Sunset Observation

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Introduction

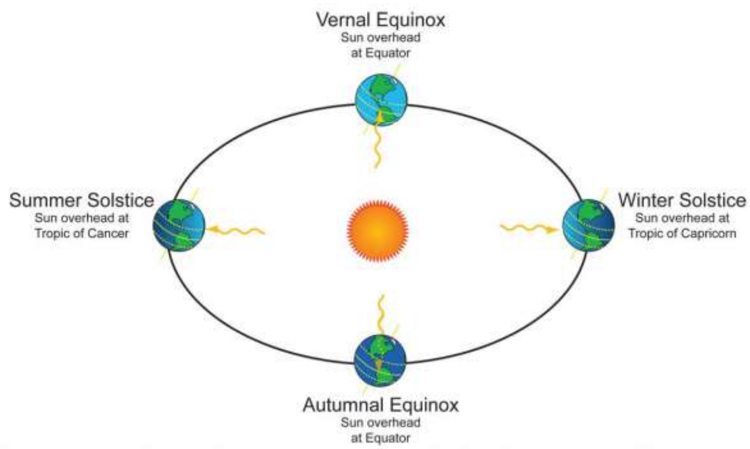
Over the past few months I have observed the bright sun set time and again and watched as it slowly meandered through the sky before dipping below the horizon. Over time, its position shifted more and more south, signaling the arrival of winter and the shortening days.

As a citizen of planet Earth, I believe the sunset observation project allowed me to reconnect with the universe, providing me with a real sense for my place in the world. Although not my first time observing sunset, this is definitely the first time that I have taken note of its changing position relative to the changing seasons. Observing the Sun every week or so in the same location enabled me to notice subtle differences that otherwise would not be visible. Why does the Sun move south? Why does the Sun set earlier? As questions like these arise, a new area of exploration I was not aware of before is open to me.

The purpose of this exercise is to learn about the Solar System and the Universe using my own eyes and logic. By observing the Sun, I will interpret its movements myself and verify the currently accepted model of the Sun's movement. Because the Sun is the center of our Solar System, it will provide insight into how ancient astronomers organized their lives around the patterns of the Sun. In addition, recording the variation of the sunset position along the horizon will allow me to interpret its effects on seasons using my knowledge of the Sun's movements gained through observations. This activity will allow me to think for myself and use the natural resources available to me instead of relying on textbook knowledge.

Background Information

Before I discuss my observation data, I want to first cover some information about how the Earth revolves around the Sun. Although Earth's orbit around the Sun is nearly completely circular, it has a 23.5° tilt about its axis.



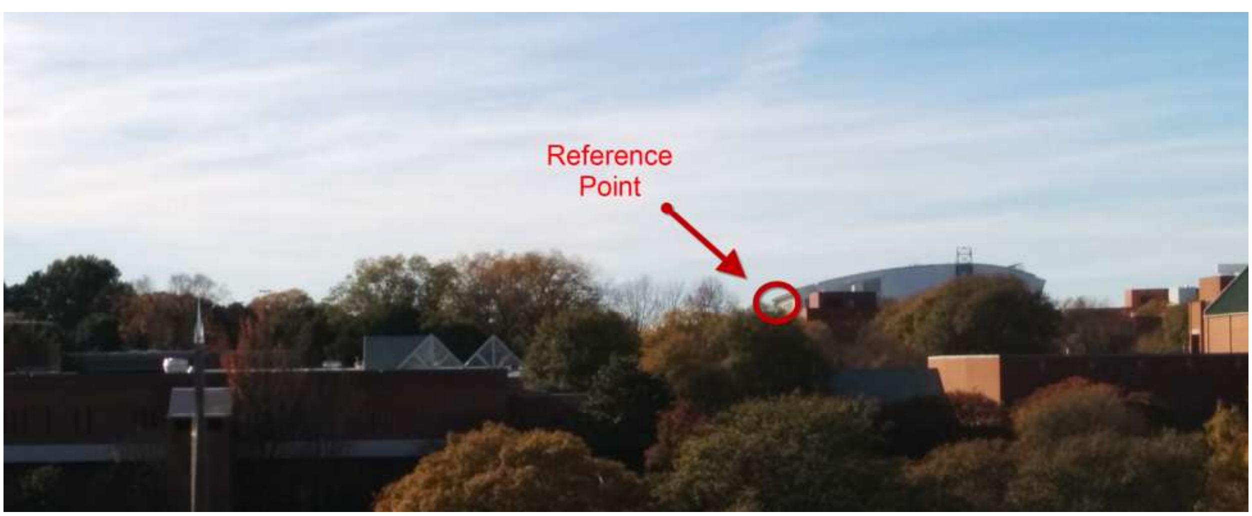
[1]

As shown in diagram 1, Earth's tilt causes sunlight to hit different parts of the Earth at different angles. The Earth is warmer if sunlight hits closer to a 90° angle and colder if sunlight hits the Earth at less direct. This is why seasons exist. During the transition from fall to winter, the Sun's altitude will seem to decrease over time, but this effect is caused by Earth's tilt. Another interesting fact that can be extrapolated from this information is that the inclination of the Earth's rotation axis causes the position of sunrise and sunset to change every day. The past few months have allowed me to view these phenomena with my own eyes.

Sunset Observation Setup

Although there were many good locations to choose from, given that it is an easily accessible vantage point, I decided to take my pictures at the Clough Undergraduate Learning Common's rooftop garden.

All observations were taken at the same time of day and location. I positioned myself a few feet away from the right corner as shown in the image above. While this area provided a clear view of the sunset, I would occasionally have to account for some extremely tall trees. To take my pictures, I used the camera on my Nexus 5 phone, capable of taking crisp and detailed photos. All pictures are 8 megapixels and are 3264 x 2448 pixels. For the purposes of this project, I thought this resolution was high enough.



Of the available features I could use as my reference point, I decided to use the left corner of the CRC as shown in the image above.

Although most people's fists are about 10° wide, I decided to calibrate the angular diameter of my fist by using the following equation:

$$tan\alpha = \frac{Fist\ Length}{Arm\ Length}$$

where α is the angular diameter of my fist.

Fist length does not include my thumb. Using measuring tape, I measured my arm length to be 24 inches and my fist length to be 3.3 inches. I calculated my fist size to have an angular diameter of approximately 7.8°. To measure the angular distance the sun traveled, I used the knuckles on my hands as breakpoints to get my measurements as accurate as possible. Each knuckle on my hand was counted as one-fourth of a fist and I used this data to calculate the degrees traveled by the Sun. Since I knew that there would be some imprecision in my measurements, I rounded to the nearest degree for each observation.

Sunset Observation Data

During my observations, I recorded the date, time, degrees away from the reference point, weather condition, temperature, and length of daylight in a notebook. All times are in Eastern Time. Negative degrees indicate the Sun is to the left of the reference point and positive degrees indicate the sun is to the right of the reference point. The next few pages include the data I collected and a description of each sunset picture I obtained.

Observation	Date	Time (pm)**	Degrees	Weather Conditions	Temperature (°F)	Length of Day
1	8/25/15	7:59	2	Clear	82	13:06
2	9/4/15	7:46	-1	Slightly Cloudy	77	12:46
3	9/17/15	7:30	-6	Slightly Cloudy	76	12:22
4	10/6/15	6:58	-16	Clear	75	11:40
5	10/14/15	6:54	-17	Clear	71	11:24
6	10/21/15	6:44	-20	Clear	72	11:10
7	11/10/15	6:20*	-25	Clear	59	10:33
8	11/19/15	6:13*	-32	Clear	62	10:19

* Adjusted for end of daylight savings time
** All times are in Eastern Time

The temperature data was gathered from The Weather Channel and is the temperature at the time the observation was taken [2]. The data for the length of day was obtained from the US Naval Observatory and provides two numbers. The first is the amount of daylight in hours and the second is the number of minutes of daylight on that particular day [3]. Below are each of my individual observation pictures with explanations for each one.

8/25/15

This is the first observation I obtained and it was taken on a clear day at 7:59 pm. The CRC is difficult to see in this image since the sunlight obscures the left corner, but it was 2° away from the reference point. The temperature was 82°F, which is expected for late August. Since this was my first observation I made sure to take several pictures, with some turning out better than others. Over the horizon the sky changes color from blue to an orange-yellow color due to the low altitude of the Sun and diffraction of light. The evening was very nice and calm.

9/4/15

Surprisingly, this is one of two observations that had clouds. This may have been due to the presence of storms in September and October, explaining why the only appearances of clouds are both in September. These clouds may have foreshadowed the more severe weather that would come later in the month, preventing me from obtaining clear photos during that time. The Sun is -1° away from the reference point, and since it is lower than in the last picture, the camera lens is less flooded with light and the left corner of the CRC is easily discernible. The picture was taken at 7:46 pm. The temperature was 77°F, which was expected since we are approaching winter.

9/17/15

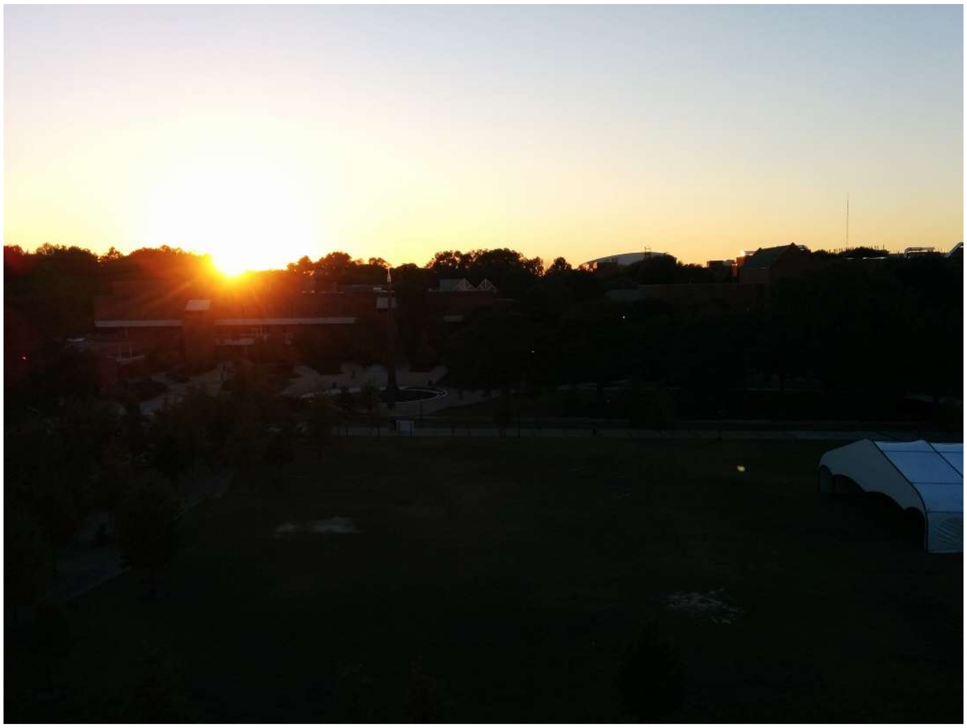
This is the only other observation where clouds were present. Unfortunately, the Sun had begun to set behind the trees. Since the trees are actually higher than the CRC, the Sun set a bit earlier than expected. Despite this, the sun is -6° from the reference point and the temperature was 76°. The weather was partly cloudy, but clear enough for a good sunset picture. This was taken at 7:30 pm.

10/6/15

After several weeks of anxious waiting for the storms to leave, there was finally a series of clear evenings. One interesting thing about this image is the faint clouds to the right. I suspect these are remnants from the storm since this was taken the first available clear day. Another noteworthy object is the small circle of light illuminated in the dark. I doubt this is a natural light, but it may be from some object or it could be just a camera effect. The truth is beyond my knowledge. Lastly, I would like to point out how far the Sun has moved since the last observation. The Sun is -16° from the reference point, a bit less than three times than the last observation. The picture was taken at 6:58 pm, significantly earlier than usual, and the temperature was 75°F, which was a bit surprising since I was expecting it to get colder. The October evening was fairly steady and getting clear pictures was much easier than during the storm.

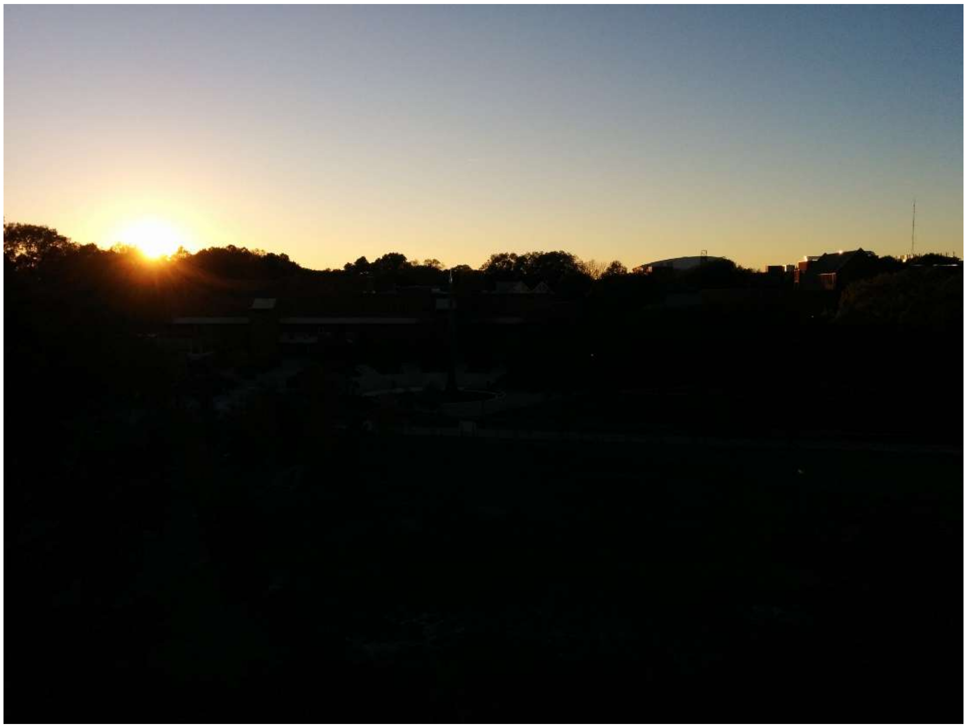
10/14/15

I took this picture eight days after my last observation. Like my other October observations, this was also a clear evening. Taken at 6:54 pm, it was amazing to see the Sun be the only object in the sky for some time. The Sun is -17° away from the reference point and the temperature is 71°F.



10/21/15

Taken exactly a week after my last observation, not too much has changed. However, there are some bright dots scattered below the horizon. The bright dot on the right may be the same one observed on October 6. The Sun is -20° away from the reference point and the temperature is 72°F. Surprisingly, the temperature has remained fairly constant for October from the data I collected. I expected it to be colder with each observation, but perhaps there may be some weather patterns trapping in the heat that I don't know about or I could be unlucky and gathered my temperature data on only warm evenings. This observation was taken at 6:44 pm.

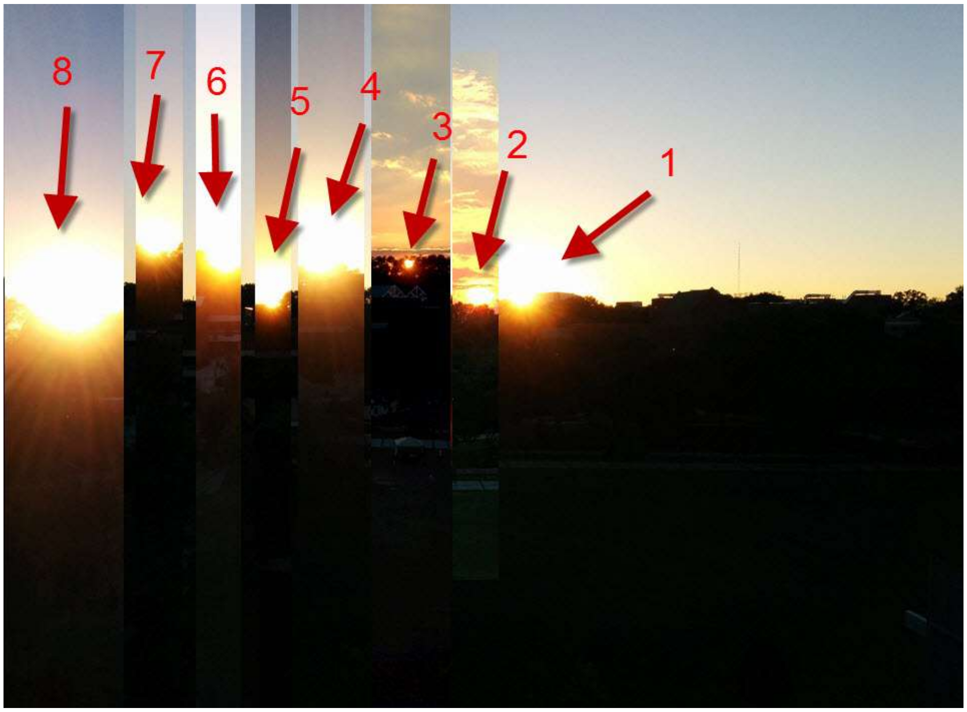


11/10/15

Once again, there was another string of cloudy nights which prevented me from taking any pictures these past two weeks. Like my first observation in October, however, the sun has moved a significant distance again. The Sun is now -25° away from the reference point and the temperature is 59°. Unlike October, it seems that moving into November has caused the temperature to drop drastically. Because I expected the temperature to decrease at a relatively constant rate, the sudden drop in temperature was a bit surprising. It was definitely much colder. There were some winds this evening but it was not very significant. This observation was taken at 6:20 pm, accounting for daylight savings time.

11/19/15

I decided that this picture was the last possible observation that I could obtain. I managed to find a clear sky that day and got a good picture of the Sun as it was about to set. A noticeable feature about this picture is the green dot to the right. Though white dots have been spotted in my other observations, this green glow is not in the same location and the picture gives no indication of what it could be. Other than that, it was a beautiful day and the sky was a nice deep blue. There were some winds that evening, but I did not record any wind speeds. The Sun was -32° from the reference point and it was 62°F. This observation was taken at 6:13 pm, accounting for daylight savings time.



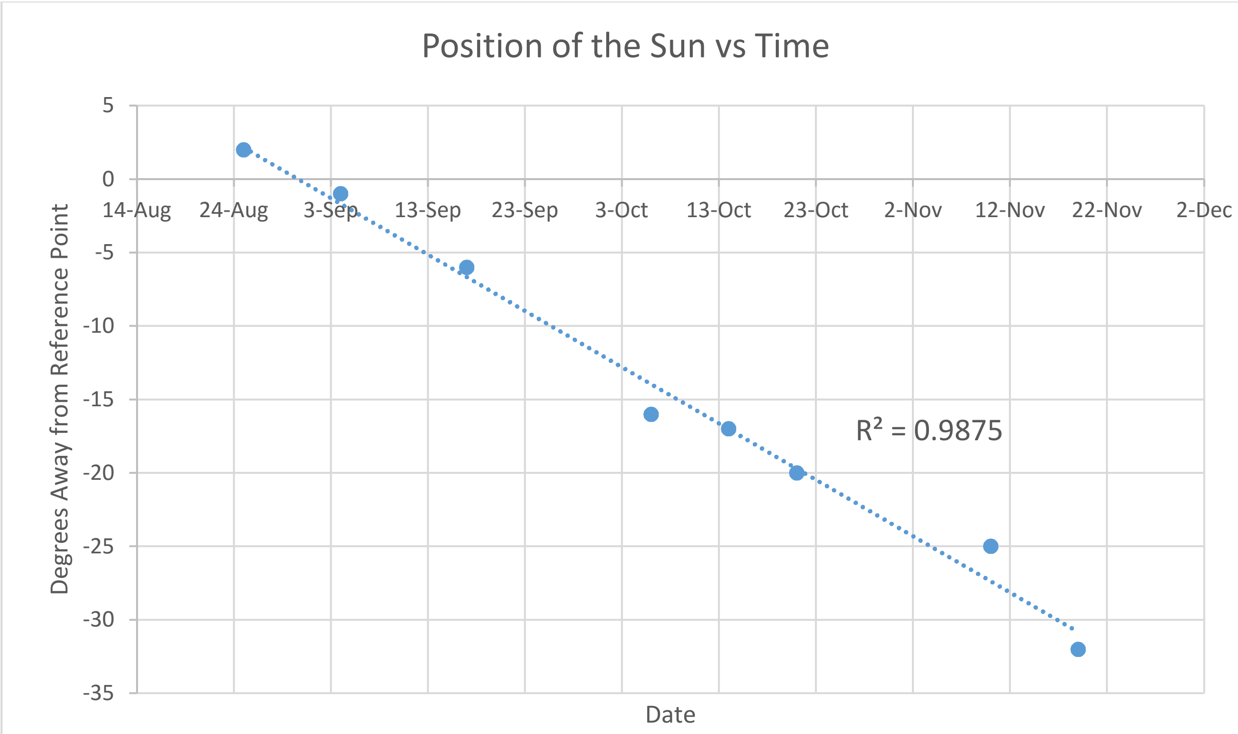
As seen in the image above, which each observation, the Sun moves south along the horizon. One of the fascinating things about this image is not only the position of the Sun, but the color of the sky. Each image shows a different shade of the sky depending on how early or late I took the picture relative to the exact sunset time. Because of these slight deviations, meshing together my observation pictures created a beautiful collage of colors and patterns that would be difficult to see otherwise. I also think it's interesting to see in a single image how far the sun has traveled throughout the semester. With each individual picture, unless you view them side by side, it can be difficult to tell that the sun has moved a great deal. This image brings out the changes in the Sun over time and makes it easier to draw conclusions.

Sunset Observation Analysis

To analyze the data I collected, I decided to plot several graphs with linear regression lines to see if there was any relationship between the data I collected. To make data analysis a bit simpler, I changed the length of day data to be in minutes. Below is a chart with all the data I used.

Observation	Date	Degrees	Temperature (°F)	Length of Day (Minutes)
1	8/25/15	2	82	786
2	9/4/15	-1	77	766
3	9/17/15	-6	76	742
4	10/6/15	-16	75	700
5	10/14/15	-17	71	684
6	10/21/15	-20	72	670
7	11/10/15	-25	59	633
8	11/19/15	-32	62	619

My first analysis will be time versus the Sun's position, that is, date versus degrees. From the data, the Sun seems to be moving south at a uniform rate. The time that has elapsed with each observation seems to be proportional with the number of degrees the Sun has moved from its last position. To confirm this, I created a linear regression line and calculated the R^2 value. I also calculated the average degrees traveled per day between each data point.

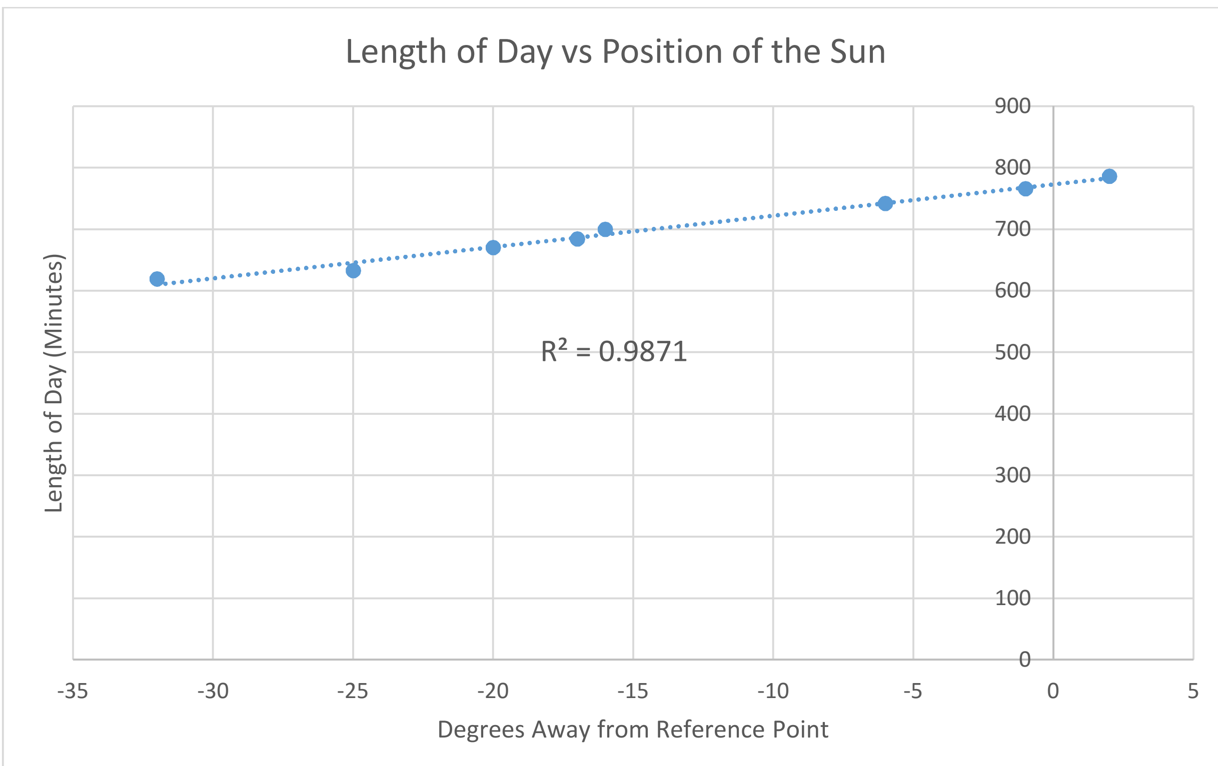


This plot indicates that there is indeed a linear relationship between the time and position of the sun. The extremely high R^2 confirms this idea. To calculate the average degrees per day, I found the number of days between each observation and the number of degrees traveled between any two observations. I then divided the degrees traveled by the number of days to get the degrees traveled per day between any two observations. Below are my findings.

Differences	Days	Degrees	Degrees/Day
Observations 1/2	10	-3	-0.3
Observations 2/3	13	-5	-0.38462
Observations 3/4	19	-10	-0.52632
Observations 4/5	8	-1	-0.125
Observations 5/6	7	-3	-0.42857
Observations 6/7	20	-5	-0.25
Observations 7/8	9	-7	-0.77778
Average	12.28571	-4.85714	-0.3989
Standard Deviation	5.282496	2.968084	0.211282

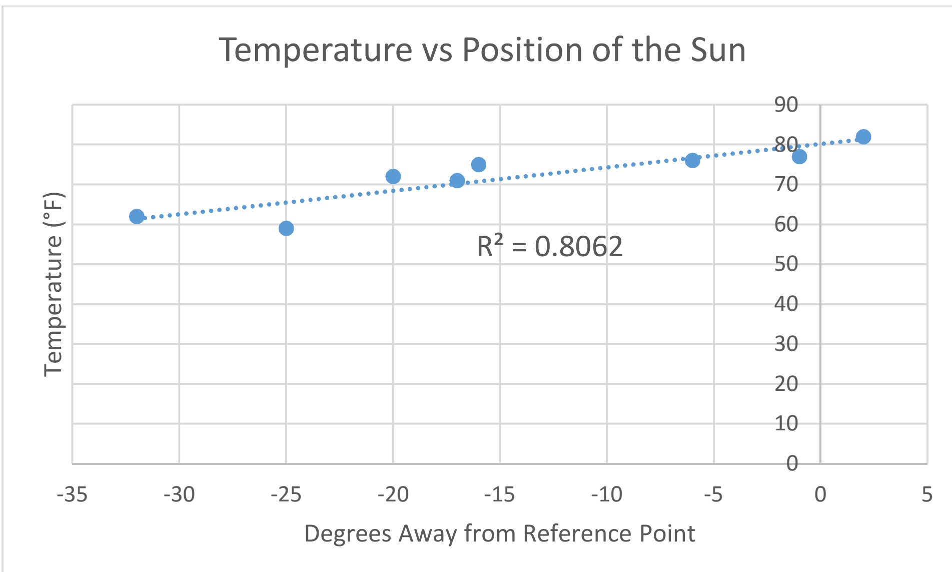
This data also seems to indicate that the movement of the sun across the sky is a linear relationship with time. Although there are some deviations in the degrees per day data, all of the values are within two standard deviations of the mean. Only the last data point seems a bit high, but the numbers tend to hover around -0.4 degrees per day. Therefore, my final conclusion is that the Sun's sunset position vs time is a linear relationship.

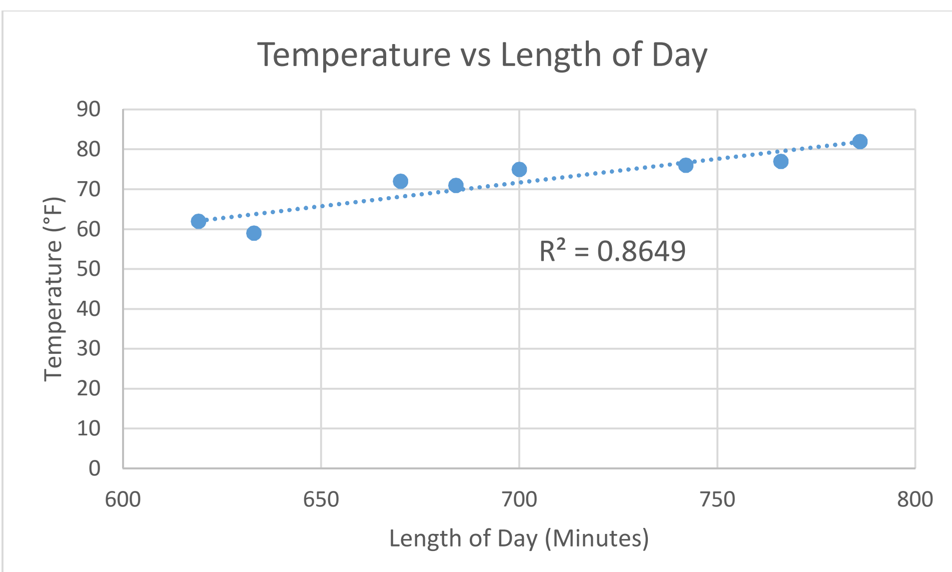
My second analysis will be on the position of the Sun versus the length of day. Although it is clear that the Sun sets in the west and is moving to the south in my observations, it seems like there should also be a relationship with the length of day. To calculate the number of minutes in each day I just multiplied the number of hours by 60 and added this number to the minutes. I plotted the data points and used a linear regression line to find out if there was a linear relationship.



According to the data above, I concluded that the position of the sun forms a linear relationship with the length of day. The extremely high R^2 value validates my conclusion. This means that the length of the day can be predicted by looking at the position of the sunset. The more south it is from my reference point, the shorter the day, and vice versa.

My next analysis will be temperature versus the position of the Sun and length of day. Since temperature is associated with the Sun's position in the sky, I predict that there will be a linear relationship since the position of the sunset and the length of day are both indicators of a change in seasons, which is a good predictor of temperature. Below are the two graphs plotting this data.





As predicted, there seems to be a linear relationship. The decreased R^2 value can be attributed to the sudden decrease in temperature for my last two observations and the constant temperature throughout October. However, despite this, these values are still high enough to conclude that there is a linear relationship between temperature versus the position of the sun and length of day. As the day gets shorter and Sun moves further south, the colder it gets.

From my observations and data, I can infer that the position of the Sun at noon was decreasing throughout the semester. The reason I think this is because the decrease in temperature could be attributed to a greater angle of sunlight hitting the Earth, heating it up less than if it had hit at a 90° angle. Because of this decreasing temperature, it makes sense for the Sun to be at a lower altitude so that it can hit the Earth at a greater angle, hence decreasing temperature as the semester went on. Another more obvious consequence of this is the elongation of shadows. With the Sun at a greater angle, shadows will also be longer. Though I do not have data on this, it is a reasonable conclusion. Moreover, as we travel around the sun, it makes sense for the sun to go through a cyclical motion in the sky where its altitude increases and decreases due to the axial tilt of Earth. Therefore, this explains both why the seasons are changing, and the decrease in the Sun's altitude as we approach winter.

Although much of the results were expected, I still find the data to be very impressive. One thing that I thought was most surprising was how fast the Sun moved across the sky. Looking at the first linear regression plot, the steepness of the regression line indicates that the Sun was moving quite quickly. In a mere four months, it traveled over 30° south. The reason I find this so shocking is that nobody actually notices that the sunset is moving every day. Even though everybody knows where the Sun sets, they don't know just how rapidly the sunset position is changing. Being able to see this for myself and actually gather data on the degrees traveled is an experience I will cherish.

Conclusion

These past few months have allowed to see the effects of the Sun on Earth's seasons for myself and the data I gathered has allowed me to grasp a firm understanding of how and why the Sun moves the way it does. But naked eye observation does not just stop at the Sun. For the duration of this semester, I have been more aware of my surroundings and more observant of the sky. For instance, I often found myself looking at the sky more often, wondering if tonight would be a clear night. Because I did this almost every day, I managed to find two sundogs glittering beautifully in the sky on either side of the Sun. If that weren't enough, I also saw two circumzenithal arcs hovering above the Sun smiling at the world with their rainbow mouths. A circumzenithal arc is an optical phenomenon where an upside down rainbow appears around the Sun due to refraction of sunlight through ice crystals, generally in cirrus or cirrostratus clouds. Although the Sun is one of the most important objects in our Solar System and is definitely the main focus of this project, I think this sunset observation assignment does more than just let us watch the Sun travel across the sky. It allows us to observe the sky more often, see what is normally missed, and understand the hundreds of astronomical phenomena that we did not know even existed. Observing, recording data, and drawing conclusions follows the scientific method and is a process all astronomers follow. I have learned from this project that there is much more beyond my current understanding, but careful observation of celestial patterns and movements will not only provide me with the information to be an excellent astronomer, but the skills to be a great engineer as well.

References

[1] "SciJinks It's All about Weather!" NOAA's SciJinks. Web. 22 Nov. 2015. <http://scijinks.jpl.nasa.gov/solstice/>.

[2] The Weather Channel. Web. 22 Nov. 2015. <http://www.weather.com/weather/today/l/USGA0028:1:US>.

[3] "Duration of Daylight/Darkness Table for One Year." Duration of Daylight/Darkness Table for One Year. Web. 22 Nov. 2015. <http://aa.usno.navy.mil/data/docs/Dur_OneYear.php>.