

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
library(tidyverse)

## Warning: package 'tidyverse' was built under R version 4.1.2
## -- Attaching packages ----- tidyverse 1.3.1 --
## v ggplot2 3.3.5      v purrr  0.3.4
## v tibble  3.1.2      v dplyr  1.0.6
## v tidyr   1.1.3      v stringr 1.4.0
## v readr   2.0.2      v forcats 0.5.1
## Warning: package 'ggplot2' was built under R version 4.1.1
## Warning: package 'readr' was built under R version 4.1.1
## Warning: package 'purrr' was built under R version 4.1.1
## Warning: package 'forcats' was built under R version 4.1.1
## -- Conflicts ----- tidyverse_conflicts() --
## x dplyr::filter() masks stats::filter()
## x dplyr::lag()    masks stats::lag()
library(agricolae)

## Warning: package 'agricolae' was built under R version 4.1.2
```

```

library(lubridate)

## Warning: package 'lubridate' was built under R version 4.1.2
##
## Attaching package: 'lubridate'
##
## The following objects are masked from 'package:base':
##
##     date, intersect, setdiff, union
lake.chem <- read.csv("../Data/Raw/NTL-LTER_Lake_ChemistryPhysics_Raw.csv")
class(lake.chem$sampdate)

## [1] "character"
lake.chem$sampdate <- as.Date(lake.chem$sampdate, format = "%m/%d/%y")

#2
mytheme <- theme_bw(base_size = 10) +
  theme(axis.text = element_text(color = "black"),
        legend.position = "right")
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: Lake depth has no effect on lake temperature recorded in July across all lakes. Ha: Lake depth has an effect on lake temperature recorded in July 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.

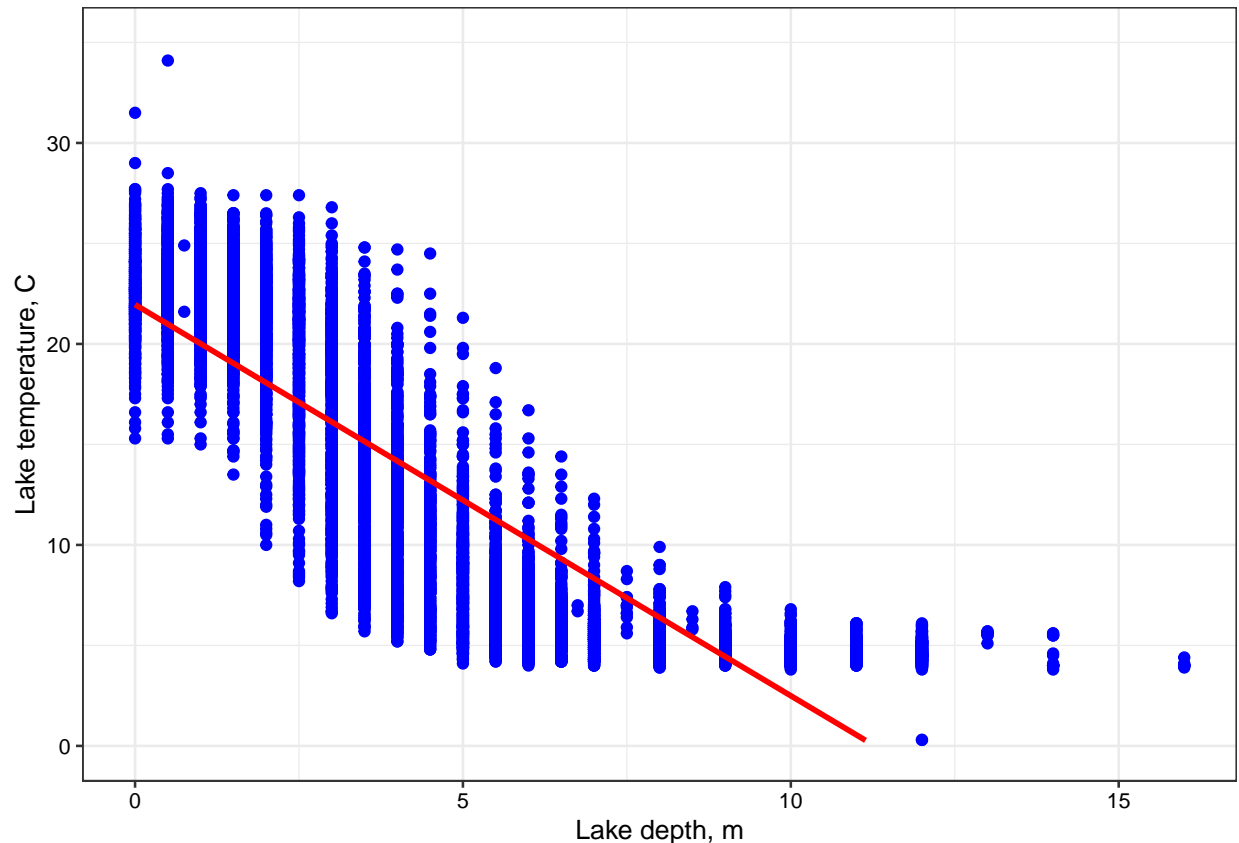
```

#4
lake.chem.sub <- lake.chem %>%
  mutate(month = month(sampdate)) %>%
  filter(month == 7) %>%
  select(lakename:daynum, depth, temperature_C) %>%
  drop_na()

#5
plot1 <- ggplot(lake.chem.sub, aes(x=depth, y=temperature_C)) +
  geom_point(col="blue") + geom_smooth(method=lm, se=F, col="red") +
  ylim(0,35) + xlab("Lake depth, m") + ylab("Lake temperature, C")
print(plot1)

## `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 anything about the linearity of this trend?

Answer: The figure suggests that there is a negative relationship between lake depth and temperature. It appears that the relationship could follow a sigmoidal trend as opposed to just a linear trend due to the slower rate of decrease at shallower depths compared to middle depths, as well as the tail flattening out as it reaches a temperature of zero.

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

```
#7
lm.1 <- lm(temperature_C ~ depth, data = lake.chem.sub)
summary(lm.1)

##
## Call:
## lm(formula = temperature_C ~ depth, data = lake.chem.sub)
##
## 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: A linear regression shows that there is a significant negative relationship between lake depth and temperature ($F=27500$; $df=1,9726$; $p<0.001$). Lake depth accounts for 73.9% of the variability in temperature ($R^2 = 0.739$), and for every 1m change in lake depth, temperature decreases by approximately 1.95 degrees Celsius.

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
lm2.aic <- lm(temperature_C ~ year4 + daynum + depth, data = lake.chem.sub)
step(lm2.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.chem.sub)
##
## Coefficients:
## (Intercept)      year4      daynum      depth
##   -8.57556      0.01134      0.03978     -1.94644

#10
lm2.final <- lm(temperature_C ~ year4 + daynum + depth, data = lake.chem.sub)
summary(lm2.final)

##
## Call:
## lm(formula = temperature_C ~ year4 + daynum + depth, data = lake.chem.sub)
##
## 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 of explanatory variables includes year, day number, and depth. This model explains 74.1% of the observed variance, which is not considerably higher than the amount explained by only depth (73.9%).

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
lm.3 <- lm(temperature_C ~ lakenamename, data = lake.chem.sub)
summary(lm.3)

##
## Call:
## lm(formula = temperature_C ~ lakenamename, data = lake.chem.sub)
##
## 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 ***
## lakenamenameCrampton Lake    -2.3145    0.7699  -3.006 0.002653 **
## lakenamenameEast Long Lake   -7.3987    0.6918 -10.695 < 2e-16 ***
## lakenamenameHummingbird Lake -6.8931    0.9429  -7.311 2.87e-13 ***
## lakenamenamePaul Lake       -3.8522    0.6656  -5.788 7.36e-09 ***
## lakenamenamePeter Lake      -4.3501    0.6645  -6.547 6.17e-11 ***
## lakenamenameTuesday Lake    -6.5972    0.6769  -9.746 < 2e-16 ***
## lakenamenameWard Lake       -3.2078    0.9429  -3.402 0.000672 ***
## lakenamenameWest 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

aov.3 <- aov(temperature_C ~ lakename, data = lake.chem.sub)
summary(aov.3)
```

```
##              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
```

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

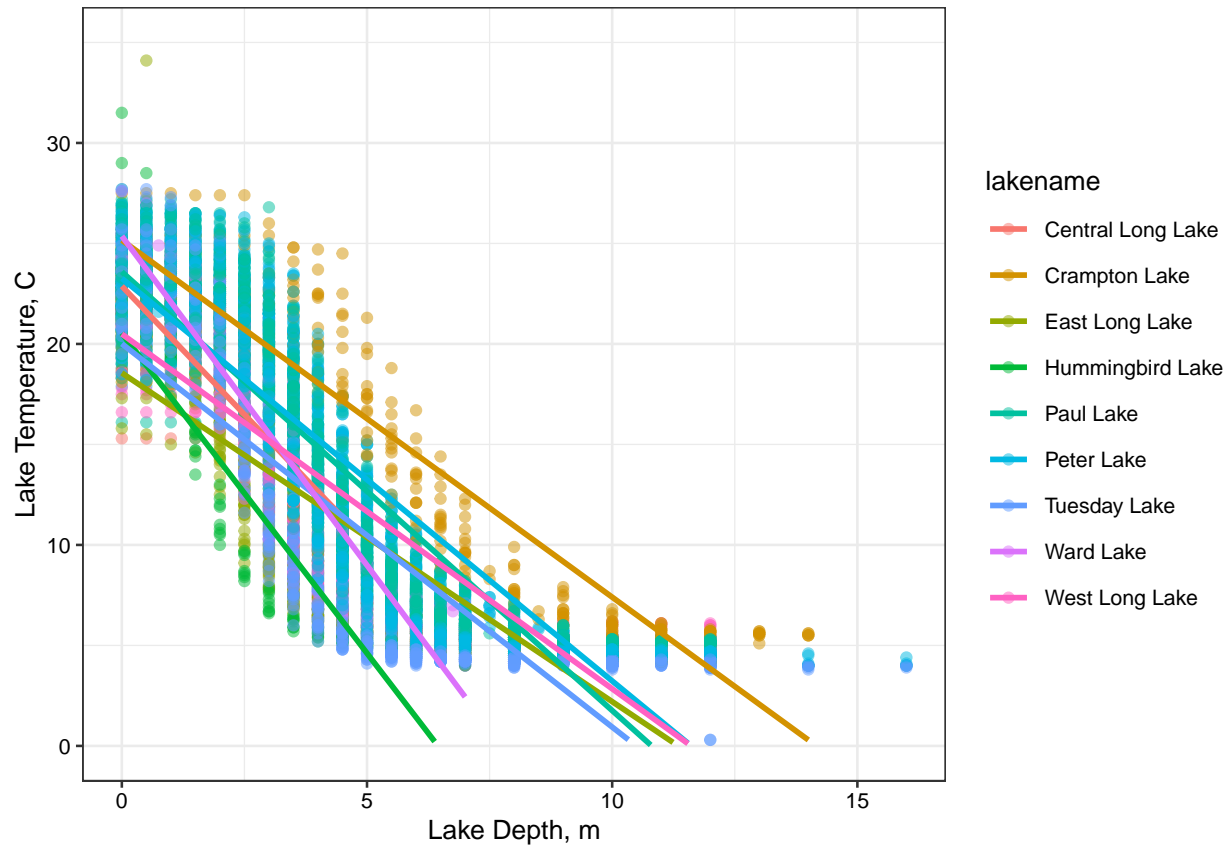
Answer: After performing an ANOVA test, it was determined that there was a significant difference in mean temperature among lakes ($F=50$; $df=8,9719$; $p<0.001$).

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.2 <- ggplot(data = lake.chem.sub, aes(x = depth, y = temperature_C,
                                           color = lakename)) +
  geom_point(alpha = 0.5) + geom_smooth(method = "lm", se = F) +
  ylim(0,35) + labs(x = "Lake Depth, m", y = "Lake Temperature, C",
                   legend = "Lake Name")
print(plot.2)
```

```
## `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(aov.3)
```

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

```
Temp.pairs <- HSD.test(aov.3, "lakename", group = TRUE)
Temp.pairs
```

```
## $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: There is no significant difference in mean temperature between Peter Lake and Paul Lake ($p=0.224$) or between Peter Lake and Ward Lake ($p=0.783$). No one lake has a mean temperature that is statistically distinct from all the 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: Another test that could be used to compare the temperatures of Peter Lake and Paul Lake is the two-way t-test.