# 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. 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] "/Users/Jack/Documents/Duke/Spring 2022/Environmental Data Analytics/Environmental_Data_Analytics
```

```
library(tidyverse)
```

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

## v ggplot2 3.3.5     v purrr   0.3.4
## v tibble  3.1.4     v dplyr   1.0.7
## v tidyr   1.1.3     v stringr 1.4.0
## v readr   2.0.1     v forcats 0.5.1

## -- Conflicts ------------------------------------------ tidyverse_conflicts() --
## x dplyr::filter() masks stats::filter()
## x dplyr::lag()    masks stats::lag()
```

```
library(lubridate)
```

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

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

```
library(agricolae)
library(corrplot)
```

```
## corrplot 0.92 loaded
```

```
NTL_LTER_Lake_chemphys <- read.csv("./Data/Raw/NTL-LTER_Lake_ChemistryPhysics_Raw.csv", stringsAsFactor

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

#2
theme_set(theme_classic(base_size = 10) +
          theme(axis.text = element_text(color = "black"),
                legend.position = "right"))
```

## 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: Mean temperature does not change with depth across all lakes in July. Ha: Mean temperature changes with depth across all lakes in July.

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

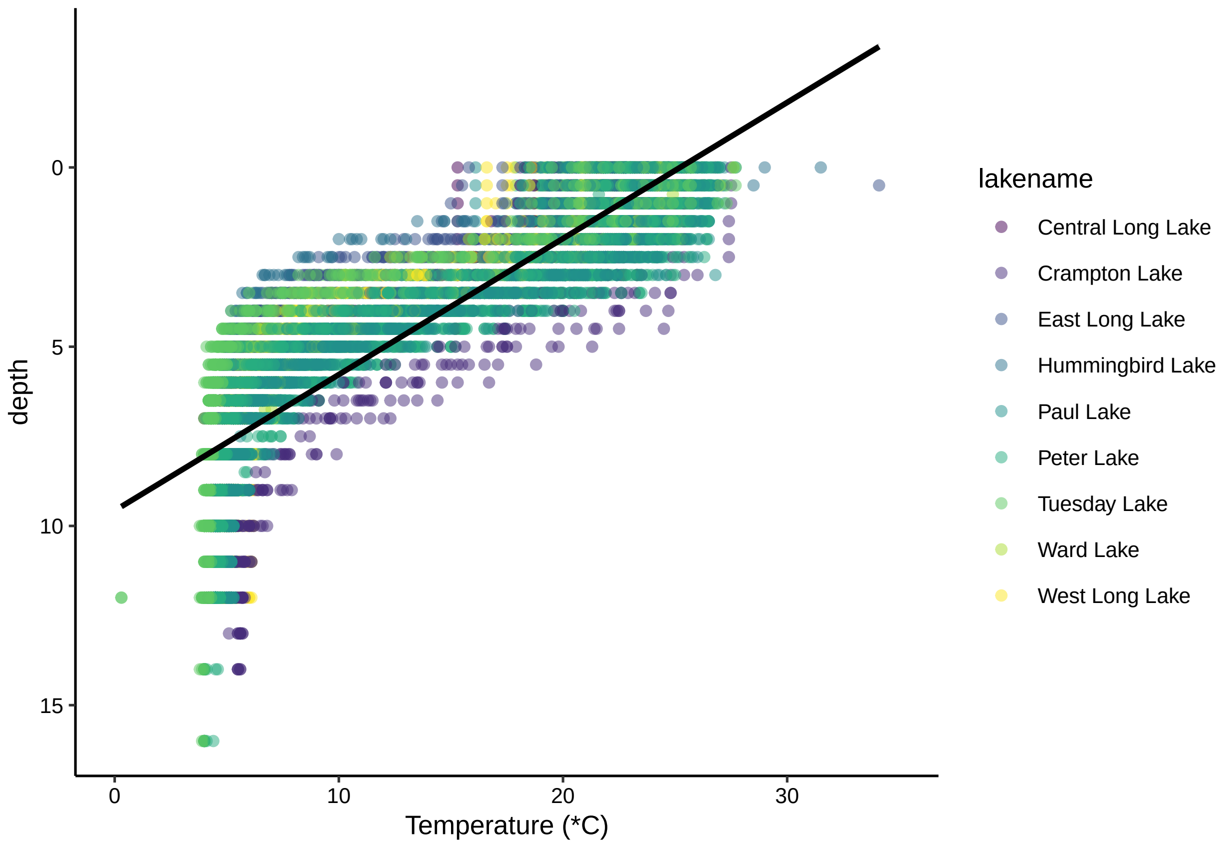
- Only dates in July.
- Only the columns: `lakename`, `year4`, `daynum`, `depth`, `temperature_C`
- Only complete cases (i.e., remove NAs)

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
July_data <- NTL_LTER_Lake_chemphys %>%
  mutate(Month = month(sampledate)) %>%
  filter(Month == "7") %>%
  select(lakename, year4, daynum, depth, temperature_C) %>%
  na.omit()

#5
Julyplot <- ggplot(July_data,
                   aes(x = temperature_C, y = depth, color = lakename)) +
  geom_point(alpha = 0.5) +
  geom_smooth(method = "lm", se = TRUE, color = "black") +
  xlim(0,35) +
  scale_y_reverse() +
  scale_color_viridis_d() +
  labs(x = expression("Temperature (*C)", y = "Depth (m)"))
Julyplot
```

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




```
# I know temperature by depth means temperature on the y, depth on the x, but plotting by depth typical
```

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 is generally warmer at the surface and cooler at depth, with a rapid change between 3 and 5 meters (thermocline depth). Not the most linear trend, there are areas of more rapid change.

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

```
#7
July_lm <- lm(July_data$temperature_C ~ July_data$depth)
summary(July_lm)
```

```
##
## Call:
## lm(formula = July_data$temperature_C ~ July_data$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 ***
## July_data$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
```

```
#p-value = 2.2e-16
#r-squared = 0.7387
#df = 9726
```

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: 74% of the variability in temperature is explained by depth, as indicated by the r^2 value of 0.74 output by the model. The degrees of freedom is high at 9726, indicating that sample size is not an issue. The small p-value indicates that the null, that mean temp does not change with depth, is very very unlikely to be due to chance, and that depth and temperature are significantly correlated. For every meter change in depth, temperature change is predicted to be 1.9 degrees Celsius.

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## 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 Create AIC and run step test
July_AIC <- lm(data = July_data, temperature_C ~ depth + year4 + daynum)
step(July_AIC)
```

```
## Start:  AIC=26065.53
## temperature_C ~ depth + year4 + daynum
##
##          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 ~ depth + year4 + daynum, data = July_data)
##
## Coefficients:
## (Intercept)        depth        year4       daynum
##    -8.57556     -1.94644      0.01134      0.03978
```

```
# all variables above the AIC value - so keep all of them I guess
# seems weird that year4 somehow is valuable here

#10
# Since all variables passed the AIC, we can just run the same function
summary(July_AIC)
```

```
##
## Call:
## lm(formula = temperature_C ~ depth + year4 + daynum, data = July_data)
##
## 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
## depth       -1.946437   0.011683 -166.611  < 2e-16 ***
## year4        0.011345   0.004299    2.639  0.00833 **
## daynum       0.039780   0.004317    9.215  < 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 model suggests to use all three variables: depth, year4, and daynum. Year4 surprised me, but I guess that annual variability is just significant enough to matter. This model with multiple variables explains 74.11%, which is juuuuuust a smidge higher than the 73.87% explained by depth. While it does improve over the model using only depth, it is just barely so.

---

## 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
# let's see all the lake names
summary(July_data$lakename)
```

```
## Central Long Lake     Crampton Lake    East Long Lake  Hummingbird Lake
##               128               318               968               116
##         Paul Lake        Peter Lake      Tuesday Lake         Ward Lake
##              2660              2872              1524               116
##    West Long Lake
##              1026
```

```
# first an anova test
July_data_anova <- aov(data = July_data, temperature_C ~ lakename)
summary(July_data_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
```

```
# same test formatted as linear model
July_data_anova2 <- lm(data = July_data, temperature_C ~ lakename)
summary(July_data_anova2)
```

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

```
#plot(July_data_anova2)
```

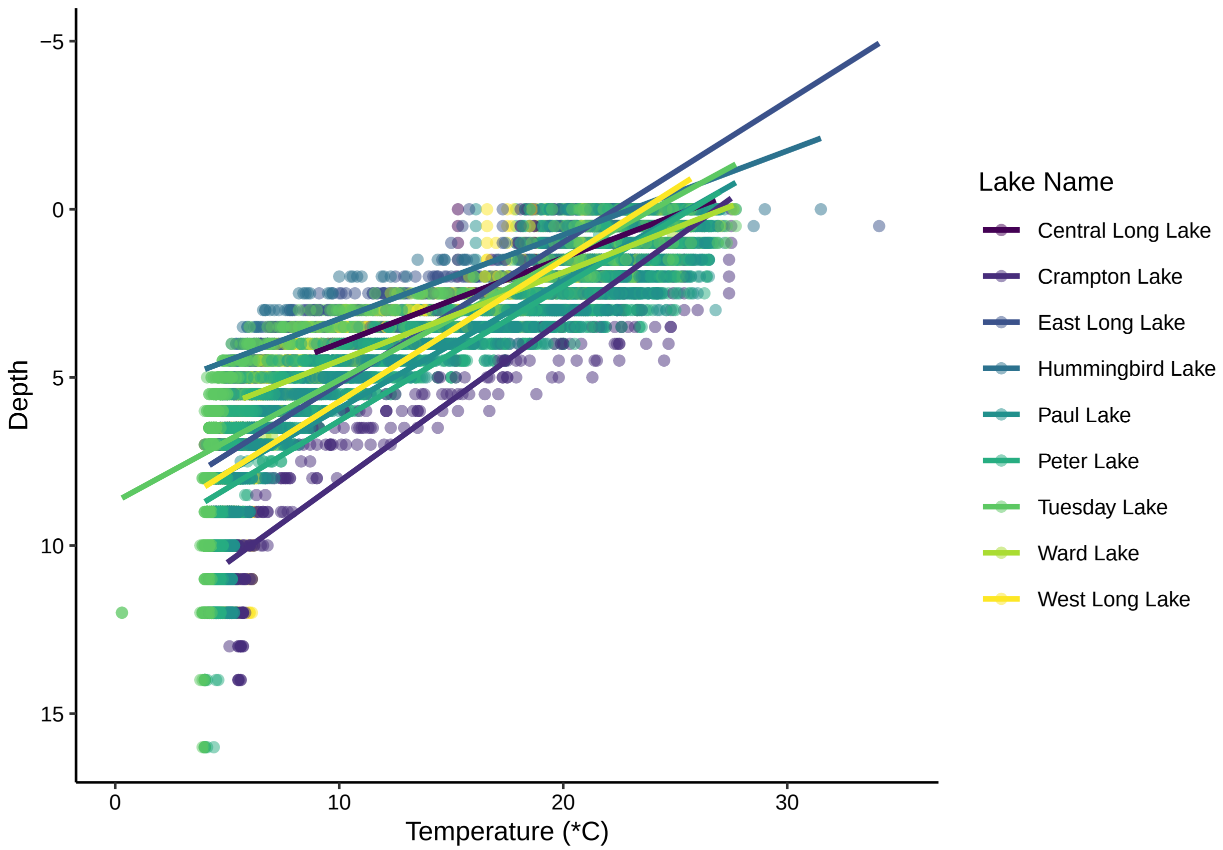
13. Is there a significant difference in mean temperature among the lakes? Report your findings.

    Answer: Yes, there is a significant difference in mean temperature. The p-values between lakes are all below 0.05, $p < 2.2e-16$ for the whole group, indicating we reject the null that there is no significant difference in mean temperature among 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.

```
#14.
July_plot_lm <- ggplot(July_data,
                       aes(x = temperature_C, y = depth, color = lakename)) +
  geom_point(alpha = 0.5) +
  scale_y_reverse() +
  xlim(0,35) +
  scale_colour_viridis_d() +
  geom_smooth(method = "lm", se = FALSE) +
  labs(x = "Temperature (*C)", y = "Depth", color = "Lake Name")
July_plot_lm
```

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




```
#tried it the other way, I really prefer the depth on the y-axis
# it just looks right to me that way
```

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

```
#15
TukeyHSD(July_data_anova)
```

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

```
# now we group them
July_data_groups <- HSD.test(July_data_anova, "lakename", group = TRUE)
July_data_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"
```

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: According to the groupings, Peter Lake has the same mean temperature as Paul Lake, statistically. Central Long Lake is the only one that is completely distinct from all the others, statistically.

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: Just looking at Peter and Paul, we could run a two-sample t-test to see if their means are distinct. Null hypthesis is that they are equivalent, and alternative is that they are not.