Will it be a Good Ski Season? Correlation between El Niño and U.S. Weather

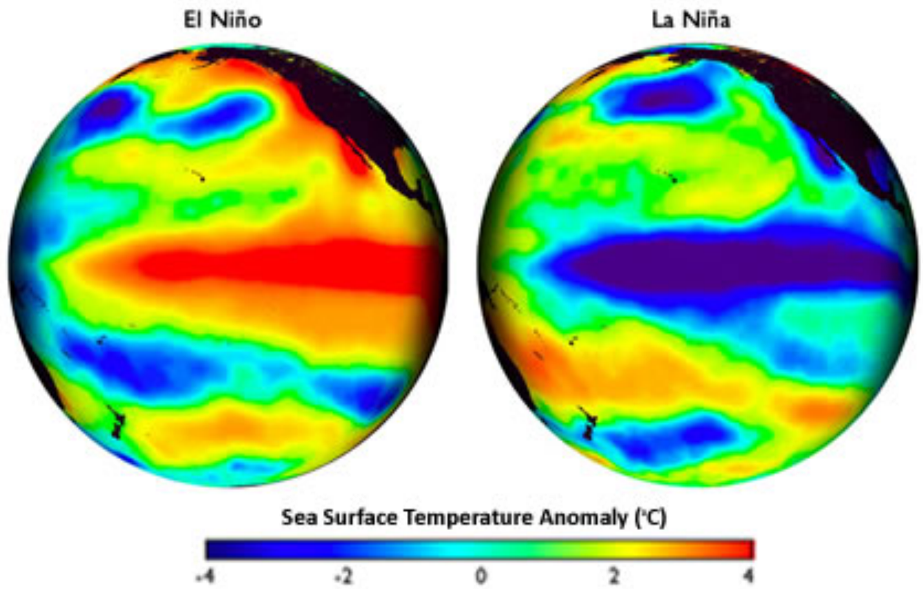
Lillian Petersen[1]

Abstract

This study investigates the correlation between El Niño and the weather across the U.S. El Niño is defined as warmer waters in the equatorial Pacific. La Niña is colder waters in that same area. The correlation between El Niño index and weather station data from 25 U.S. cities was computed for three variables: precipitation, snowfall and temperature. Daily weather data was averaged by month and year. It was found that El Niño correlates differently for different regions of the U.S. From New Mexico to the east coast, the weather is colder and wetter during El Niño and warmer and drier during La Niña (statistically significant and highly significant correlations). The whole southern half of the U.S. is wetter during an El Niño. The north-western U.S. is warmer, and areas near Ohio are drier. However, the correlation is not immediate. The data shows about a five month time lag between El Niño and the wintertime snowfall. The previous August El Niño index is the best predictor of total winter snowfall for most U.S. cities. El Niño is a good predictor of seasonal weather, but not perfect. The difference between strong El Niño and strong La Niña snowfall in Los Alamos, New Mexico, is 30 in. on average, while the standard deviation of the error of the best fit line is 27 in. This means that the prediction is almost as large as the variability.

El Niño is an oscillation in the earth's climate that influences weather around the world (Brown et al. 2002, Knauss 1997, Talley et al. 2011). El Niño is classified as warmer waters (>28^{o}C) in the equatorial Pacific, and La Niña is colder waters (<25^{o}C) in that same area (Figure 1a, Talley et al. 2011, p. 346). The El Niño index ranges from -2.5 to 2.5. If the index is positive, it is an El Niño, and if it is negative, it is a La Niña. If it is at zero, it is neutral. If the index is one, that means the sea surface temperature of the Nino 3.4 region (Figure 1b) is one degree warmer than average, and if it is negative one, it is one degree colder.

[1] Corresponding Author: lilliank.la@gmail.com



a.

b.

Figure 1. Sea surface temperature anomaly (difference from the average) of El Niño (left) and La Niña (right) in the equatorial Pacific (a) (Fiondella 2015). The Nino 3.4 region (b) (Dahlman 2009).

El Niño affects the jet stream (Figure 2). When there is an El Niño, the jet stream is further south, causing more storms and colder temperatures in the southern U.S. and northern Mexico. When there is a La Niña, the jet stream moves further north giving more storms to Alaska, Canada, and the northern U.S. (NOAA 2015c). El Niño-related temperature and precipitation impacts across the United States occur during the cold half of the year (Halpert 2014).

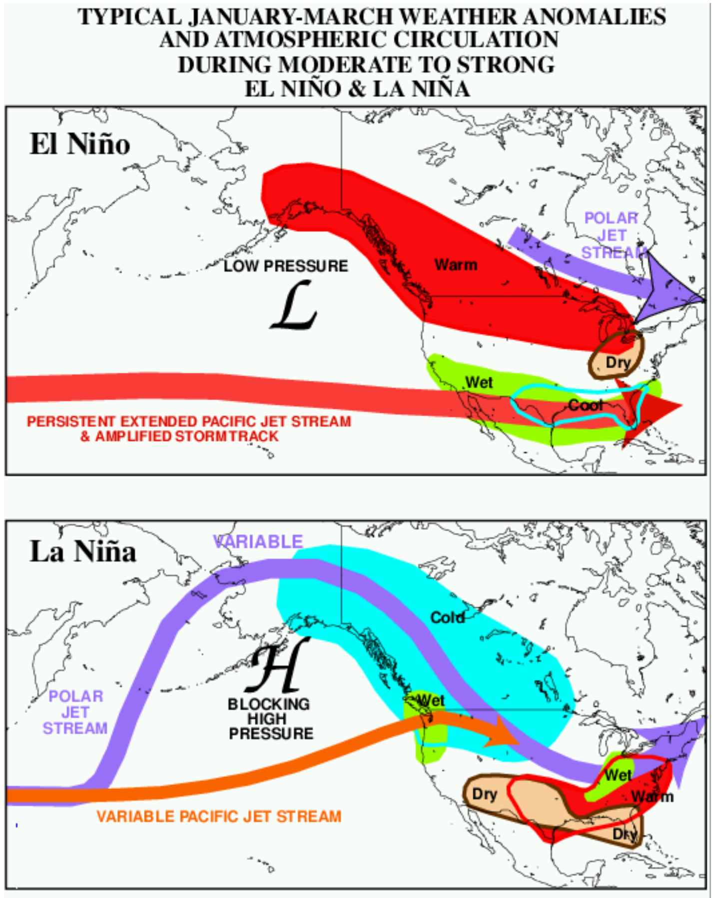


Figure 2. Typical weather patterns for El Niño and La Niña during the winter months (NOAA 2015c).

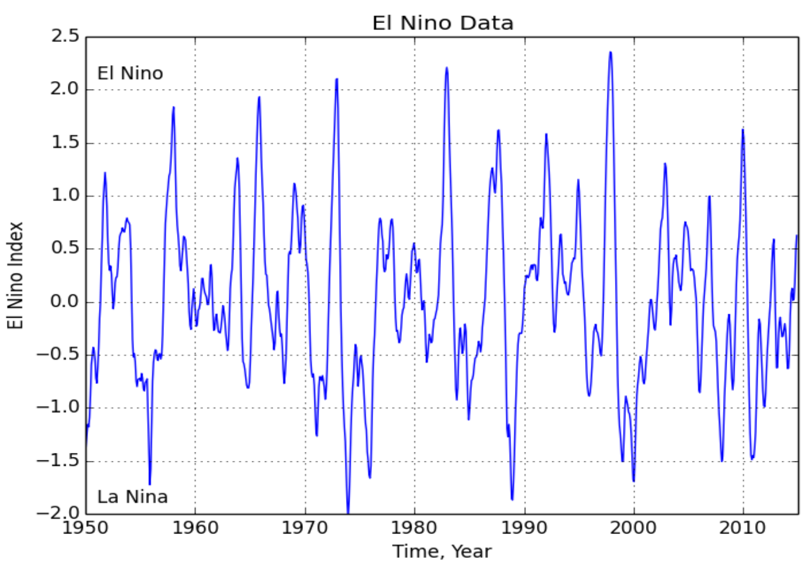
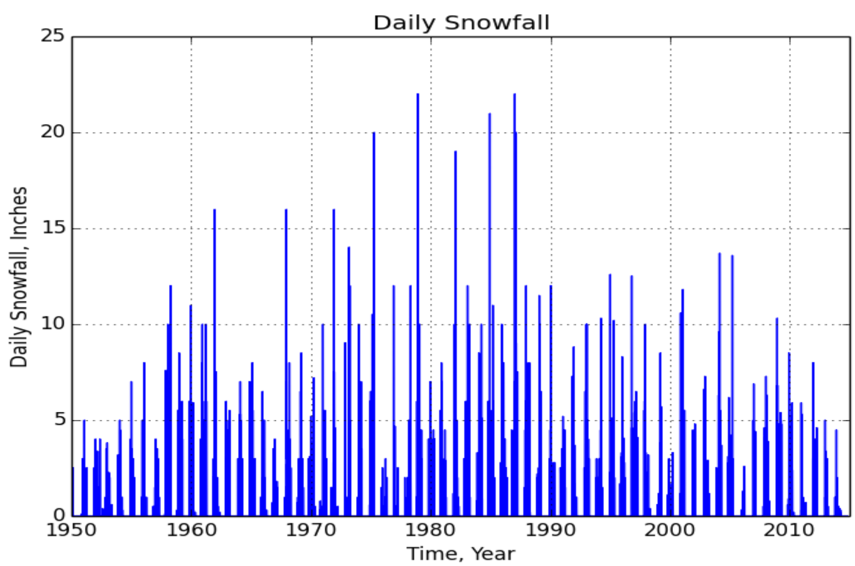


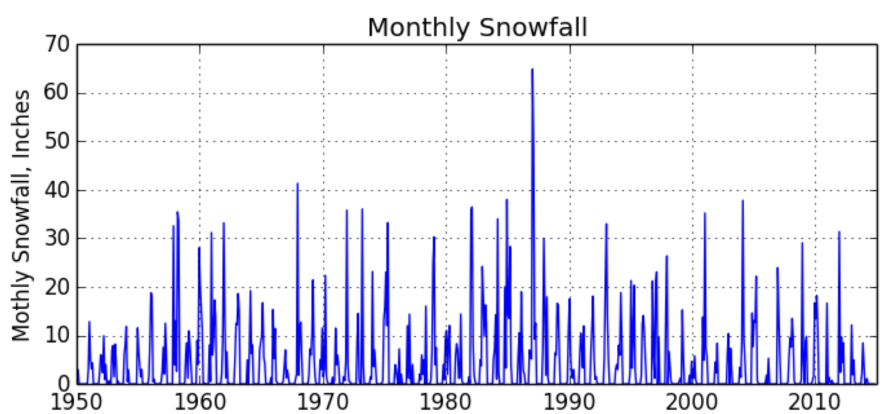
Figure 3. El Niño 3.4 index since 1950. This is the temperature anomaly in the equatorial Pacific in ^{o}C (NOAA 2015b). This and all following plots made by author.

Methods

This section will explain how data and graphs were plotted. First, El Niño Index 3.4 data from NOAA was downloaded (NOAA 2015b), as shown in Figure 3. Daily maximum temperature, minimum temperature, precipitation, and snowfall was downloaded from NOAA for 25 cities across the U.S. (NOAA 2015a). Daily data was averaged for each month and year (Figure 4). Python code was written to compute the correlation of the El Niño index and the monthly average weather. Month by month, for example the January El Niño index to January's snowfall, the correlation was very low at 0.01. However, when weather data was averaged over the winter months, the correlation with the yearly El Nino index was a lot higher.



a.



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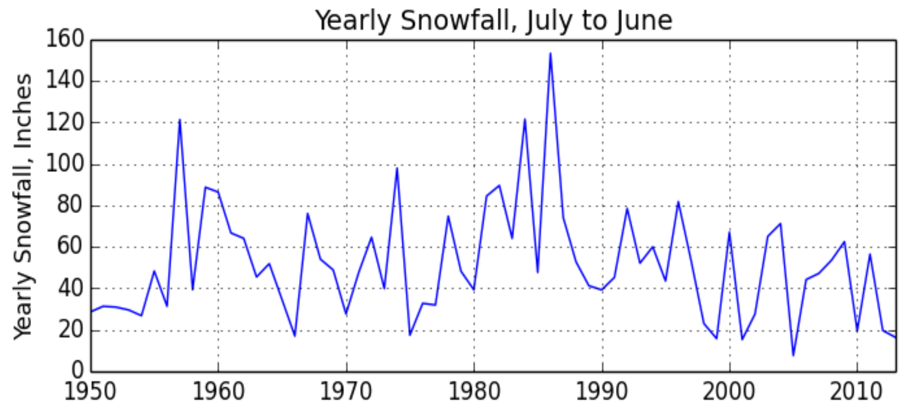


c.

Figure 4. Los Alamos snowfall data since 1950 for every day (a), summed for every month (b), and the total snowfall for each year (c). (NOAA 2015b).

The formulas used are as follows:

The *average* of N numbers, $x_1, x_2, x_3, \ldots, x_N$, is:

$$\mu_x = \frac{1}{N}\sum_{i}^{N} x_i$$

The python code to compute the average is:

```
def AvgList(x):
        xAvg=0.
        for k in range(len(x)):
                xAvg=xAvg+x[k]
        xAvg=xAvg/(k+1)
        return xAvg
```

The *standard deviation* measures the spread of the data:

$$\sigma_x = \sqrt{\frac{1}{N}\sum_{i}^{N}(x_i - \mu_x)^2}$$

The python code for the standard deviation is:

```
def stdDev(x): #function to compute standard deviation
        xAvg=AvgList(x)
        xdev=0.
        for k in range(len(x)):
                xdev=xdev+(x[k]-xAvg)**2
        xdev=xdev/(k+1)
        xdev=sqrt(xdev)
        return xdev
```

The *correlation* between two data sets may be between negative one and one, where one means they are 100% correlated, and negative one means they are oppositely correlated. When the correlation is zero, it is completely random. The correlation between a dataset x and a dataset y is:

$$r_{xy} = \frac{\frac{1}{N}\sum_{i}^{N}(x_i - \mu_x)(y_i - \mu_y)}{\sigma_x \ \sigma_y}$$

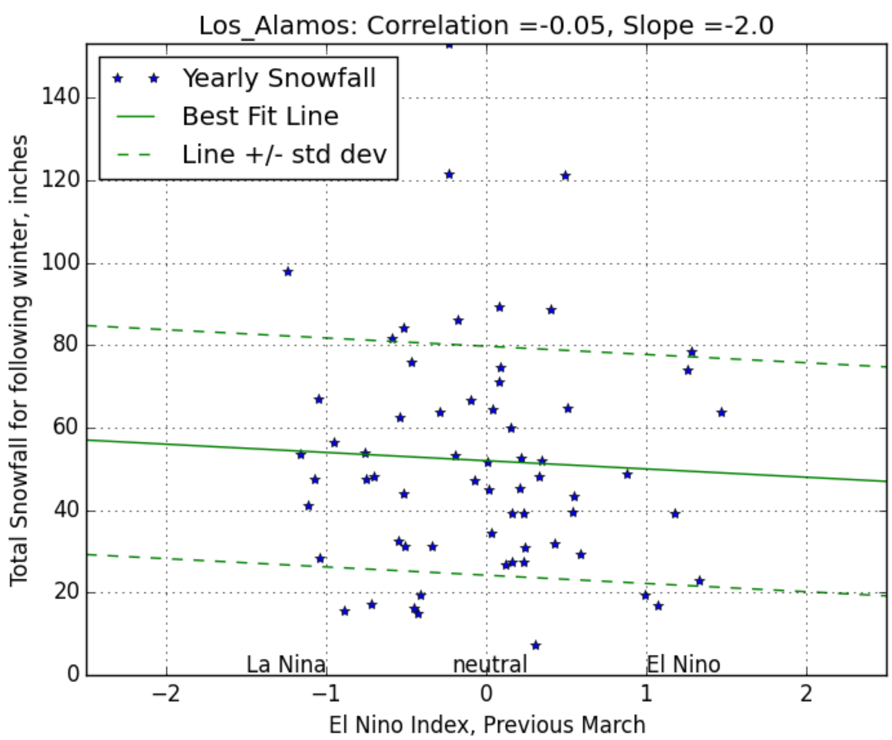
The python code for the correlation is:

```
def corr(x,y):
        xAvg=AvgList(x)
        yAvg=AvgList(y)
        rxy=0.
        n=min(len(x),len(y))
        for k in range(n):
                rxy=rxy+(x[k]-xAvg)*(y[k]-yAvg)
        rxy=rxy/(k+1)
        stdDevx=stdDev(x)
        stdDevy=stdDev(y)
        rxy=rxy/(stdDevx*stdDevy)
        return rxy
```

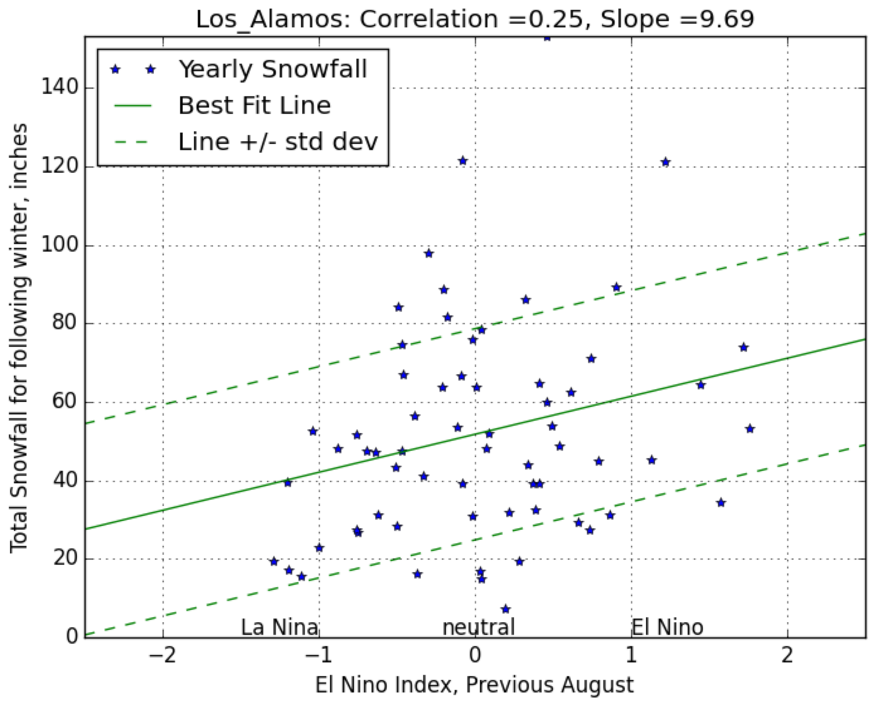
The best fit line was also added to all the plots. The best fit line is the line that best fits the data. In other words, it is the line that is the least possible distance squared to all the points. The equation of a line is $y=mx+b$. A python library was used to compute the best fit line. The 500 lines of python code is available upon request from the author, which also shows how data was read in and how plots were made.

Results

For this project, correlations between the El Niño index and temperature, precipitation, and snowfall were evaluated. For the same month, the correlation was very low—0.01 or lower. Therefore El Niño and weather do not correlate during the same month. After summing the snowfall for every year, there was a higher correlation with the El Niño index from previous months. As seen in Figure 5, the amount of snowfall in winter in Los Alamos has the highest correlation with the El Niño index from the previous August. This is true for most of the cities across the U.S., and the ones with the highest correlations were the cities that were colder and wetter during an El Niño. The only places where the highest correlation wasn't with August were Oregon (October) and northern California (June). This shows that there is about a five-month time lag between El Niño and the weather that follows for most of the cities across the U.S.



a.



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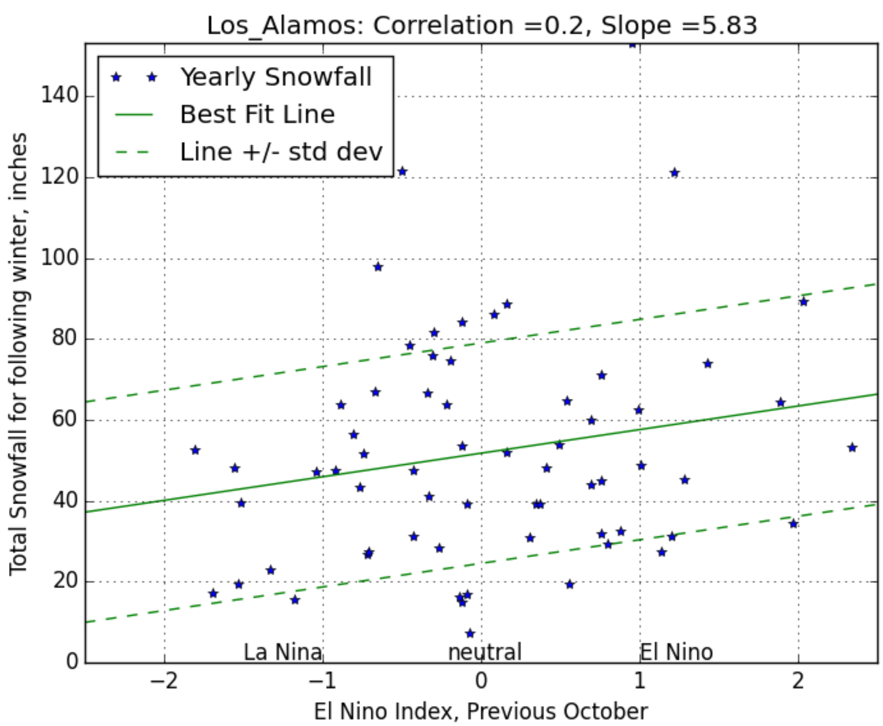


c.

Figure 5. Total snowfall for the following winter as a function of the El Niño index for the previous March (a), August (b), and October (c). Each dot is for a winter in Los Alamos from 1950 to 2015. The dashed lines show the standard deviation of the error of the best fit line.

A correlation is considered *statistically significant* if there is less than one in 20 chance (five percent) that it happened randomly. It is considered *highly significant* if there is less than one in 100 chance (one percent) that it happened randomly. For 60 points, a significant correlation is above 0.25 and a highly significant correlation is above 0.32 (Crow et al. 1960, p.241). The correlation in August is considered statistically significant.

The best fit line in Figure 5 is a simple model to predict snowfall. For August in Los Alamos, this model predicts 70 inches during a strong El Niño and 40 inches during a strong La Niña, a difference of 30 inches. To measure the accuracy of the best fit line, the standard deviation of the error of the best fit line was computed. This was 27 inches for August, showing that the variability in winter snowfall is almost as big as the difference between El Niño and La Niña.

Next, data was binned into the years classified as a strong, moderate and weak El Niño or La Niña, as seen in Figure 6. First, the El Niño index was smoothed by averaging over consecutive three-month intervals. For a year, spanning from July to June, to be classified as a strong El Niño, the smoothed index has to be over 1.5 for at least three months in a row, as described in Null 2015. These years are circled in red. The values for weak and moderate El Niño's are 0.5 and 1. La Niña classification is the same but negative. Next, the average was taken for the precipitation, snowfall, and temperature of all the years classified as a strong El Niño (Figure 7). This was then done for all the different categories of El Niño.

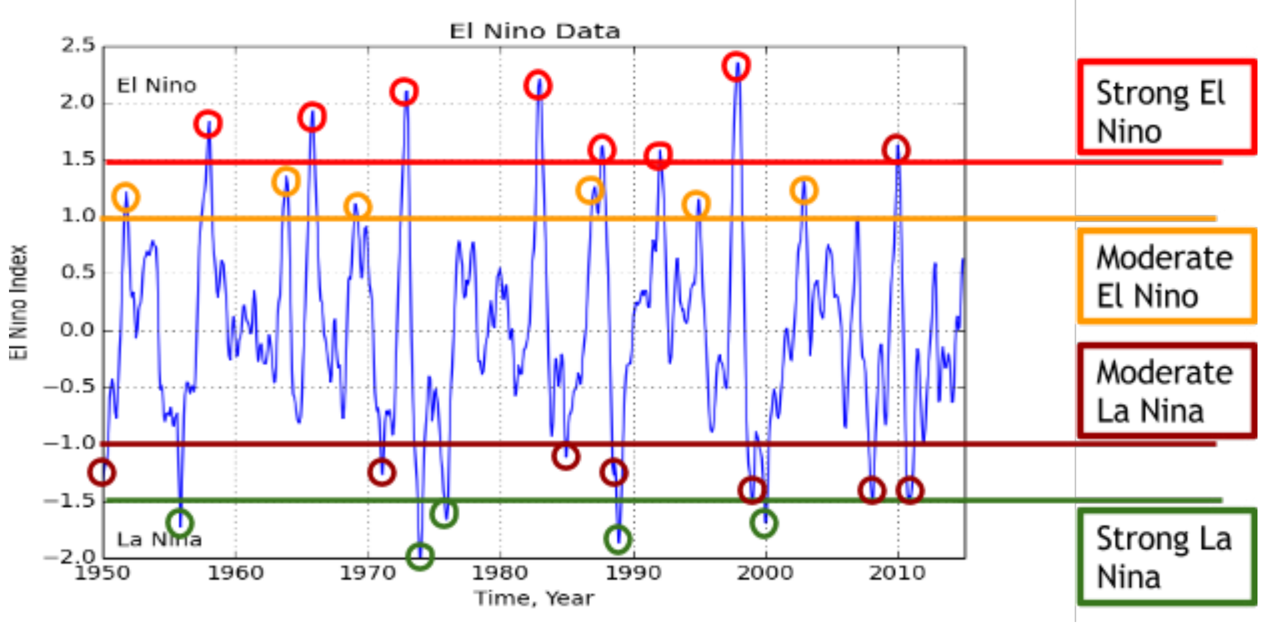
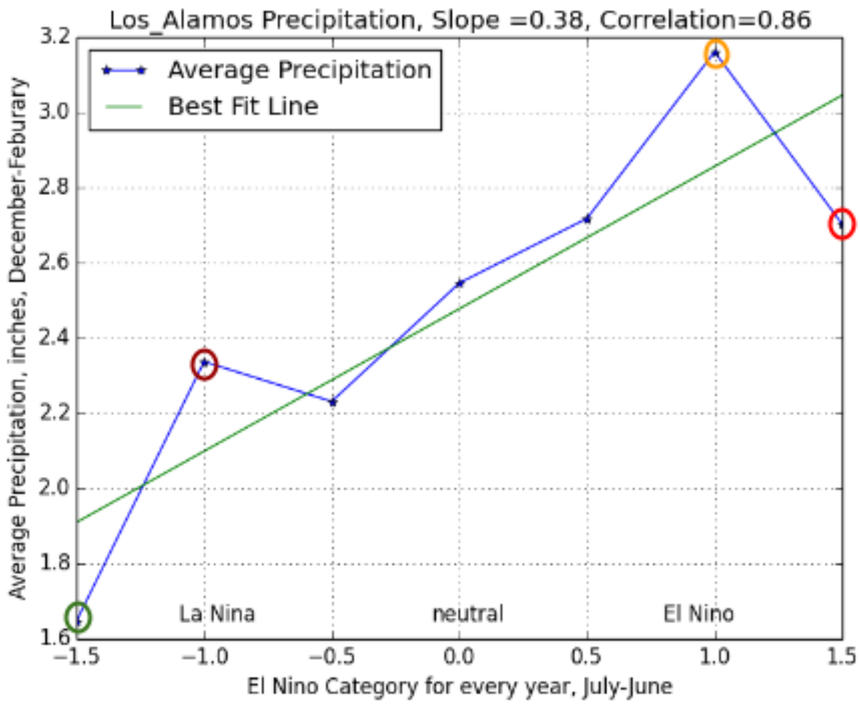
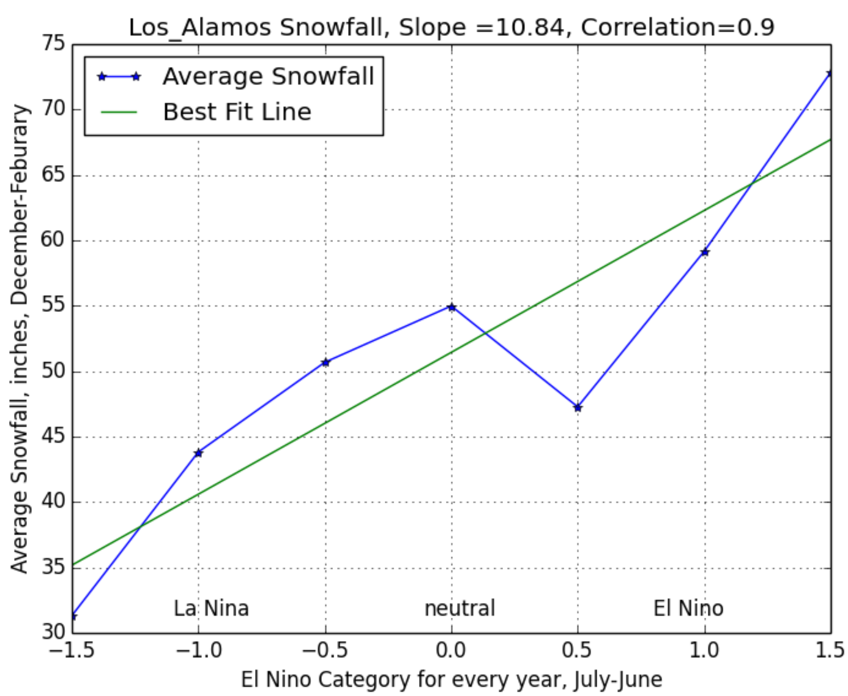
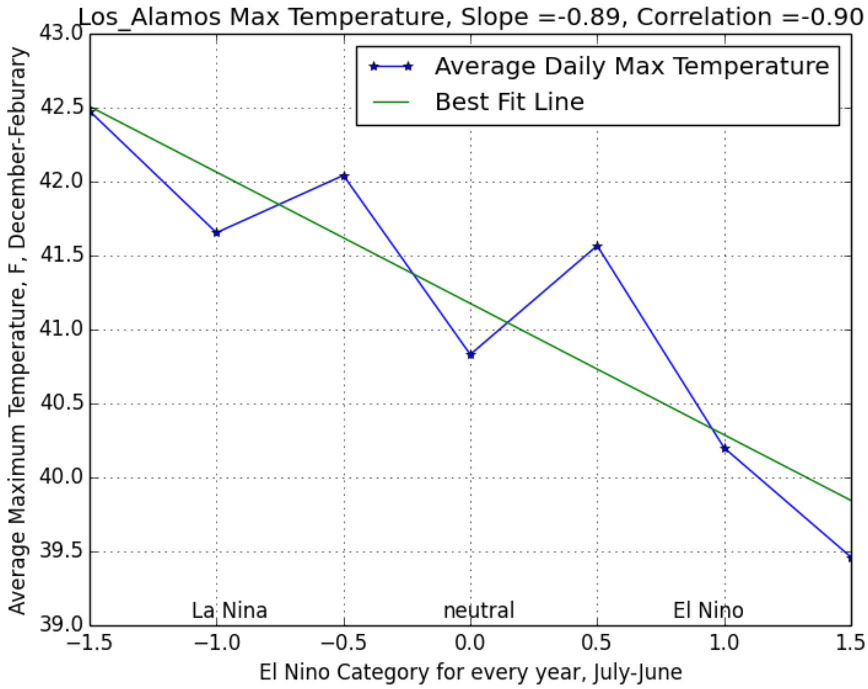


Figure 6. For a whole year to be classified as a strong El Niño, the index of that year has to be above 1.5 for at least three months in a row. Likewise is for strong La Niña, moderate El Niño, moderate La Niña, weak El Niño, and weak La Niña, using values of -1.5, 1.0, -1.0, 0.5, and -0.5, respectively.


Los_Alamos Precipitation, Slope =0.38, Correlation=0.86
Average Precipitation
Best Fit Line
Average Precipitation, inches, December-Feburary
La Nina
neutral
El Nino
El Nino Category for every year, July-June
3.2
3.0
2.8
2.6
2.4
2.2
2.0
1.8
1.6
−1.5
−1.0
−0.5
0.0
0.5
1.0
1.5
a.


Los_Alamos Snowfall, Slope =10.84, Correlation=0.9
Average Snowfall
Best Fit Line
Average Snowfall, inches, December-Feburary
La Nina
neutral
El Nino
El Nino Category for every year, July-June
75
70
65
60
55
50
45
40
35
30
−1.5
−1.0
−0.5
0.0
0.5
1.0
1.5
b.



c.

Figure 7. The average was taken of the precipitation, snowfall, and temperature for all of the categorized years (strong, moderate, and weak El Niño and La Niña). During a stronger El Niño, Los Alamos is wetter (a), gets more snow (b), and has colder temperatures (c). The circles on (a) correspond to the average of the years in Figure 6 with the same color.

In the town of Los Alamos, the weather is cooler and wetter during an El Niño. During a La Niña, it is warmer and drier. This is also true for multiple towns across New Mexico and Colorado. As seen in Figure 8, from New Mexico to the east coast, the weather is colder and wetter during an El Niño and opposite during a La Niña. West of New Mexico, it is wetter during an El Niño, but temperature effects have a low correlation. The north-western U.S. is warmer and areas near Ohio are drier. Some examples of this are Louisiana, which is colder and wetter (Figure 9), and Cincinnati, which is drier (Figure 10). If the correlation was between -0.5 and 0.5, the location was categorized as a low correlation. In Figure 7, the correlation is shown in the top of each panel. For seven points, a significant correlation is above 0.67, and a highly significant correlation is above 0.8 (Crow et al. 1960, p.241).

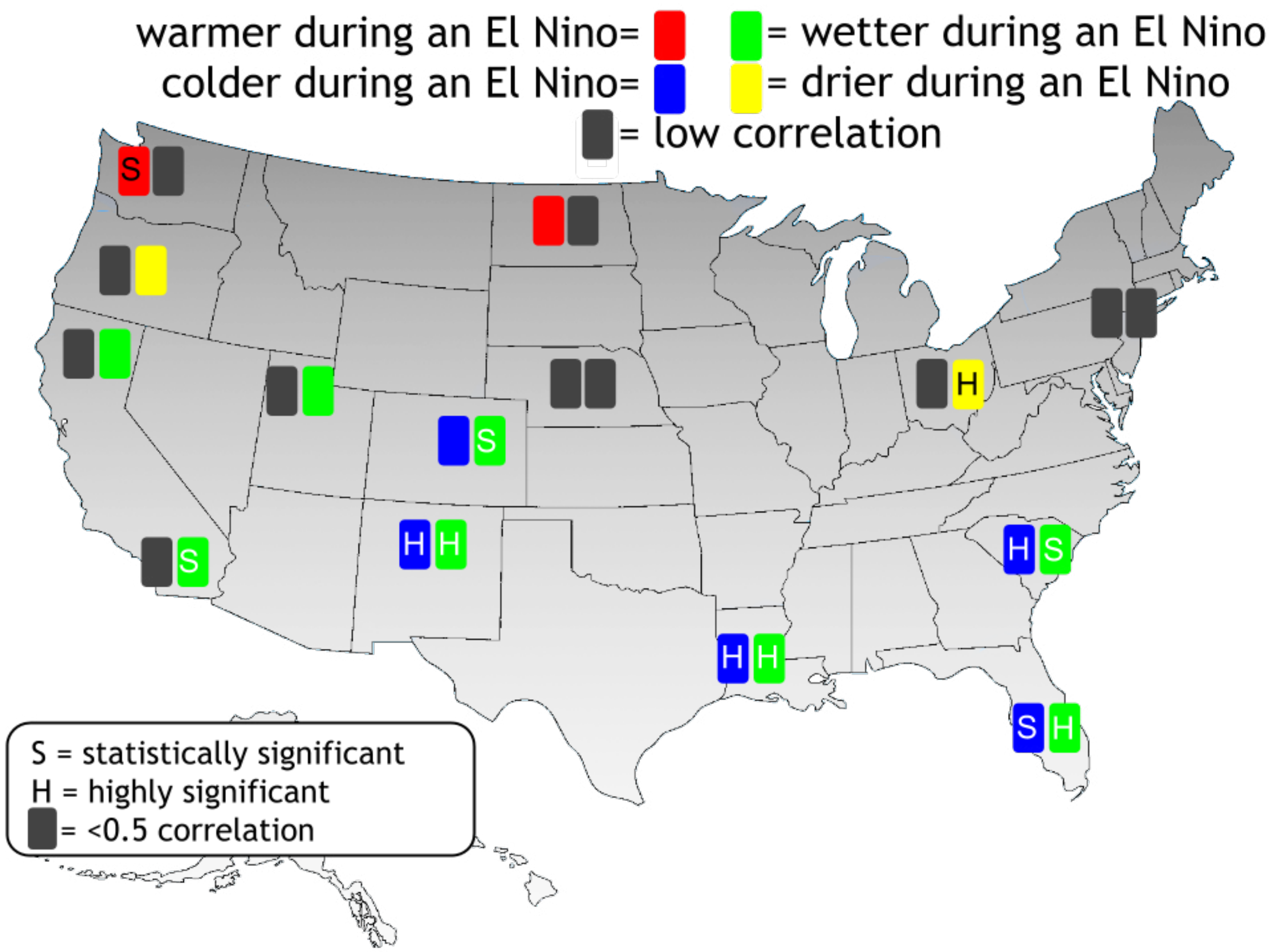
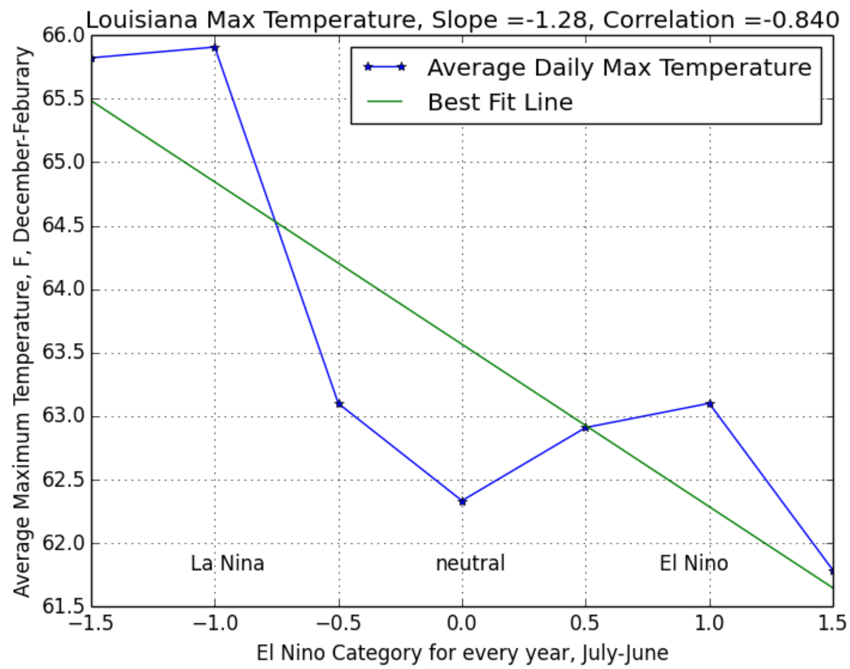
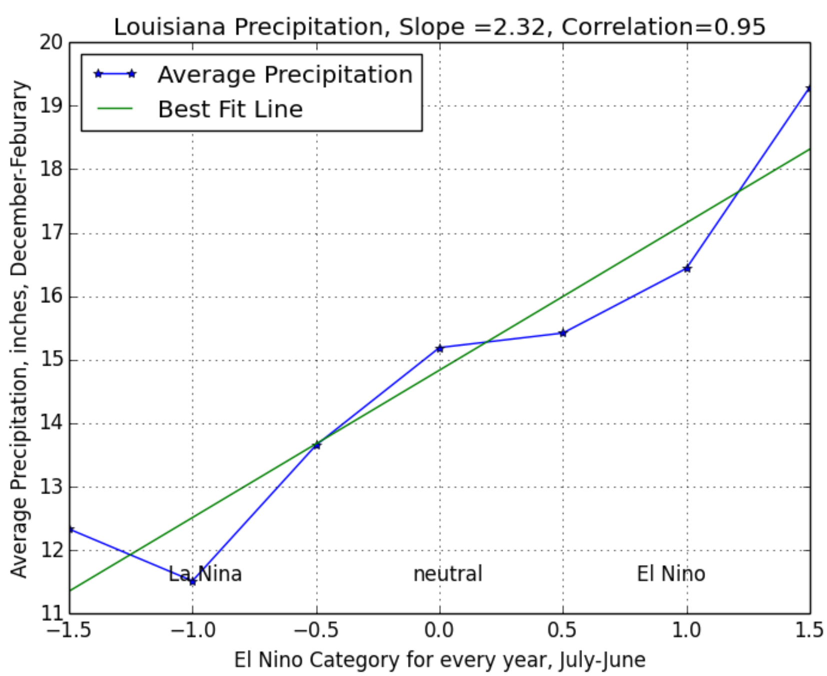


Figure 8. Effects of El Niño across the U.S. A graph with seven points is considered significant if the correlation is above 0.67. It is considered highly significant if the correlation is above 0.8. If the correlation was between -0.5 and 0.5, that location was classified as a low correlation.

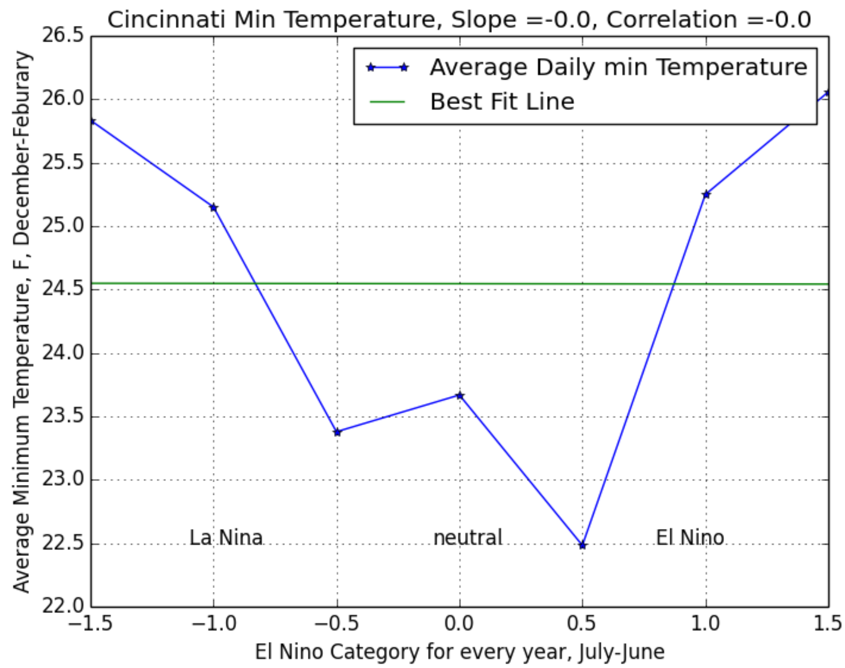


a.

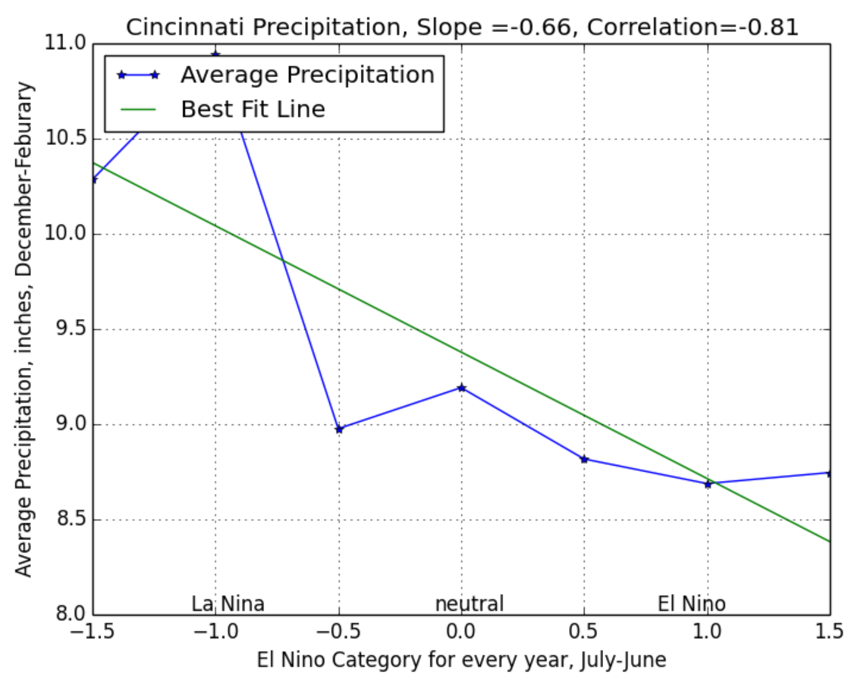


b.

Figure 9. Effects of El Niño for Louisiana. Louisiana is colder and wetter during an El Niño. Both of the correlations are highly significant.



a.



b.

Figure 10. Effects of El Niño for Ohio. Ohio is drier during an El Niño with a high significance

Conclusions

El Niño has different effects on the weather for different locations across the U.S. In New Mexico, it is colder and wetter during an El Niño. Significant and highly significant correlations were found between the El Niño index and temperature, precipitation, and snowfall, particularly in the Southern U.S. There was a five month time lag between El Niño and the weather that follows. This study shows that the El Niño index is a weak predictor of the next season's weather. This could be used for agriculture, drought prediction, snow removal planning, fire preparedness, and even deciding whether to buy a ski pass for the next ski season.

Acknowledgements

Over the past year, I learned how to program in python from Mark Petersen of Los Alamos National Laboratory. He taught me how to download data, make plots, and explained statistics such as correlation. Kimberly Petersen reviewed my writing and helped me improve my paper. Phillip Wolfram of Los Alamos National Laboratory suggested improvements. I also want to thank all of the judges at the NMAS paper competition and the Science Fairs, who gave advice on how to improve my project.

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