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

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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
getwd()
```

```
## [1] "/home/guest/R/EDA-Fall2022"
```

```
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   1.2.0      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(lubridate)
```

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

```r
library(ggplot2)
library(ggpubr)
library(corrplot)
```

```
## corrplot 0.92 loaded
```

```r
RawData <- read_csv("Data/Raw/NTL-LTER_Lake_ChemistryPhysics_Raw.csv")
```

```
## Rows: 38614 Columns: 11
## -- Column specification --------------------------------------------------------
## Delimiter: ","
## chr (4): lakeid, lakename, sampledate, comments
## dbl (7): year4, daynum, depth, temperature_C, dissolvedOxygen, irradianceWat...
##
## i Use `spec()` to retrieve the full column specification for this data.
## i Specify the column types or set `show_col_types = FALSE` to quiet this message.
```

```r
RawData$sampledate <- as.Date(RawData$sampledate, format = "%m/%d/%y")

# 2

mytheme <- theme_classic(base_size = 14) + theme(axis.text = element_text(color = "black"),
    legend.position = "top")

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 recorded during July does not change with depth across all lakes or there is no linear relationship between lake temperature and depth across the data selected. Ha: The mean lake temperature recorded during July does change with depth across all lakes or there is a linear relationship between lake temperature and depth across the data selected.

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

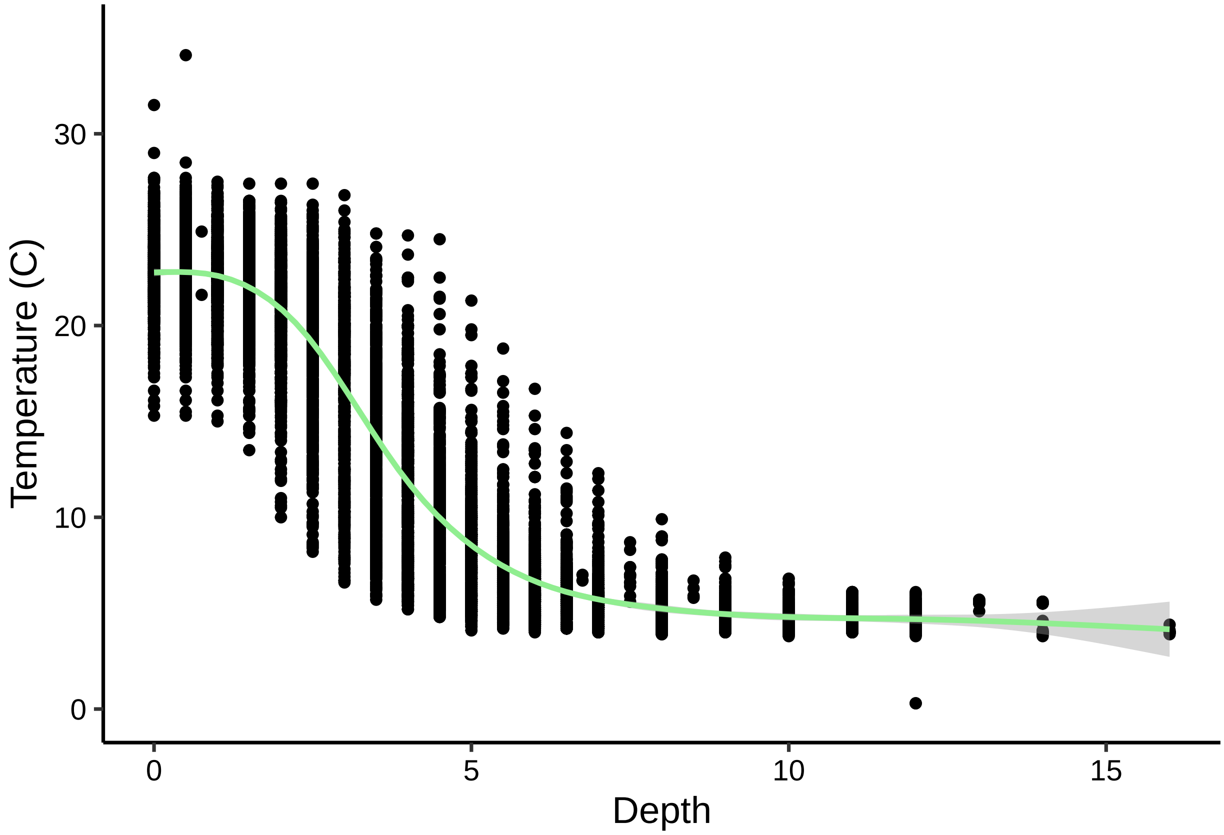
- Only dates in July.
- Only the columns: `lakename`, `year4`, `daynum`, `depth`, `temperature_C`
- Only complete cases (i.e., remove NAs)

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

WrangledData <- RawData %>%
    mutate(Month = month(sampledate)) %>%
    filter(Month %in% c(7)) %>%
    select(lakename, year4, daynum, depth, temperature_C) %>%
    na.omit()

# 5
```

```r
Ex5 <- ggplot(WrangledData, aes(x = depth, y = temperature_C)) + geom_point() + geom_smooth(method = NUI
    color = "lightgreen") + ylab("Temperature (C)") + xlab("Depth") + scale_y_continuous(limits = c(0,
    35))

print(Ex5)
```

```
## `geom_smooth()` using method = 'gam' and formula 'y ~ s(x, bs = "cs")'
```



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: The plot suggests a general trend with greater depths relating to colder temperatures. It is not a linear relationship though. The more gradual slope at the lesser depths suggests a mixed layer where warmed surface water is cycled. This mixed layer seems to be bordered at around 5m of depth, when the slope becomes far steeper, indicating more minimal mixing with more surface level sun-warmed waters. This indicates a rejection of the null hypothesis.

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

```r
# 7

TempDepthRegression <- lm(WrangledData$temperature_C ~ WrangledData$depth)

summary(TempDepthRegression)
```

```
##
## Call:
## lm(formula = WrangledData$temperature_C ~ WrangledData$depth)
```

```
##
## 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 ***
## WrangledData$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:This linear regression shows a very strong relationship between depth and temperature within this selected dataset. The adjusted R-squared is 0.7387. This indicates that about 73.9% of the variability in temperature is explained by depth. This finding is with a single degree of freedom since it is only considering temperature and depth. The finding is statistically significant and the null hypothesis can be rejected because the p value is 2e-15, far lower than 0.05. The temperaure is predicted to drop around 1.9 degrees for every meter of depth.

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

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

```
## 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 = WrangledData)
##
## Coefficients:
```

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

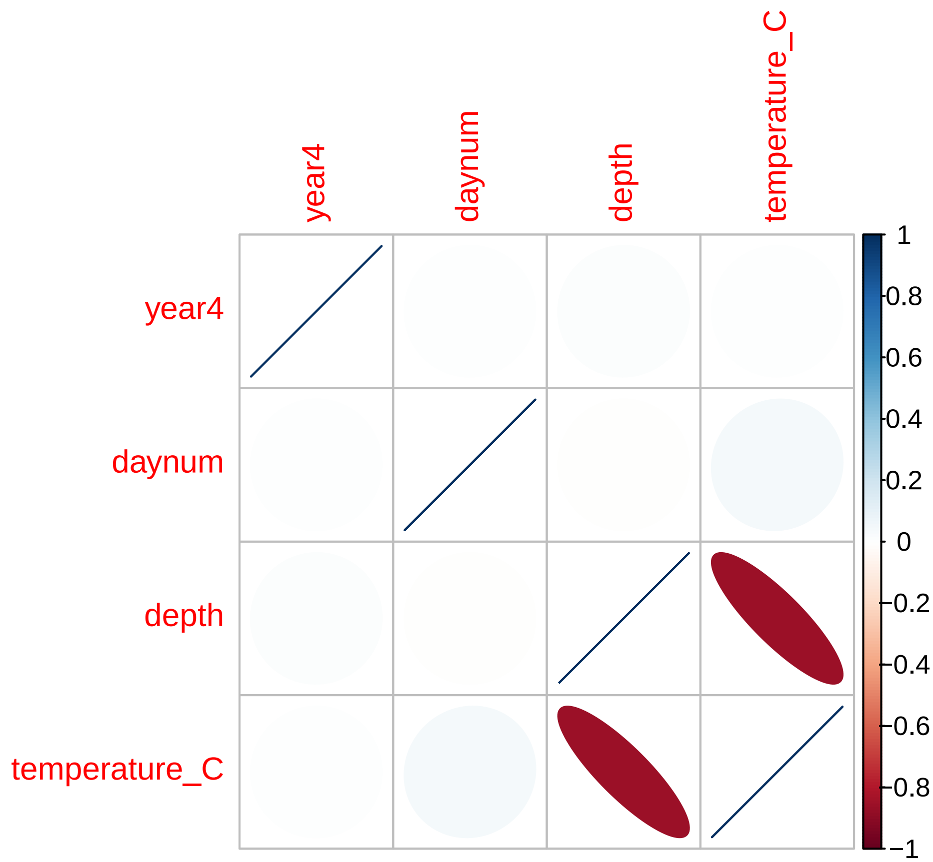
```
summary(LakeModel)
```

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

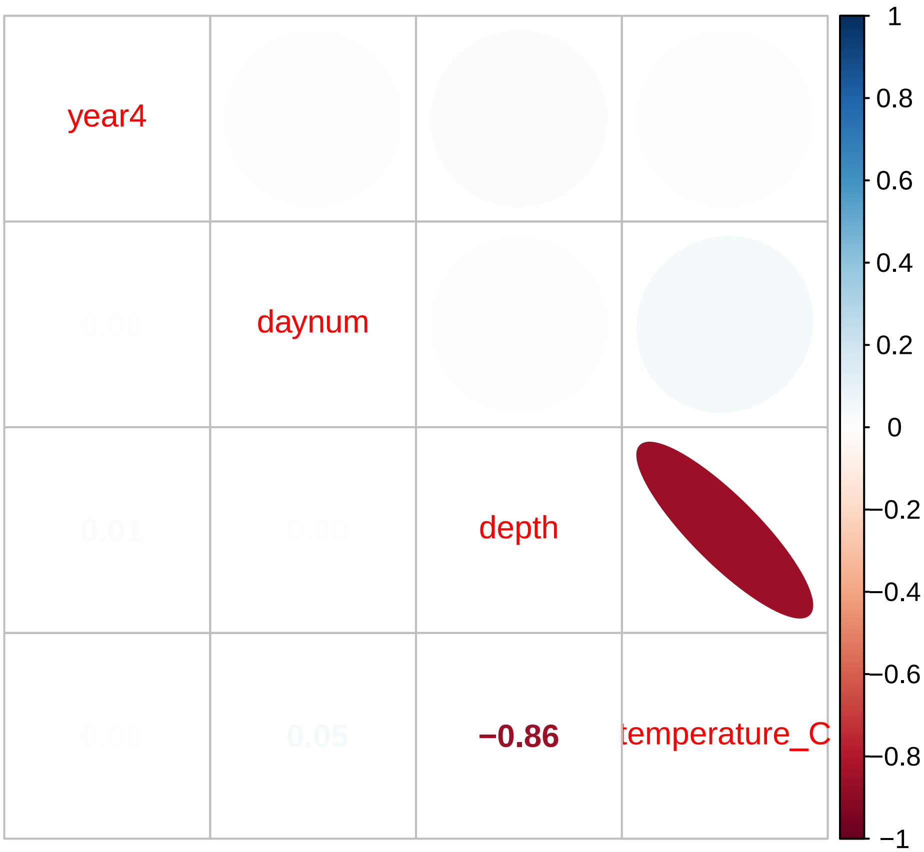
```
# since both daynum and depth have very small p-values, this test indicates
# that both of these variables should be considered.

WrangledData2 <- WrangledData %>%
    select(year4, daynum, depth, temperature_C) %>%
    na.omit()

LakeAIC <- cor(WrangledData2)
print(LakeAIC)
```

```
##                     year4        daynum         depth temperature_C
## year4         1.000000000  0.0048603276  0.0105584225    0.00477053
## daynum        0.004860328  1.0000000000 -0.0009266367    0.04840330
## depth         0.010558422 -0.0009266367  1.0000000000   -0.85949893
## temperature_C 0.004770530  0.0484033019 -0.8594989332    1.00000000
```

```
corrplot(LakeAIC, method = "ellipse")
```




```
corrplot.mixed(LakeAIC, upper = "ellipse")
```




```r
# Here you can see the very strong correlation between depth and temperature
# and a very shallow slight correlation of 0.05 for temperature and daynum.
# Although the daynum contribution seems insignificant, this coroborates the
# previous finding.

# 10

TempDepthDaynumRegression <- lm(WrangledData$temperature_C ~ WrangledData$depth +
    WrangledData$daynum)

summary(TempDepthDaynumRegression)
```

```
##
## Call:
## lm(formula = WrangledData$temperature_C ~ WrangledData$depth +
##     WrangledData$daynum)
##
## Residuals:
##     Min      1Q  Median      3Q     Max
## -9.6174 -2.9809  0.0845  2.9681 13.4406
##
## Coefficients:
##                      Estimate Std. Error  t value Pr(>|t|)
## (Intercept)         14.088588   0.855505   16.468   <2e-16 ***
## WrangledData$depth  -1.946111   0.011685 -166.541   <2e-16 ***
## WrangledData$daynum  0.039836   0.004318    9.225   <2e-16 ***
```

```
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 3.818 on 9725 degrees of freedom
## Multiple R-squared:  0.741,  Adjusted R-squared:  0.741
## F-statistic: 1.391e+04 on 2 and 9725 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 final set of explanatory variables for temperature across all lakes is both depth and day number. This model explains 74.1% of the variability in temperature. This is a marginal improvement to the R-value from the previous analysis with only depth although I am not sure this small improvement is worth the added complexity of adding an additional parameter.

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

Lake.Totals.anova <- aov(data = WrangledData, temperature_C ~ lakename)
summary(Lake.Totals.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
```

```
# results: reject null hypothesis

Lake.Totals.anova2 <- lm(data = WrangledData, temperature_C ~ lakename)
summary(Lake.Totals.anova2)
```

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

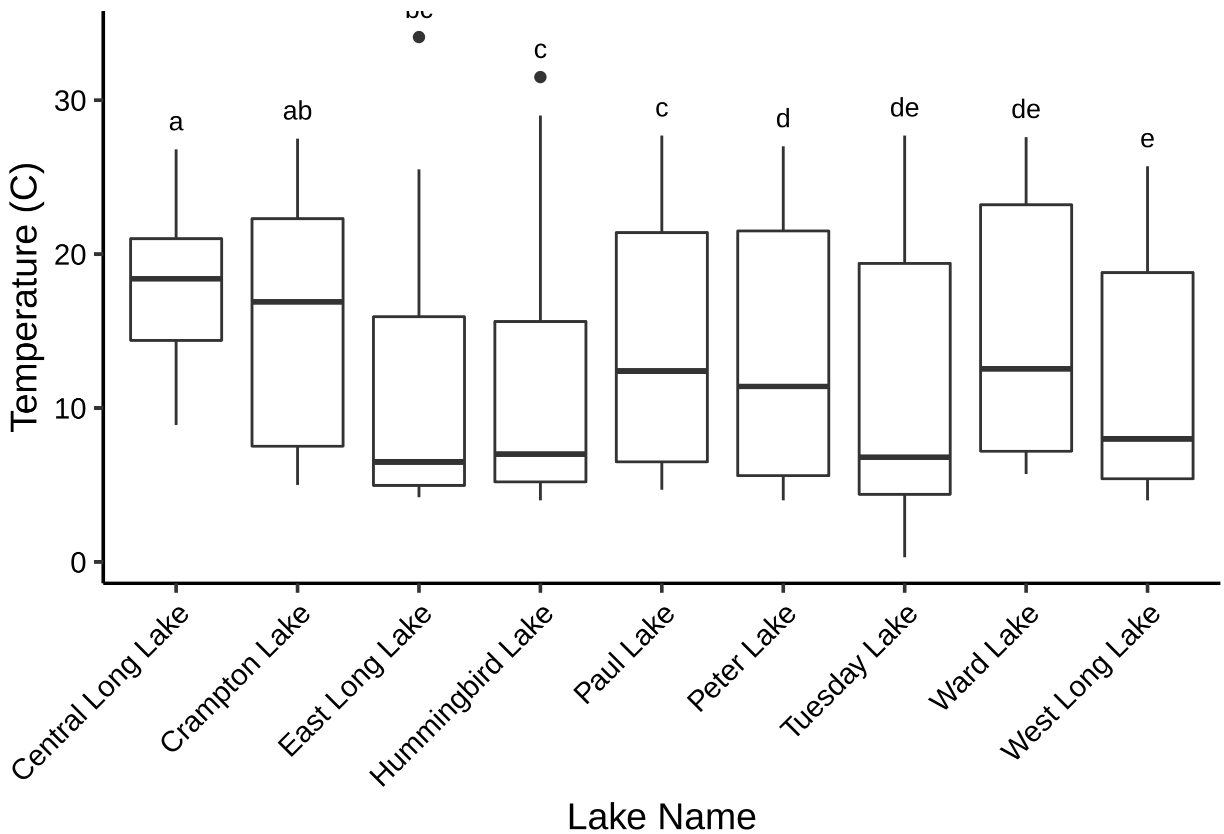
```
## lakenameTuesday Lake      -6.5972     0.6769  -9.746  < 2e-16 ***
## lakenameWard Lake         -3.2078     0.9429  -3.402 0.000672 ***
## lakenameWest Long Lake    -6.0878     0.6895  -8.829  < 2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard 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
```

```r
Lake.Totals.groups <- HSD.test(Lake.Totals.anova, "lakename", group = TRUE)
Lake.Totals.groups
```

```
## $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"
```

```r
Lake.Totals.plot <- ggplot(WrangledData, aes(x = lakename, y = temperature_C)) +
    geom_boxplot() + theme(axis.text.x = element_text(angle = 45, hjust = 1)) + stat_summary(geom = "te
    fun = max, vjust = -1, size = 3.5, label = c("a", "ab", "bc", "c", "c", "d",
        "de", "de", "e")) + labs(x = "Lake Name", y = "Temperature (C)")
```

```r
print(Lake.Totals.plot)
```



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

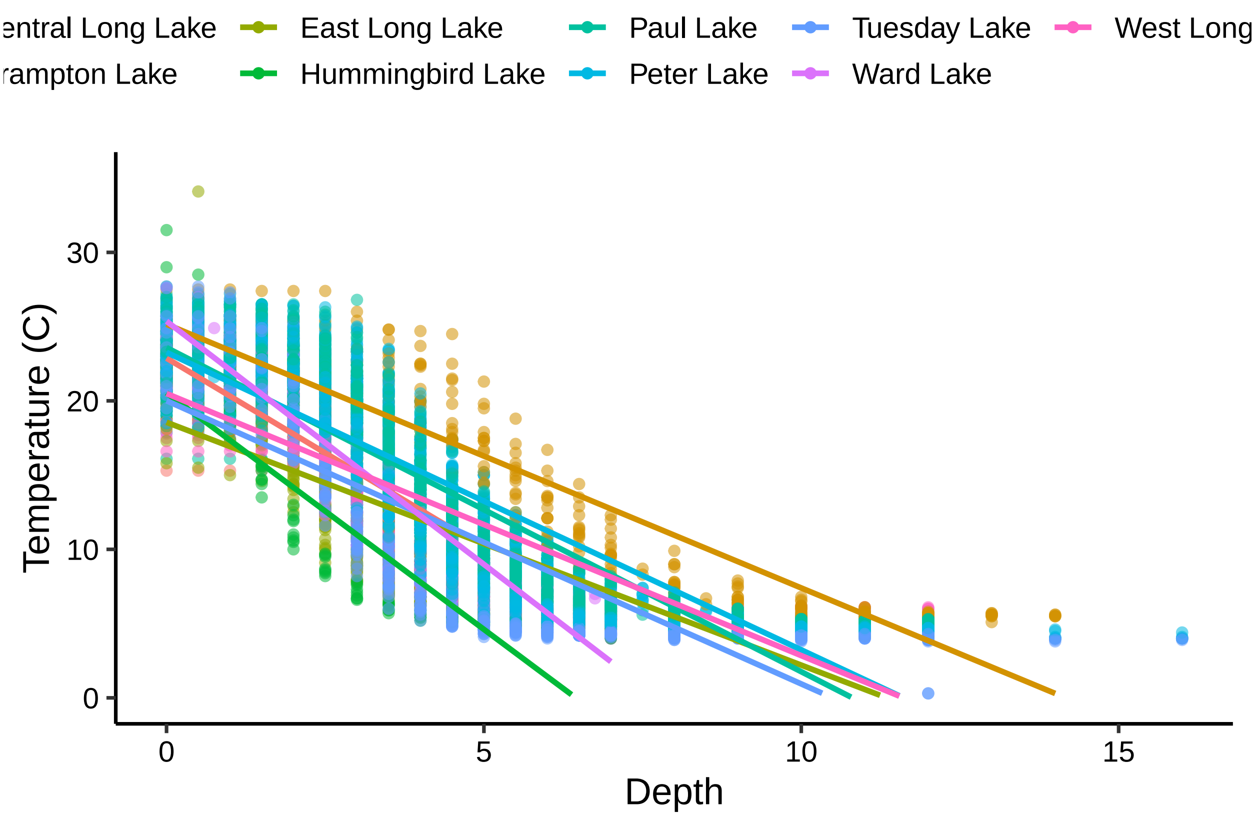
    Answer: There is a significant difference between some lakes, while others are not significantly different. The anova model shows that significant difference does exist as a whole as the p-value is extremely low. The linear model bettef shows the differentiation between the variability of different lakes. This is all best visualized in the graph immediately above. There seems to be a few distinct groupings (a, b, c, d, and e) but there is overlap in several lakes.

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.

```r
# 14.

Ex14 <- ggplot(WrangledData, aes(x = depth, y = temperature_C, color = lakename,
    alpha = 0.5)) + geom_point() + geom_smooth(method = "lm", se = FALSE) + ylab("Temperature (C)") +
    xlab("Depth") + scale_y_continuous(limits = c(0, 35))

print(Ex14)
```

```
## `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.Totals.anova)
```

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

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 are the two lakes with no statistically significant difference in mean temperature to Peter Lake. There are no lakes that are statistically significant 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: You can do this by running a two-sample T-test on Peter Lake 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?

```
WrangledData2 <- RawData %>%
    mutate(Month = month(sampledate)) %>%
    filter(Month %in% c(7)) %>%
    select(lakename, year4, daynum, depth, temperature_C) %>%
    filter(lakename %in% c("Crampton Lake", "Ward Lake")) %>%
    na.omit()

Lake.CramptonWard <- t.test(WrangledData2$temperature_C ~ WrangledData2$lakename)
Lake.CramptonWard
```

```
##
##  Welch Two Sample t-test
##
## data:  WrangledData2$temperature_C by WrangledData2$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 
## 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 t-test gives a p-value of 0.2649. As this is far greater than 0.05, we can reject the null hypothesis that the two lakes do not have statistically equivalent mean temperatures. The two lakes have a statistically significant difference in temperature, as is seen in the Turkey's HSD test completed above.