Assignment 7: 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>_A07_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

#install.packages(c("tidyverse", "agricolae", "lubridate", "here"))

# Load the packages
library(tidyverse)
library(agricolae)
library(lubridate)
library(here)
library(ggplot2)

# Check your working directory
getwd()
```

```
## [1] "/home/guest/EDE_Fall2024"
```

```
#upload raw data
LakeChemistryPhysics <- read.csv(
  here("Data/Raw/NTL-LTER_Lake_ChemistryPhysics_Raw.csv"),
  stringsAsFactors = TRUE)

# Set date to date format
LakeChemistryPhysics$sampledate <- as.Date(LakeChemistryPhysics$sampledate,
                                            format = "%m/%d/%y")

#2

mytheme <- theme_minimal(base_size = 14) +
  theme(axis.text = element_text(color = "grey", face = "bold"),
         axis.title = element_text(size = 12),
                                  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?

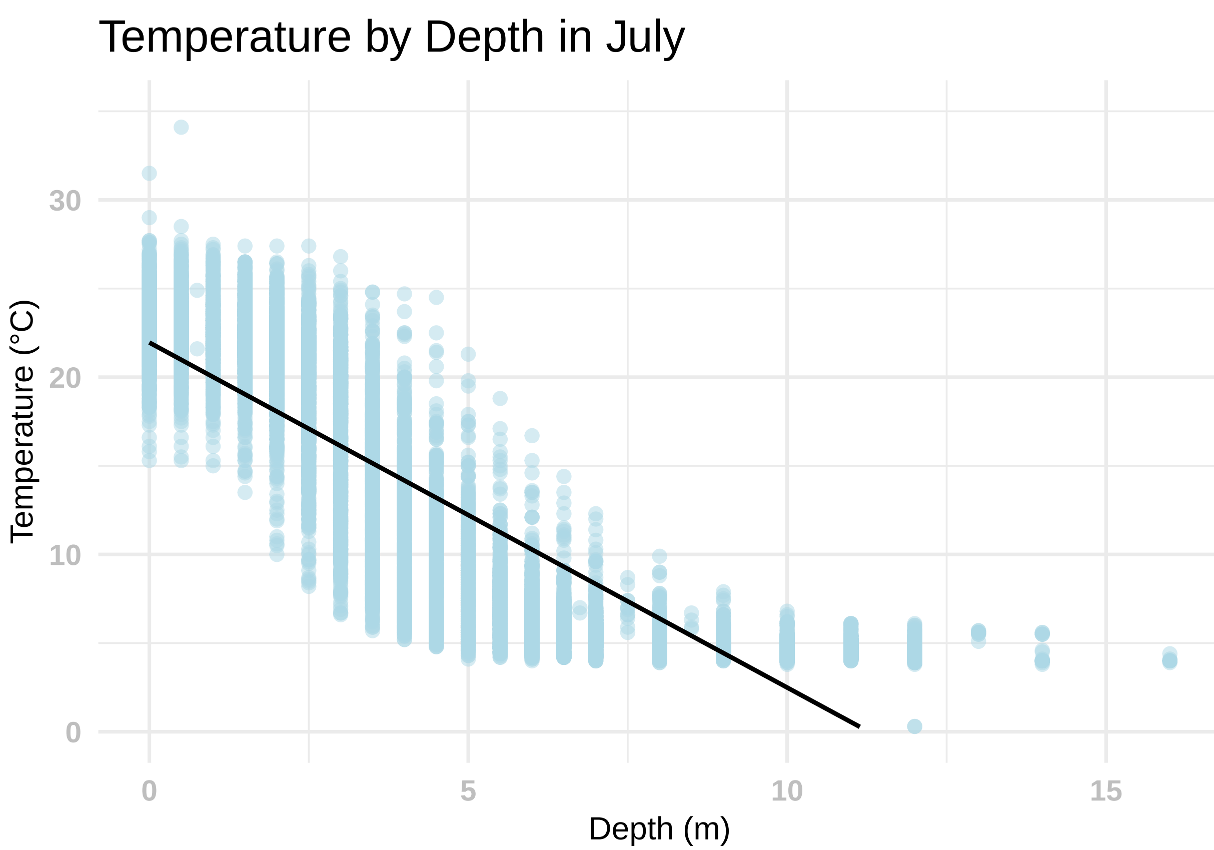
3. State the null and alternative hypotheses for this question: > Answer: H0: Mean lake temeprature in July is the same across all lakes (it does not change) across different depths. Ha: Mean lake temperature in July changes across different depths.
4. Wrangle your NTL-LTER dataset with a pipe function 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

Lake.subset <- LakeChemistryPhysics %>%
  filter(month(sampledate) == 7) %>%
  select(lakename:daynum, depth:temperature_C) %>%
  drop_na()

#5

plot1 <- ggplot(Lake.subset,
  aes(x= depth, y= temperature_C))+
    geom_point(alpha = 0.5, size = 2, color = "lightblue")+
    geom_smooth(method = lm, se = FALSE, color = "black", size = 0.8)+
  ylim(0 , 35)+
   labs(
    title = "Temperature by Depth in July",
```

```r
    x = "Depth (m)",
    y = "Temperature (°C)")+
  mytheme

print(plot1)
```



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: There is a negative relationship between depth and temperature which means that as depth increases, temperature decreases. At shallower depths (0-5 meters), the temperature values show greater variability which might indicate there are other variables that might be affecting the variability - that influence influence temperature near the surface which a linear model is not capturing. At deeper depths you see that variability is smaller.

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

```r
#7

reg.depth <- lm(data = Lake.subset, temperature_C ~ depth)

summary(reg.depth)
```

```
##
```

```
## Call:
## lm(formula = temperature_C ~ depth, data = Lake.subset)
##
## 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: According to the results, 73.05 of the variability in termrpature is explained by changes in depth. The degrees of freedon are 9,726 (n-parameters) and thee results are statistically significat at a 5% level (0.05 alpha) given that the p-values are very small for the intercept and depth but also for the general model (p-value: $<$ 2.2e-16). Thus, we can reject the null hypothesis that depth has no effect on temperature. For every 1 m increase in depth, temperature will decrease by approximately 1.95°C.

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

LakesDepth.all <- lm(data = Lake.subset, temperature_C ~ depth + year4 + daynum)
step(LakesDepth.all)
```

```
## 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 = Lake.subset)
##
## Coefficients:
## (Intercept)        depth        year4       daynum
##    -8.57556     -1.94644      0.01134      0.03978
```

```r
#10

# Multiple regression with the selected predictors
LakesDepth.model <- lm(temperature_C ~ depth + year4 + daynum, data = Lake.subset)
summary(LakesDepth.model)
```

```
##
## Call:
## lm(formula = temperature_C ~ depth + year4 + daynum, data = Lake.subset)
##
## 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 stepwise AIC process suggests that all three variables (depth, year4, daynum) should remain in the model, as removing any of them increases the AIC, indicating a worse fit. Approximately 74.11% of the variability is explaines by the independent variables (Xs) which shows a slight improvement to the 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

#Using aov
LakeTemp.anova <- aov(data = Lake.subset, temperature_C ~ lakename)
summary(LakeTemp.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-values very small thus reject the null hypothesis

# Using Linear model
LakeTemp.LmAnova <- lm(data = Lake.subset, temperature_C ~ lakename)
summary(LakeTemp.LmAnova)
```

```
##
## Call:
## lm(formula = temperature_C ~ lakename, data = Lake.subset)
##
## 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
```

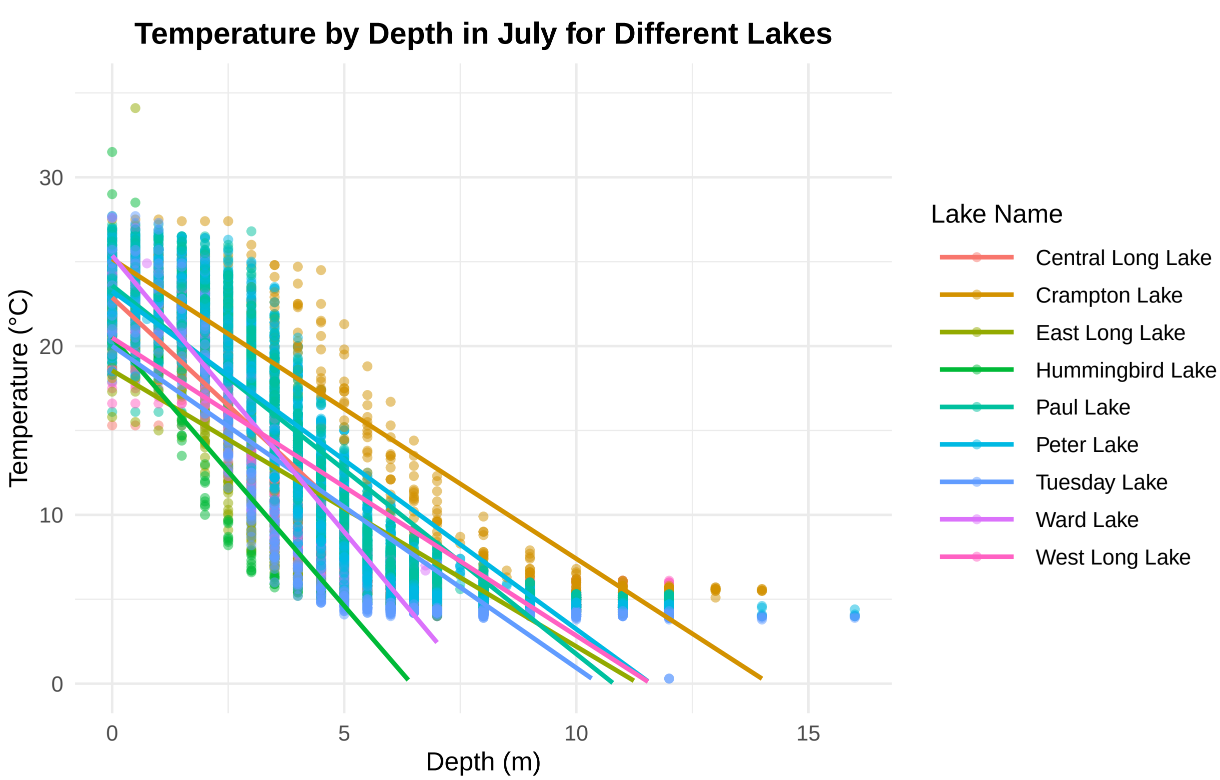
13. Is there a significant difference in mean temperature among the lakes? Report your findings.

Answer: There is a significant difference. In both models p-values are very small and almost zero which mans that we reject the null hypothesis (temperatures are the same) and conclude that the lake's average temperature differs from 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.
plot.template <- ggplot(Lake.subset,
  aes(x= depth, y = temperature_C, color = lakename))+
    geom_point(alpha = 0.5) +
    geom_smooth(method = "lm", se= FALSE)+
    ylim (0, 35)+
    labs(title = "Temperature by Depth in July for Different Lakes",
    x = "Depth (m)",
    y = "Temperature (°C)", color = "Lake Name", size = 3)+
  theme_minimal(base_size = 12) +
  theme(
    plot.title = element_text(hjust = 0.5, face = "bold"),
    axis.title = element_text(face = "plain"),
    legend.position = "right",
     legend.text = element_text(size = 10),
    legend.key.width = unit(1.5, "cm")
  )

print(plot.template)
```

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



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

```
#15

#still just looking at July
tukey.anova<- TukeyHSD(LakeTemp.anova)
print(tukey.anova)
```

```
##   Tukey multiple comparisons of means
##     95% family-wise confidence level
##
## Fit: aov(formula = temperature_C ~ lakename, data = Lake.subset)
##
## $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
#For my own visualization
#plot(tukey.anova, las = 1)

#Finding ways to do it more automatically
tukey_df <- as.data.frame(tukey.anova$lakename)
peter_lake_comparisons <- tukey_df[grep("Peter Lake", rownames(tukey_df)), ]
same_mean_as_peter <- peter_lake_comparisons %>%
  filter(`p adj` > 0.05 & lwr < 0 & upr > 0)
print(same_mean_as_peter)
```

```
##                             diff       lwr       upr     p adj
## Peter Lake-Paul Lake -0.4979952 -1.112062 0.1160717 0.2241586
## Ward Lake-Peter Lake  1.1423602 -1.018749 3.3034693 0.7827037
```

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: Pual Lake and Ward Lake have a mean temperature that is statistically the same as Peter Lake and there is no lake that has a statistically distinct mean temperature from all others,

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: Possibly a two sample t- test

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_data <- Lake.subset %>%
  filter(lakename %in% c("Crampton Lake", "Ward Lake"))

# Perform the two-sample t-test
two_test <- t.test(
  temperature_C ~ lakename,
  data = Crampton_Ward_data)

print(two_test)
```

```
##
##  Welch Two Sample t-test
##
## data:  temperature_C by 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 result matches the result for part 16 thus, the mean temperatures of Crampton Lake and Ward Lake are not significantly different.