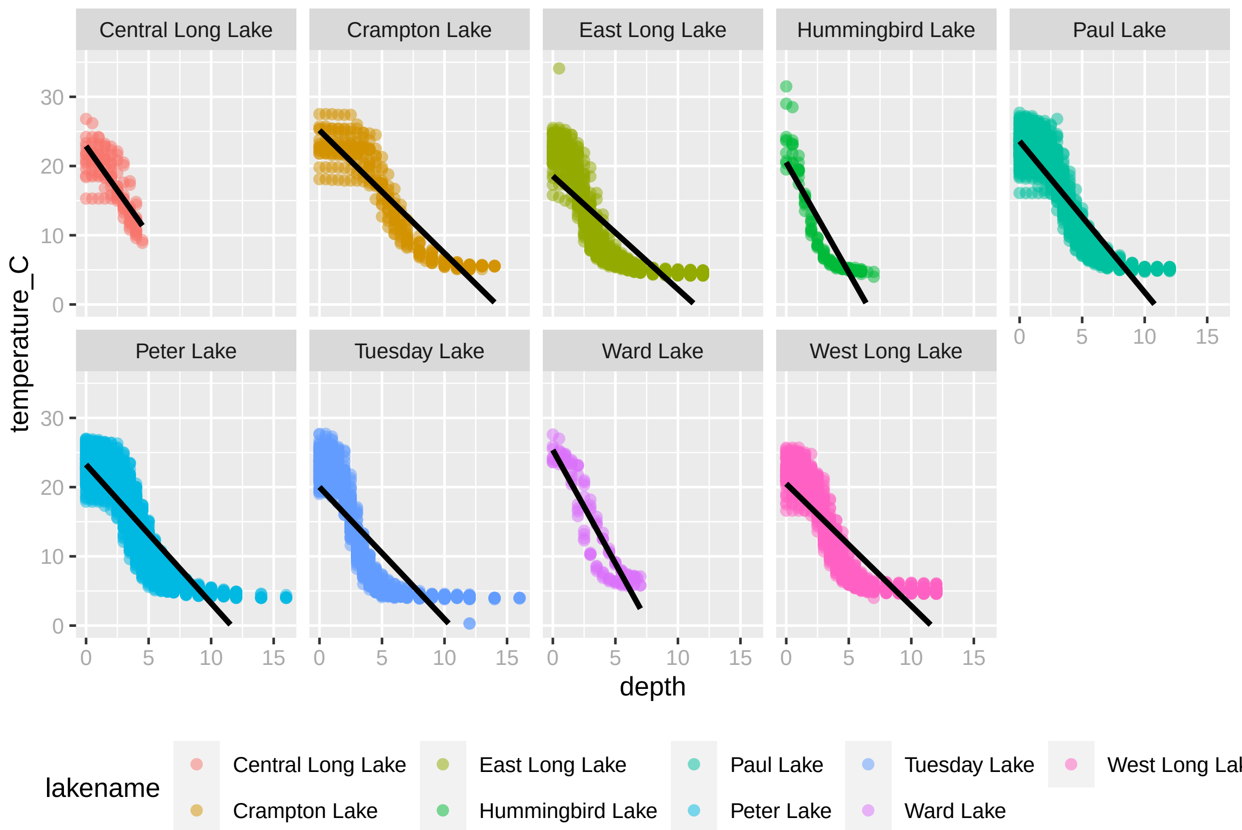
14. Create a graph that depicts temperature by depth, with a separate color for each lake. Add a geom_smooth (method = "lm", se = FALSE) for each lake. Make your points 50 % transparent. Adjust your y axis limits to go from 0 to 35 degrees. Clean up your graph to make it pretty.

```
#14.

NTLplot <- ggplot(NTL_Wrangled_July, aes(x = depth, y =temperature_C, color=lakename)) +
  geom_point(alpha=0.5) +
  geom_smooth(method = "lm",color="BLACK", se= FALSE)+
  ylim(0,35)+
  facet_wrap(vars(lakename), nrow = 2)
print(NTLplot)
```

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

## Warning: Removed 73 rows containing missing values (geom_smooth).
```



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

```
#15
TukeyHSD(Lake_Temp_anova)#assessing difference between means
```

```
##   Tukey multiple comparisons of means
##     95% family-wise confidence level
##
## Fit: aov(formula = temperature_C ~ lakename, data = NTL_Wrangled_July)
##
## $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
```

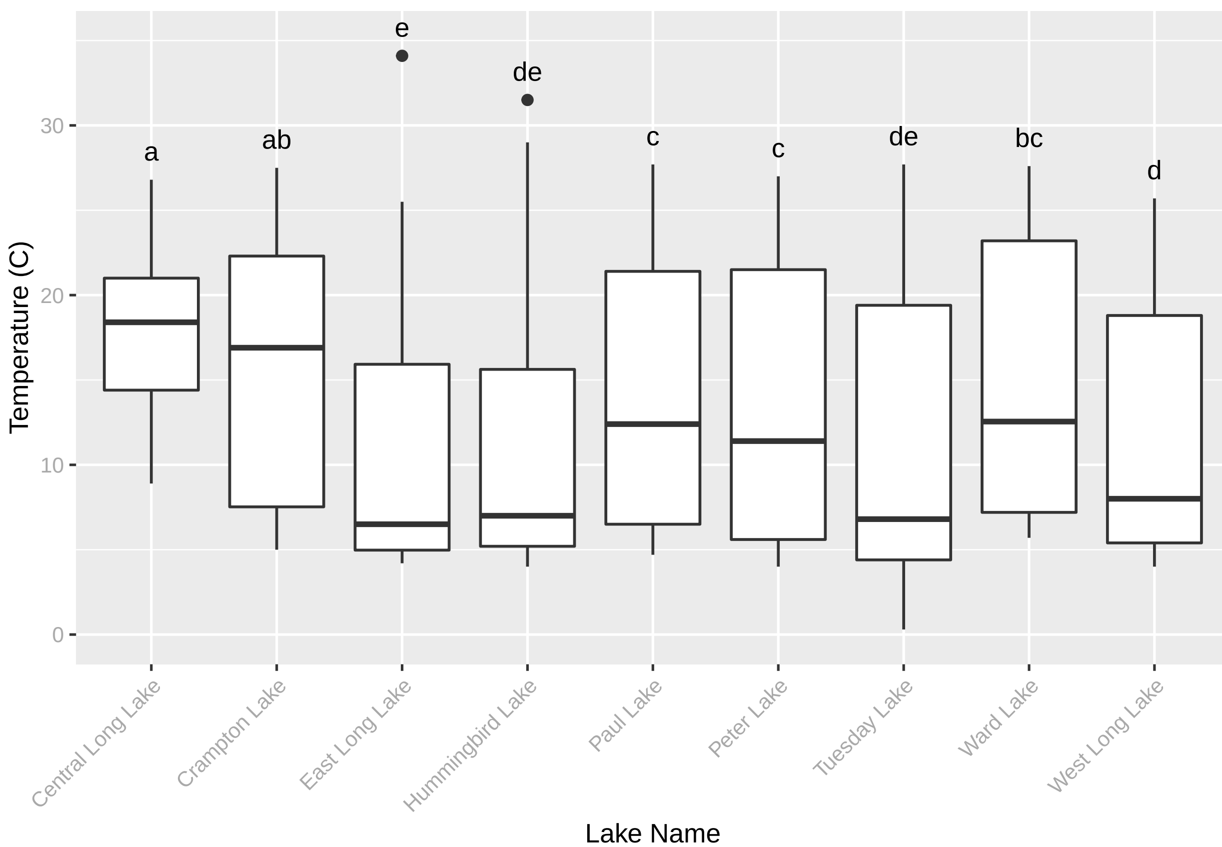
```
## Hummingbird Lake-East Long Lake      0.5056106 -1.7364925  2.7477137 0.9988050
## Paul Lake-East Long Lake             3.5465903  2.6900206  4.4031601 0.0000000
## Peter Lake-East Long Lake            3.0485952  2.2005025  3.8966879 0.0000000
## Tuesday Lake-East Long Lake          0.8015604 -0.1363286  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
```

```
TreatmentGroups_LakeTemp <- HSD.test(Lake_Temp_anova,"lakename", group = TRUE)
TreatmentGroups_LakeTemp #grouping lakes which have similar means
```

```
## $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"
```

```
#visualizing these groupings
HSDGroups.plot <- ggplot(NTL_Wrangled_July, aes(x = lakename, y = temperature_C)) +
  geom_boxplot() +
  theme(axis.text.x = element_text(angle = 45, hjust = 1)) +
  stat_summary(geom = "text", fun = max, vjust = -1, size = 3.5,
               label = c("a", "ab", "e", "de", "c", "c",
                         "de", "bc", "d")) +
  labs(x = "Lake Name", y = "Temperature (C)") +
  ylim(0, 35)
print(HSDGroups.plot)
```



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: Peter, Paul and Ward Lake all fall into group "c" and can be considered to have the same mean statistically. No lake has a mean that is distinct from ALL 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: We can do a two sample t-test to see the difference between the means of the two lakes -

ANOVAs are required in those cases where we have more than two samples.