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

#Load necessary packages

#install.packages("tidyverse")
library(tidyverse)
```

```
## -- Attaching core tidyverse packages ------------------------ tidyverse 2.0.0 --
## v dplyr     1.1.3     v readr     2.1.4
## v forcats   1.0.0     v stringr   1.5.0
## v ggplot2   3.4.3     v tibble    3.2.1
## v lubridate 1.9.2     v tidyr     1.3.0
## v purrr     1.0.2
## -- Conflicts ------------------------------------------ tidyverse_conflicts() --
## x dplyr::filter() masks stats::filter()
## x dplyr::lag()    masks stats::lag()
## i Use the conflicted package (<http://conflicted.r-lib.org/>) to force all conflicts to become error
```

```r
#install.packages("lubridate")
library(lubridate)
#install.packages("here")
library(here)
```

```
## here() starts at C:/Users/dhr20/OneDrive - Duke University/1 - Academics/1 - First Year/1 - Fall 202
```

```r
#install.packages("cowplot")
library(cowplot)
```

```
##
## Attaching package: 'cowplot'
##
## The following object is masked from 'package:lubridate':
##
##     stamp
```

```r
#install.packages("ggthemes")
library(ggthemes)
```

```
##
## Attaching package: 'ggthemes'
##
## The following object is masked from 'package:cowplot':
##
##     theme_map
```

```r
#install.packages("agricolae")
library(agricolae)

#Check working directory
here()
```

```
## [1] "C:/Users/dhr20/OneDrive - Duke University/1 - Academics/1 - First Year/1 - Fall 2023/2 - Enviro
```

```r
#Import relevant data files
Lake <- read.csv(here("Data/Raw/NTL-LTER_Lake_ChemistryPhysics_Raw.csv"),
                 stringsAsFactors = TRUE)
Lake$sampledate <- as.Date(Lake$sampledate,format = "%m/%d/%Y")

#2

mytheme <- theme_classic(base_size = 14) +
  theme(axis.text = element_text(color = "black"),
        legend.position = "top",
        legend.title = element_text(size = 6),
        legend.text = element_text(size = 6)
        )
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 temperature recorded during July does not change with depth across all lakes. Ha: Mean lake temperature recorded during July does change with depth across all lakes.

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

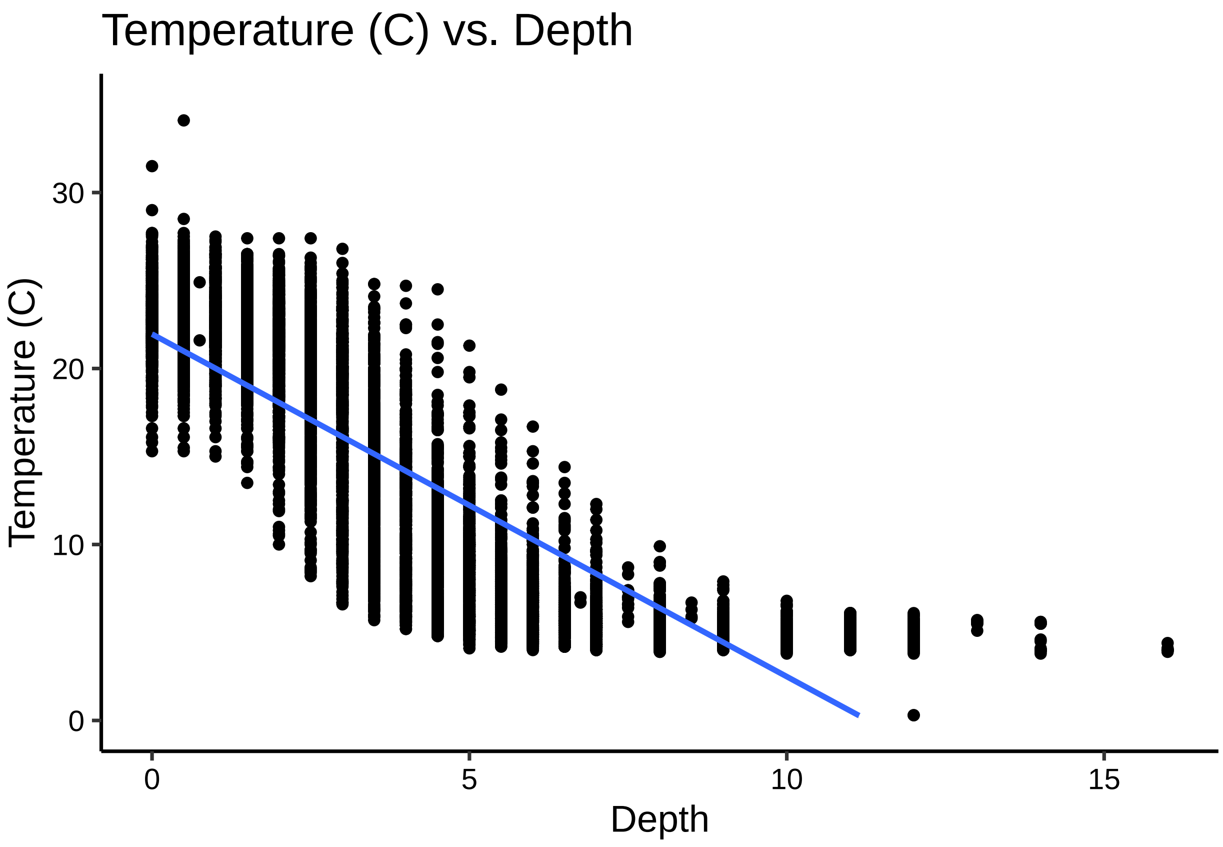
- Only dates in July.
- Only the columns: `lakename`, `year4`, `daynum`, `depth`, `temperature_C`
- Only complete cases (i.e., remove NAs)

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

#Wrangle per the requested criteria
Lake_wrangled <- Lake %>%
  filter(month(sampledate) == 7) %>%
  select(lakename, year4, daynum, depth, temperature_C) %>%
  na.omit()

#5

#Visualize the relationship
ggplot(Lake_wrangled,
       aes(
         y = temperature_C,
         x = depth
       )) +
  geom_point() +
  ylim(0,35) +
  geom_smooth(method = lm) +
  labs(y = "Temperature (C)",
       x = "Depth",
       title = "Temperature (C) vs. Depth")
```

```
## ‘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 decreases as depth increases. The distribution suggests a weak, negative correlation within a roughly linear trend.

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

```
#7

#Perform linear regression
Lake.regression <- lm(data = Lake_wrangled,
                      temperature_C ~ depth)

summary(Lake.regression)
```

```
##
## Call:
## lm(formula = temperature_C ~ depth, data = Lake_wrangled)
##
## 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: Based on the slope, we see that the temperature is decreasing by 1.94621 degrees per meter of depth. Based on the R-squared value of 0.7387, around 73.8% of the variability in temperature is explained by changes in depth. Degrees of freedom = 9726 Statistical significance = Given the low p-value of 2e-16 (less than 0.05), we can reject the null hypothesis (H0: Mean lake temperature recorded during July does not change with depth across all lakes). Thus, the mean lake temperature recorded during July does change with depth across all lakes.

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

#Run AIC and step
Lake.regression.AIC <- lm(data = Lake_wrangled, temperature_C ~ year4 + daynum + depth)

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

```
#10

#Summarize multiple regression
summary(Lake.regression.AIC)
```

```
##
## Call:
## lm(formula = temperature_C ~ year4 + daynum + depth, data = Lake_wrangled)
##
## 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 final set is to “remove none” which leaves year4, daynum, and depth. Based on the R-squared value of 0.7412, around 74.1% of the observed variance in this model is explained. Yes, this is a slight improvement over using only depth as the explanatory variable which had an R-squared value of 0.7387.

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

#ANOVA model
Lake_wrangled_ANOVA <- aov(data = Lake_wrangled, temperature_C ~ lakename)
summary(Lake_wrangled_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
```

```
#Linear model
Lake_wrangled_ANOVA_2 <- lm(data = Lake_wrangled, temperature_C ~ lakename)
summary(Lake_wrangled_ANOVA_2)
```

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

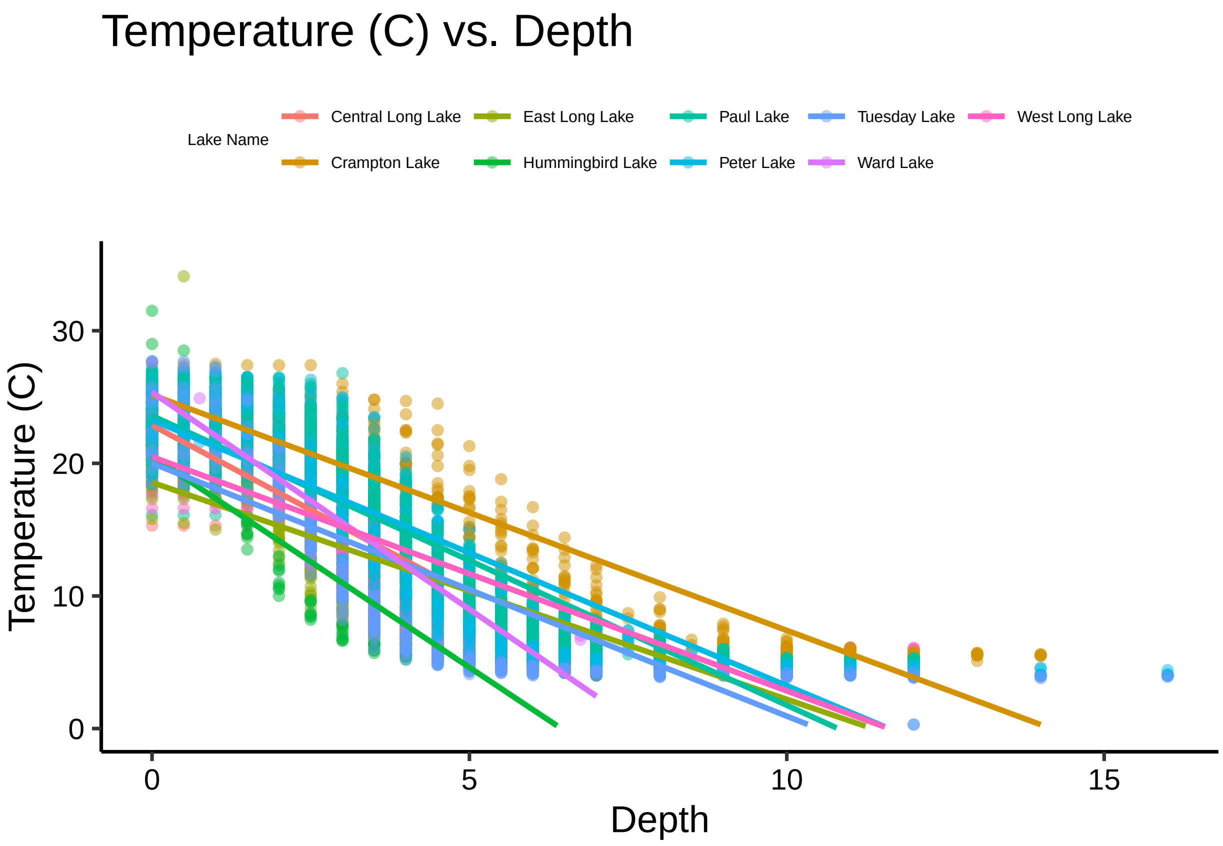
13. Is there a significant difference in mean temperature among the lakes? Report your findings.

    Answer: Based on the p-value of less than 2e-16 (less than .05), we reject the null hypothesis (H0 = the mean temperature is the same across all the lakes). Thus, the mean temperatures are not the same across all the 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

#Create graph and make it pretty (via axis labels)
ggplot(Lake_wrangled,
       aes(
         y = temperature_C,
         x = depth,
         color = lakename
       )) +
  geom_point(alpha = 0.5) +
  ylim(0,35) +
  geom_smooth(method = lm, se = FALSE) +
  labs(y = "Temperature (C)",
       x = "Depth",
       color = "Lake Name",
       title = "Temperature (C) vs. Depth")
```

```
## `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

#Tukey HSD test
print(HSD.test(Lake_wrangled_ANOVA, "lakename", group = T))
```

```
## $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        se Min  Max    Q25   Q50
## Central Long Lake      17.66641 4.196292  128 0.6501298 8.9 26.8 14.400 18.40
## Crampton Lake          15.35189 7.244773  318 0.4124692 5.0 27.5  7.525 16.90
## East Long Lake         10.26767 6.766804  968 0.2364108 4.2 34.1  4.975  6.50
## Hummingbird Lake       10.77328 7.017845  116 0.6829298 4.0 31.5  5.200  7.00
## Paul Lake              13.81426 7.296928 2660 0.1426147 4.7 27.7  6.500 12.40
## Peter Lake             13.31626 7.669758 2872 0.1372501 4.0 27.0  5.600 11.40
## Tuesday Lake           11.06923 7.698687 1524 0.1884137 0.3 27.7  4.400  6.80
## Ward Lake              14.45862 7.409079  116 0.6829298 5.7 27.6  7.200 12.55
## West Long Lake         11.57865 6.980789 1026 0.2296314 4.0 25.7  5.400  8.00
##                       Q75
## Central Long Lake 21.000
## Crampton Lake     22.300
## East Long Lake    15.925
## Hummingbird Lake  15.625
## Paul Lake         21.400
## Peter Lake        21.500
## Tuesday Lake      19.400
## Ward Lake         23.200
## West Long Lake    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: Ward Lake and Paul Lake have the same mean temperature, statistically speaking, as Peter Lake. No lake has a mean temperature that is statistically distinct from all other lakes (based on the output of the Tukey HSD in which no lake has a distinct group identifier).

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: 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
#18

#Wrangle the data
Lake_wrangled_18 <- Lake_wrangled %>%
  filter(lakename == "Crampton Lake" |
         lakename == "Ward Lake")

#Run the two-sample T-test
t.test(Lake_wrangled_18$temperature_C ~Lake_wrangled_18$lakename)
```

```
##
##  Welch Two Sample t-test
##
## data:  Lake_wrangled_18$temperature_C by Lake_wrangled_18$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: Because the p-value is greater than 0.05, we cannot reject the null hypothesis (H0 = the mean temperature is the same between Crampton Lake and Ward Lake). Thus, the mean temperatures between the two lakes are the same. Yes, this does match the answer for #15 / #16 in which Crampton Lake and Ward Lake were both in group b.