An Analysis of 500 hPa Height Fields and Zonal Wind for Fall 2010: A Utilization of Rossby Wave Theory for Observational Processes.

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ABSTRACT

This project examined the 500 hPa height fields as well as the global average zonal wind charts from the dates of September 5, 2010 to November 19, 2010. The data gathered included wave numbers, amplitudes, global average zonal wind, and wave speeds. An analysis was performed to test whether or not Rossby's Wave Theory observational data correlated to the theory itself. Results indicate that there was a slight correlation; however, most of the analysis did not support the tested theory. This study indicates the general behavior of wave dynamics in the atmosphere should be analyzed in further depth.

1. Introduction

Large-scale synoptic waves have an effect on everyday weather. An essential aid to forecasting especially long range is to pay close attention to the mean wavelength. Referring to the Quasi-Geostrophic height tendency, vorticity advection propagates ridges and troughs and has an impact on synoptic events and also displays how energy interacts within the atmosphere. Getting the full understanding of how these so called synoptic waves work is essential to anyone that has a job involving meteorology. The goal of this paper is to see whether or not one could apply Rossby's Wave Theory to a set measure of guidelines and procedures to follow for observation. For a matter of seventy-five straight days, the group documented and examined the 500 hPa charts for the Northern Hemisphere and the Southern Hemisphere as well as monitoring the zonal wind averages at the 500 hPa and the 150-300 hPa level for both Hemispheres. When the data collecting came to a close, the group analyzed the information to discover any potential relationship between Rossby Wave Theory and the observable data collected.

2. Data and Methodology

The particular data used in this project were from the Iowa State University Weather Products website (http://www.meteor.iastate.edu/wx/data). The website has an eight day archive for three separate products including: Northern Hemisphere, Southern Hemisphere, and the Zonal Wind Global Average. Each product allows for animating the previous eight days worth of analysis as well as the current day's. For the Northern Hemisphere, the plot is centered on the North Pole with lines of latitude drawn in every 10 degrees and lines of longitude drawn every 10 degrees from the Prime Meridian. The Southern Hemisphere is similar in having the plot centered on the South Pole with lines of latitude drawn in every 10 degrees and lines of longitude drawn in every 10 degrees from the Prime Meridian. The data collecting process for this project began on September 5, 2010 and lasted through November 19, 2010. Each 500 hPa and Global Zonal Average Wind plot were used from the 0000 UTC observations.

The data collection for 500 hPa involved not only just noting the general pattern, but more so the behavior of the waves. Additional variables monitored was the Integer Wave Number (N), the average Amplitude (A) of all the waves within the Integer Wave Number count, and the speed the waves are traveling (C). As for the Global Zonal Wind Average plot, the 50 degree latitude line was used to record the zonal wind average in both the Northern and Southern Hemisphere (U500). In addition to U500, the maximum global zonal wind average for the Northern and Southern Hemispheres between 150-300 hPa layers (Uupper) at the same 50 degree latitude line to visualize the upper level wind pattern in relation to the large-scale synoptic waves. The data was recorded in an Excel Spreadsheet and sent to a Google Doc spreadsheet and shared amongst the group for each member to write down the different variables each day during the duration of this project.

General guidelines were given to each group to follow for this project. This was done in an attempt to arrive at the most accurate results for the comparison. The goal of counting the Integer Wave Number (N) for both Hemispheres was to focus on a single target contour. For the Northern Hemisphere, we analyzed the 5580 m contour. The contour is in the middle range of heights and exhibits a moderately clear west-east movement in the atmosphere. As for the Southern Hemisphere, we focused on the 5280 m contour with the same reasoning behind it. Counting the Integer Wave Number was done each time the target contour crossed equator-ward of the target line of 50 degrees latitude and then dividing that particular number by two for each Hemisphere. At times, the target contour would not officially cross the 50 degree latitude line but would rather lie across it. An additional Integer Wave Number would not be counted if this were to happen.

(1) *Integer Wave Number: N = (# of Official Crossings)/2.*

The next variable in the analysis process is the average amplitude. This was calculated for every wave and was done each day. Included in the calculation process was recording the 500 hPa height maximum and minimum values. Each day had a local height maximum and a local height minimum value that was recorded in the spreadsheet. The method of tracking the maximum and minimum values were to find the two highest height contours through the 50 degree latitude line and interpolate the value between the two height contours. For each Integer Wave Number there was a local height maximum and a local minimum height. The sum of the maximum and minimum values was calculated, respectively.

(2) AveMaxima = Average of the N local height maxima;

(3) AveMinima = Average of the N local height minima;

With the acquisition of these averages, the average amplitude was then calculated daily for the Northern and Southern Hemisphere.

(4) A = (AvgMaxima – AvgMinima)/2.

A third variable to consider for this study is the wave speed. This was calculated for a given wave along with the integer wave number count. The animation loop on the Iowa State University Weather Products website was especially helpful here. For determining the motion, members of the group would choose one point where the target contour crosses the target latitude circle and would track its movement each day. The wave speed itself was calculated by making use of the difference in a particular wave location for one day prior to the target day and one day after the target day and dividing that value by two. The result was calculated each day for the duration of the project in units of degrees longitude per day according to equation below:

(5) $C = \{Longitude\ (day{+}1) - Longitude\ (day{-}1)\}/\ 2.$

This simply states that the speed is estimated as one half the changes in longitude between the day after and the day before.

The final variable to consider in this study is the global average zonal wind speed plots which were used to find the average zonal wind in two specific areas. Those locations are at the 500 hPa level (U500) and the 150-300 hPa level (Uupper) at the Northern and Southern Hemispheres using the desired target 50 degrees latitude line. This was done in order to consider the environment in which the wave is embedded and hence the reasoning behind the zonal wind cross-section is given on the plots. The 50 degree latitude line was used for both levels in an attempt to correlate more strongly the wave propagation. The benefit of looking at the 150-300 hPa layer emphasized the importance that the upper level effects have on the jet stream as well as large-scale flow.

3. Results and Analysis

A) <u>How rapidly do wave patterns move?</u>

Using the data collected over the semester, we can calculate how fast the atmospheric waves at 500 mb move and its direction. This is done by using the equation (C = {LON(day+1) - LON(day-1)} /2. LON(day+1) is the longitude the feature as at the day before and LON(day-1) is where the feature was a day after. Subtracting these two numbers and dividing by 2 gives the speed of the feature, C, in the units of degrees of longitude per day. Looking at the change in longitude of the features in the 500 mb flow, we see that they move from west to east in the Northern Hemisphere as well as in the Southern Hemisphere. The average wave speed in the Northern Hemisphere is 2.75 deg./day. In the Southern Hemisphere the average wave speed is 13.17 deg./day. The waves appear to move faster in the Southern Hemisphere than the Northern Hemisphere; this makes sense since there is less friction due to the lack of land.

Also, the fastest wave speed in the Northern Hemisphere we observed was actually a retrograde motion of 25 deg./day, but the fastest West-East movement was 15 deg./day. In the Southern Hemisphere we saw 29 deg./day in west to east motion. Assuming a feature remained intact moving around the 50 N circle, using the averaging of the wave speed, we find that it would take a wave 130.9 days to complete one circuit of the 50 N line. This value is seems too high, in our data we observed a lot of retrograde motion in general which would slow down how fast the waves should travel. For the Southern Hemisphere, it was much faster at 27.4 days at 50 S.

B) Is there a relationship between zonal wind speed and wave propagation?

To do this, we looked at the graph with the zonal wind speed plotted against wave speed. The zonal wind speed is normally in meters per second, but it was converted to deg./day so we could compare it directly to the wave speed. In Figure 1 below, we see the graph for these two characteristics of the flow for the Northern Hemisphere.

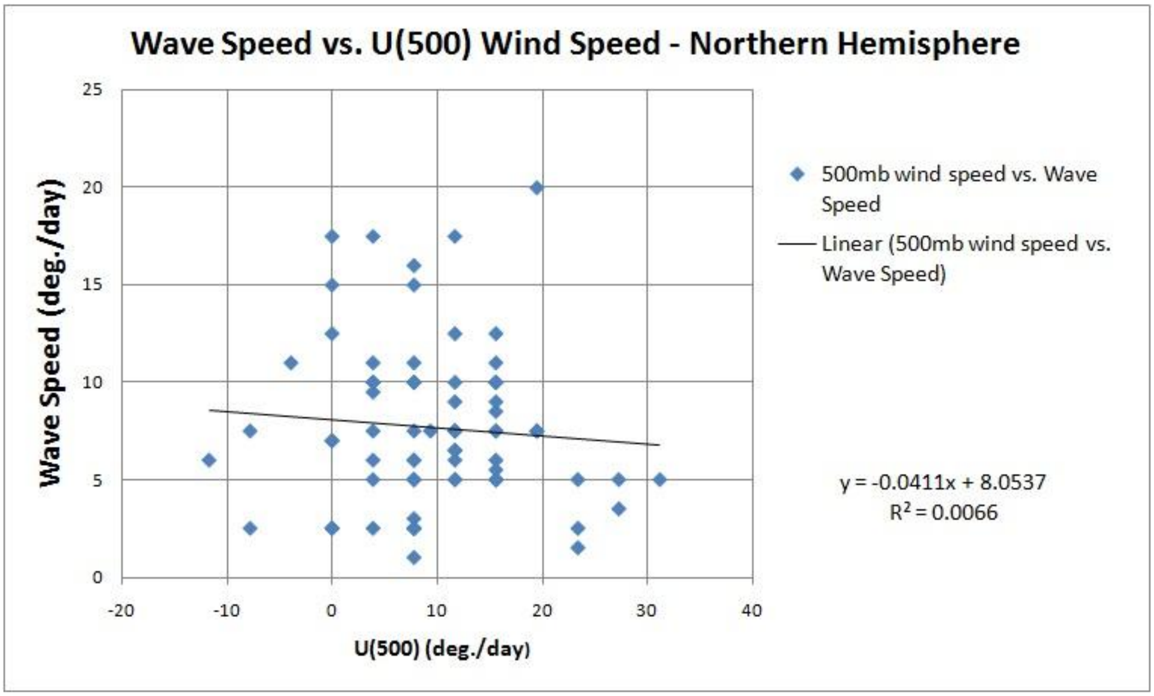

Figure 1

Looking at the data on the graph, it shows that there is a decrease in wave speed as the zonal momentum increases. The trend is slight but none the less negative. This disagrees with Rossby wave theory because phase speed is supposed to increase with U(500) as seen in the equation $c = u_{ave} + \beta/K^2$.

Naturally we compiled a graph of the same data for the Southern Hemisphere. In Figure #, we see the same thing, a negative trend. Although, it is not as negative as the trend is in the Northern Hemisphere. Both sets of data for each hemisphere the R^2 value was quite close to zero telling us that the two do not relate well to one another. Since they are not statistically significant, we believe the observation data relationship to Rossby wave theory very poor in this area.

The overall average of the zonal wind speed, U(500), was 15.1 deg./day in the Northern Hemisphere and 27.3 m/s in the Southern Hemisphere. This was faster than the average wave speed we observed and mentioned earlier. This agrees with Rossby theory because the air in the waves moves faster than the waves; similar to how short waves move faster than long waves.

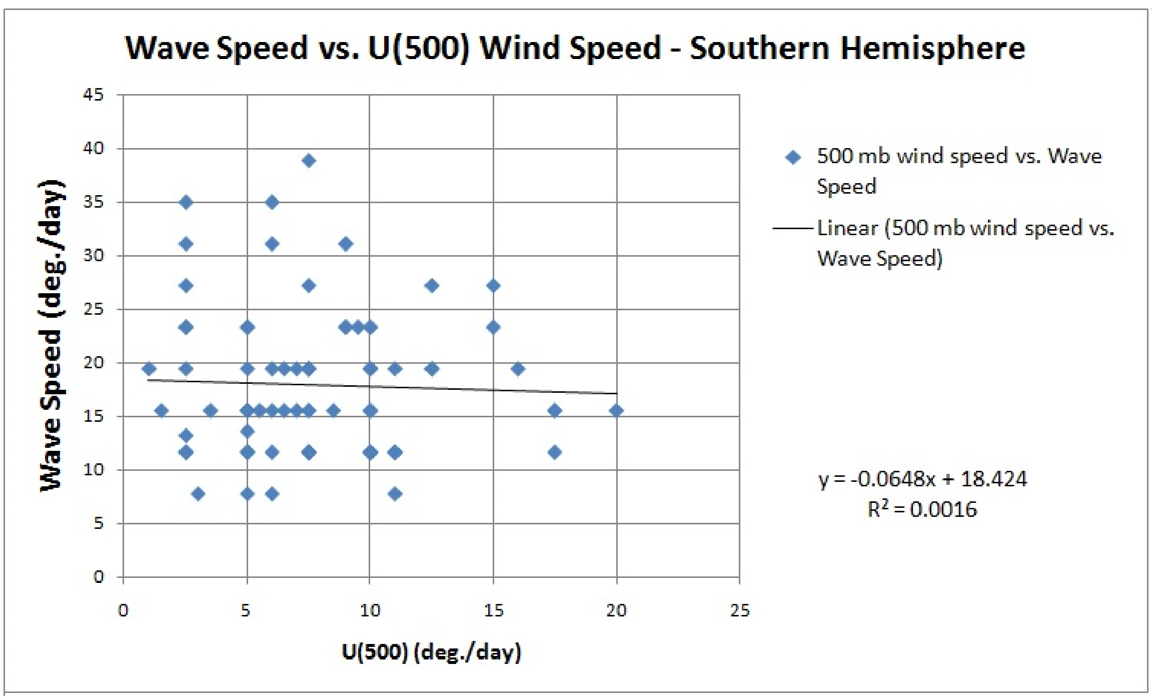

Figure 2

We also wanted to see if there was a relationship between wave speed and the speed of the air in the upper atmosphere. Here we have wave speed plotted against upper air speed for both hemispheres. Looking at the figure below for the North Hemisphere first, there does not appear to be a relationship between the two speeds in this part of the world from our data. There is a higher correlation between the two for the Southern Hemisphere though. Here, the R^2 value is much higher and there looks to be a greater dependence of upper air speeds.

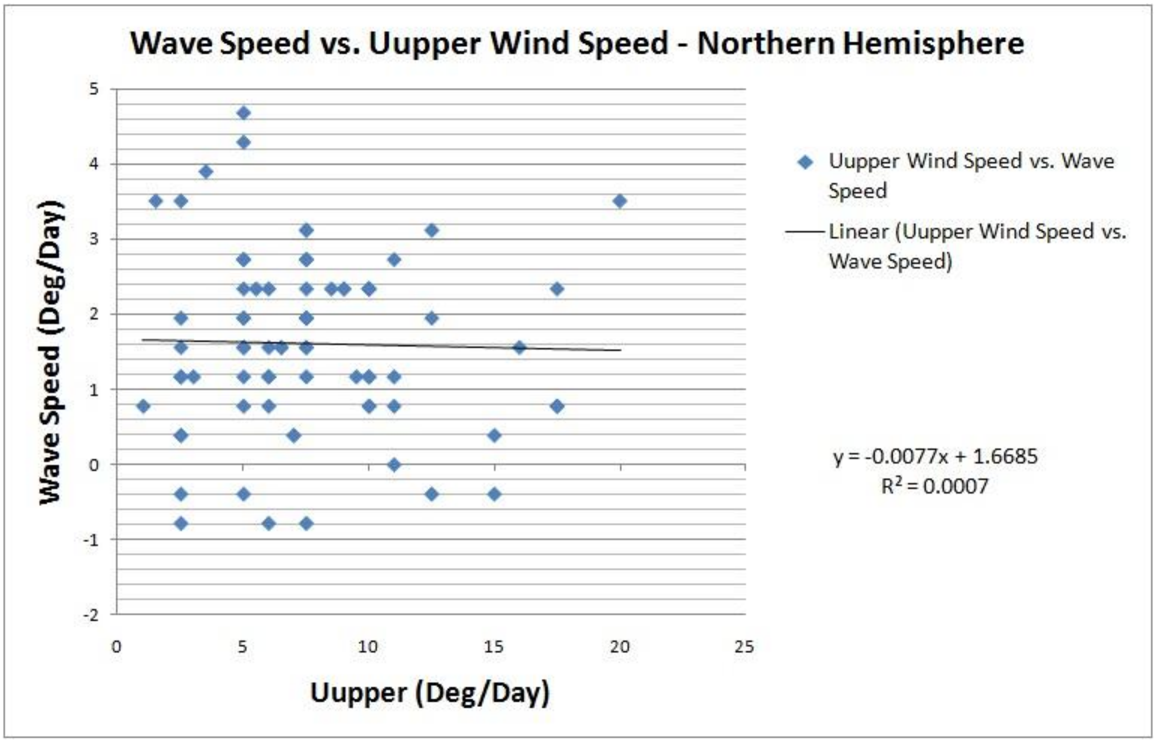

Figure 3

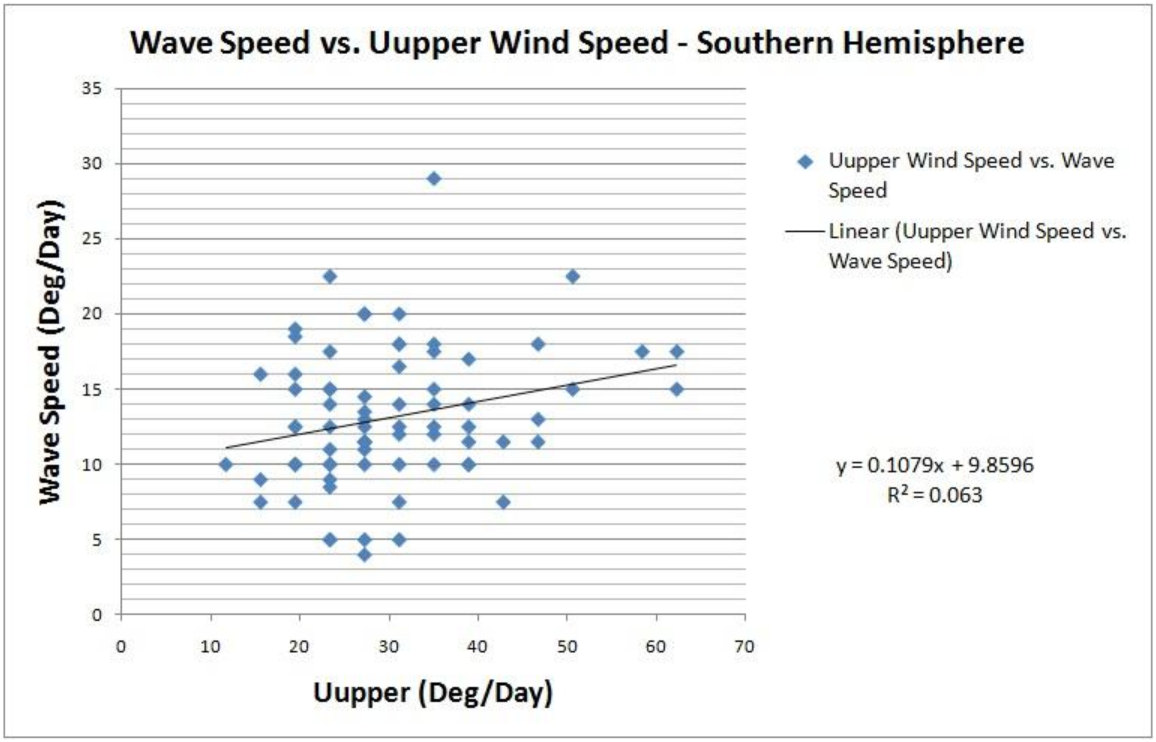

Figure 4

Rossby tells us that wave speed depends on wave number. Plotting wave speed without the affect of the U(500) wind vs. wave number will show us how they related in our data. In the figure below we see this graph. When the wave increases, we see a small increase in the wave speed for the Northern Hemisphere. The same is observed in the Southern Hemisphere except it is a little more positive. This agrees with was Rossby theory tells us. Rossby wave theory says that there should be an increase in wave speed with wave number. This is because in our phase speed equation, horizontal wave number is in the denominator of the second term, thus if it increases then that term is smaller which subtracts less from the u_{ave} giving a high phase speed.

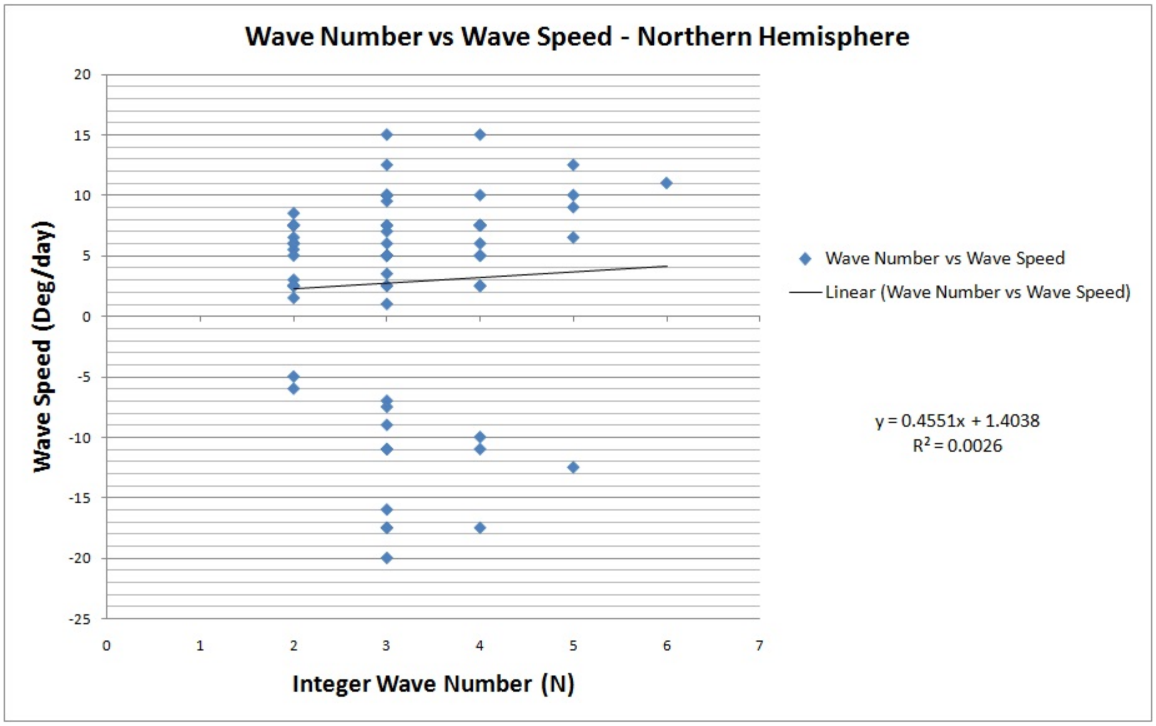

Figure 5

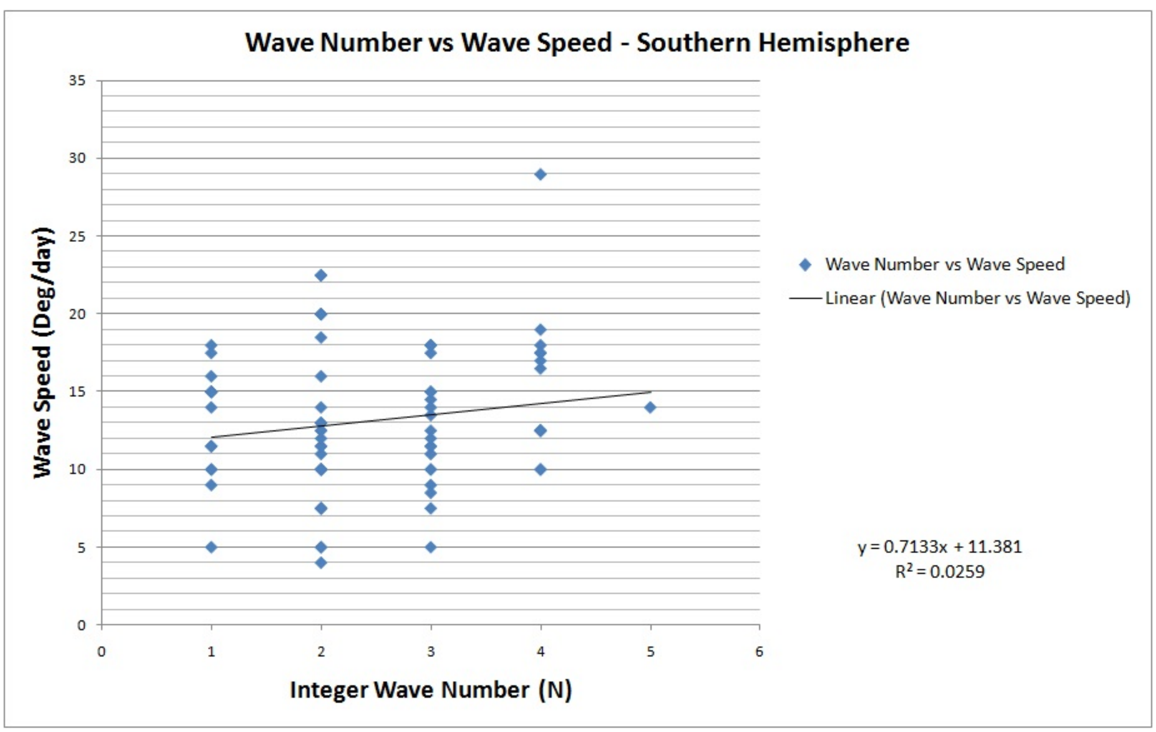

Figure 6

C) <u>How rapidly do waves increase or decrease in amplitude?</u>

Next we will look to see how amplitude is changing in time by graphing amplitude vs. time.

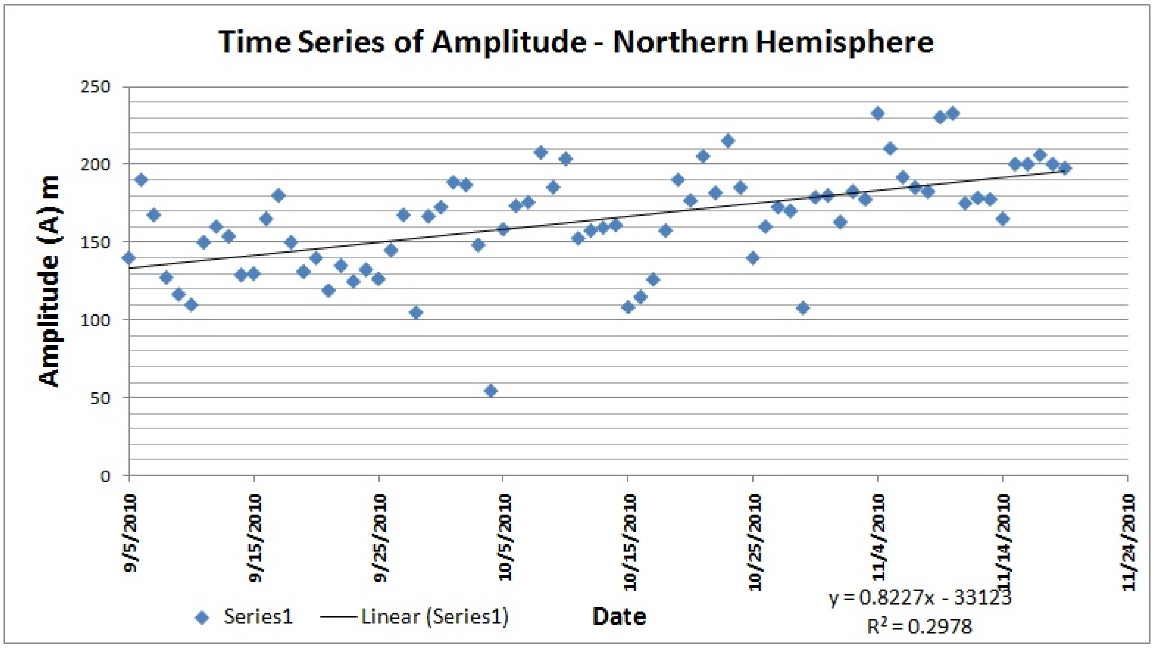

Figure 7

It would appear than there is a relationship between amplitude and time. There are a few periods where the amplitude increases for a few days and then decreases. For the Northern Hemispheres there are only about three time periods that show an increase in amplitude. On 9/28/10 – 10/2/10 the amplitude starts at 105 m and ends at 186.7 m, an increase of 78%. The period from 10/4/10 – 10/8/10 also sees growth in amplitude, increasing from 55 m to 207.5 m. This is an increase of 377%; this seems like a significant amount of growth. Shortly afterwards on 10/15/10 the amplitude is 105 and increases till 190 on 10/19/10. This is an increase of 81%.

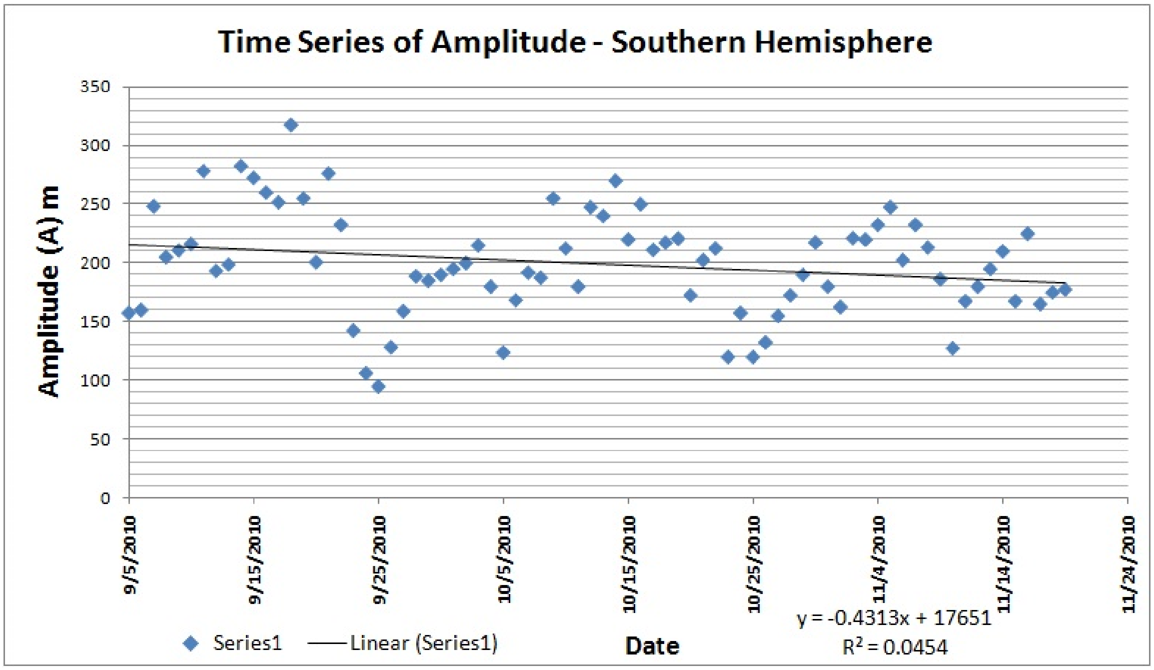

Figure 8

For the Southern Hemisphere there appear to be four periods of growth. But, in this graph there is a negative trend, opposite of what we observed in the Northern Hemisphere. It appears there are bigger decreases in amplitude here as well. The period from 9/25/10 – 10/3/10 has the amplitude increase over eight days; it begins at 95 m on the 25th and ends up at 215 m on the 3rd, which is a 126% increase. Two days after this increase, there is another increase interval from 10/5/10 – 10/10/10, a change from 123.75 m to 212.5 m, a 71.7 % increase. From 10/25/10 – 10/31/10 there is an 81 % increase with values from 120 m to 217.5 m. From 11/10/10 - 11/14/10, the amplitude changes from 127.5 to 210, this is an increase of 65%.

D) How Long Does One Identifiable Pattern Last?

From the period beginning September 5th, 2010 to November 19th, 2010 the Northern Hemisphere experienced a very weak increase in integral wave number. When analyzing the best fit line in Figure 9 it appears there was almost no change in the wave number over the study period. When analyzing the same data for the Southern Hemisphere, we can see in Figure 10 the best fit line does show a decreasing trend in integer waver number. Over the examined time period (seventy-five days) there was a decrease of about 1 integer wavelength.

When considering persistent periods where the dominant wave number remains the same or shifts only by +/- 1, we noted there are identifiable patterns for integer wave number. In the Northern Hemisphere these persistent wave number patterns lasting longer than three days include the following: 9/5/2010 to 9/23/2010 wave number 2-3 pattern, 10/1/2010 to 10/13/2010 wave number 3-4 pattern, 10/15/2010 to 10/22/2010 wave number 3-4 pattern, 10/23/2010 to10/27/2010 wave number 2-3 pattern, 10/28/2010 to 11/3/2010 wave number 4-5 pattern, and 11/4/2010 to 11/19/2010 wave number 2-3 pattern. These 6 identifiable patterns yield a mean duration of around 11.3 days which may be slightly longer than the time scale of synoptic scale weather patterns. This slower persistent wave number pattern could perhaps explain the relatively warm and dry fall experienced over much of the Midwestern United States with the lack of changing weather patterns during this time.

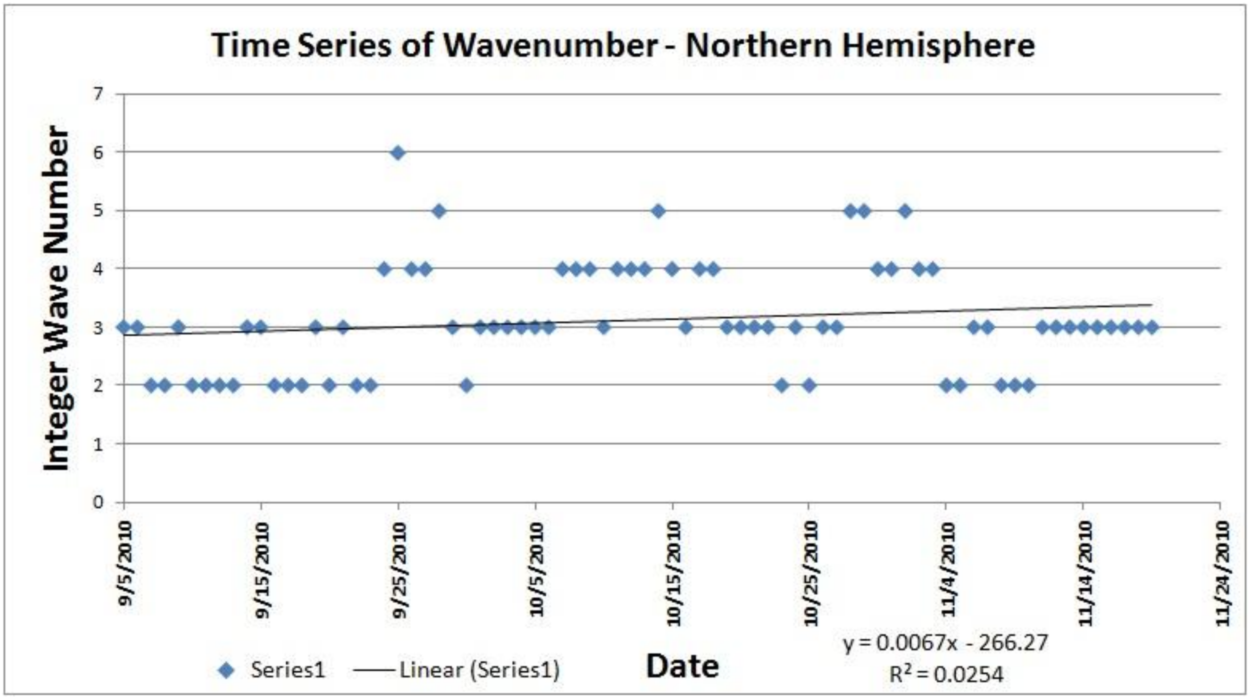

Figure 9

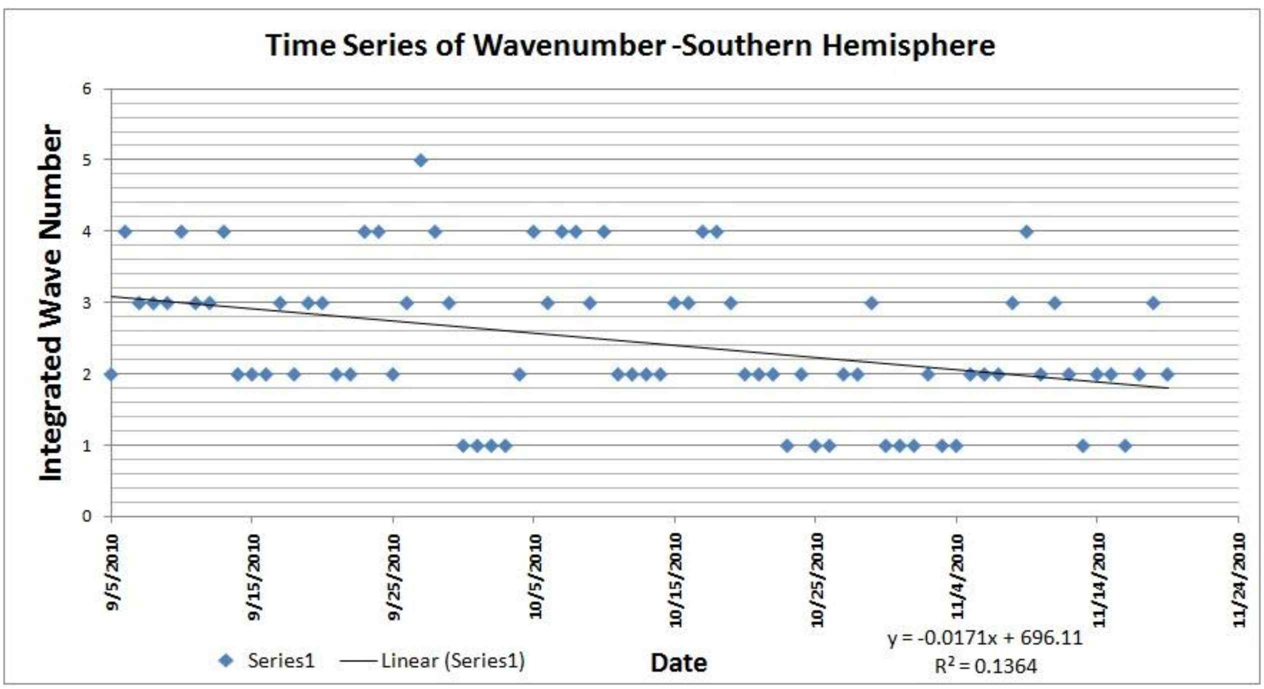

Figure 10

Looking for the same persistent wave number patterns in the Southern Hemisphere, there are some notable differences. The persistent wave number patterns lasting longer than three days include the following: 9/6/2010 to 9/13/2010 wave number 3-4 pattern, 9/14/2010 to 9/22/2010 wave number 2-3 pattern, 9/30/2010 to 10/4/2010 wave number 1-2 pattern, 10/5/2010 to 10/10/2010 wave number 3-4 pattern, 10/11/2010 to 10/16/2010 wave number 2-3 pattern, 10/18/2010 to 10/22/2010 wave number 2-3 pattern, 10/23/2010 to 10/28/2010 wave number 1-2 pattern, 10/30/2010 to 11/7/2010 wave number 1-2 pattern, and 11/12/2010 to 11/17/2010 wave number 1-2 pattern. These 9 identifiable patterns yield a mean duration of around 6.5 days which is similar to what we would expect for synoptic scale weather patterns.

Next when examining the amplitude versus wave number graphs for each hemisphere we notice a considerable finding from this project. Figure 11 shows some evidence (R-Squared value of 0.0419) that longer waves have larger amplitudes in the Northern Hemisphere. This also appears to be the case in the southern Hemisphere (Figure 12), but this graph also has a very small R-Squared value of 0.0033. This finding should make sense considering the fact that the atmosphere does not allow short waves to have larger amplitudes than that of longer waves. The primarily westerly flow in the atmosphere from the earth's rotation and global dynamics have little effect on the smaller scale short waves compared to longer waves on the larger scale.

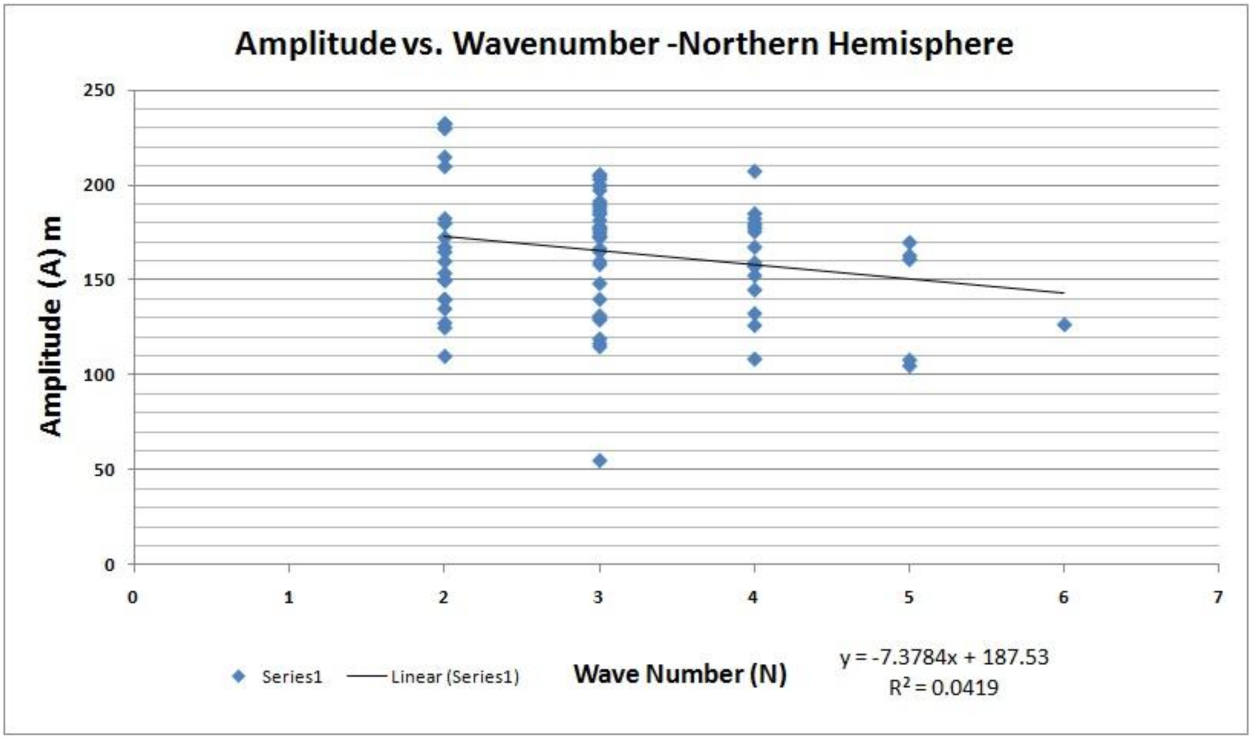

Figure 11

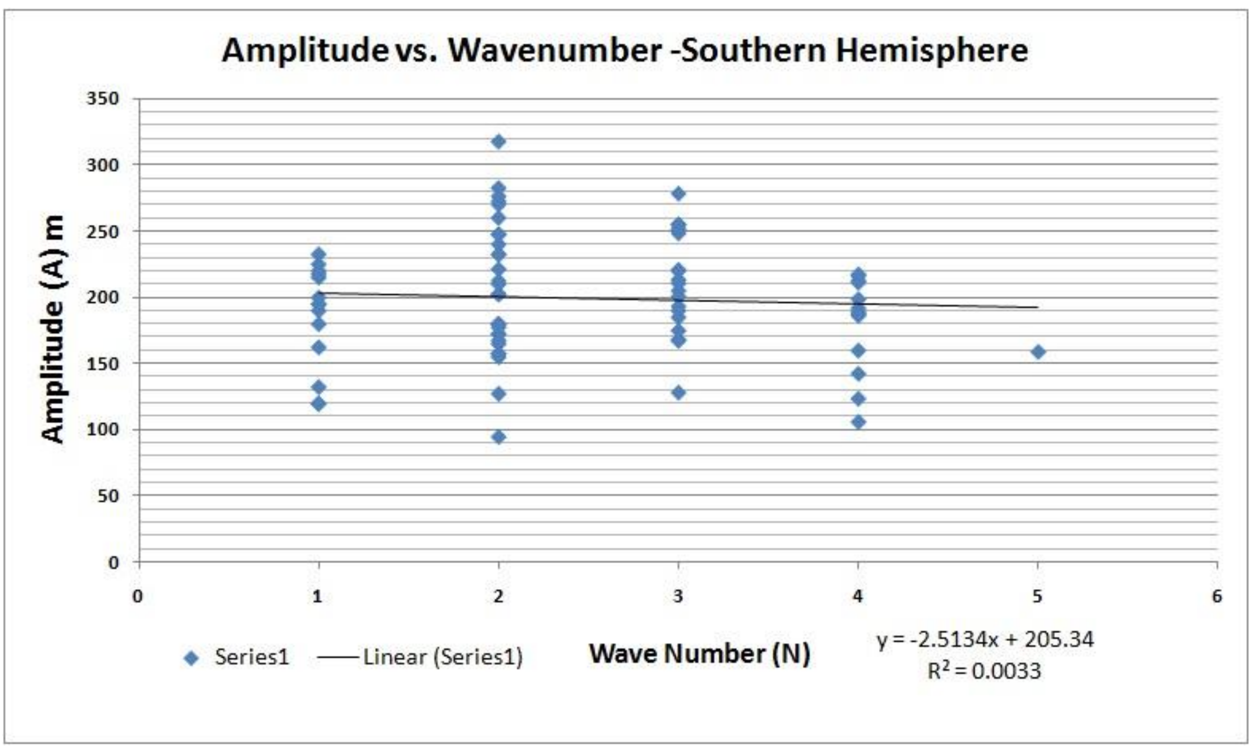

Figure 12

E) How does zonal wind evolve through the period?

Maximum zonal wind speeds were recorded for the 500 hPa layer as well as the maximum between the layer from 150 hPa to 300 hPa in both the Northern and Southern Hemisphere. The Northern Hemisphere experienced an average maximum zonal wind speed of 12.53 meters per second at 500 hPa and 20.59 meters per second between 150 hPa and 300 hPa during the study period. In the Southern Hemisphere the average maximum zonal wind speed at 500 hPa was 22.63 meters per second and 38.82 meters per second between 150 hPa and 300 hPa. Looking at these values, we can see the winds in the Southern Hemisphere are larger than the Northern Hemisphere probably due to the less land cover in the Southern Hemisphere. More land cover in the Northern Hemisphere causes friction to weaken wind speeds. It is also interesting to note there are multiple days in the Northern Hemisphere were the zonal wind is negative (easterly) at 500 hPa and/or the 150 hPa to 300 hPa layer. This is not observed in the Southern Hemisphere during the studied time period.

Figures 13 and 14 show zonal wind speeds at 500 hPa for both the Northern Hemisphere and Southern Hemisphere respectively. Both graphs also have a linear best fit trend line of the zonal wind changes over time. As we can see from Figure 13 zonal wind speeds at 500 hPa increased approximately 10 meters per second over the course of the seventy-five day study period. Wind speeds have decreased slightly in the Southern Hemisphere over the same study period. These changes are probably due to the fact that the Northern Hemisphere is shifting from summer to winter over this time period, and the Southern Hemisphere is changing from winter to summer.

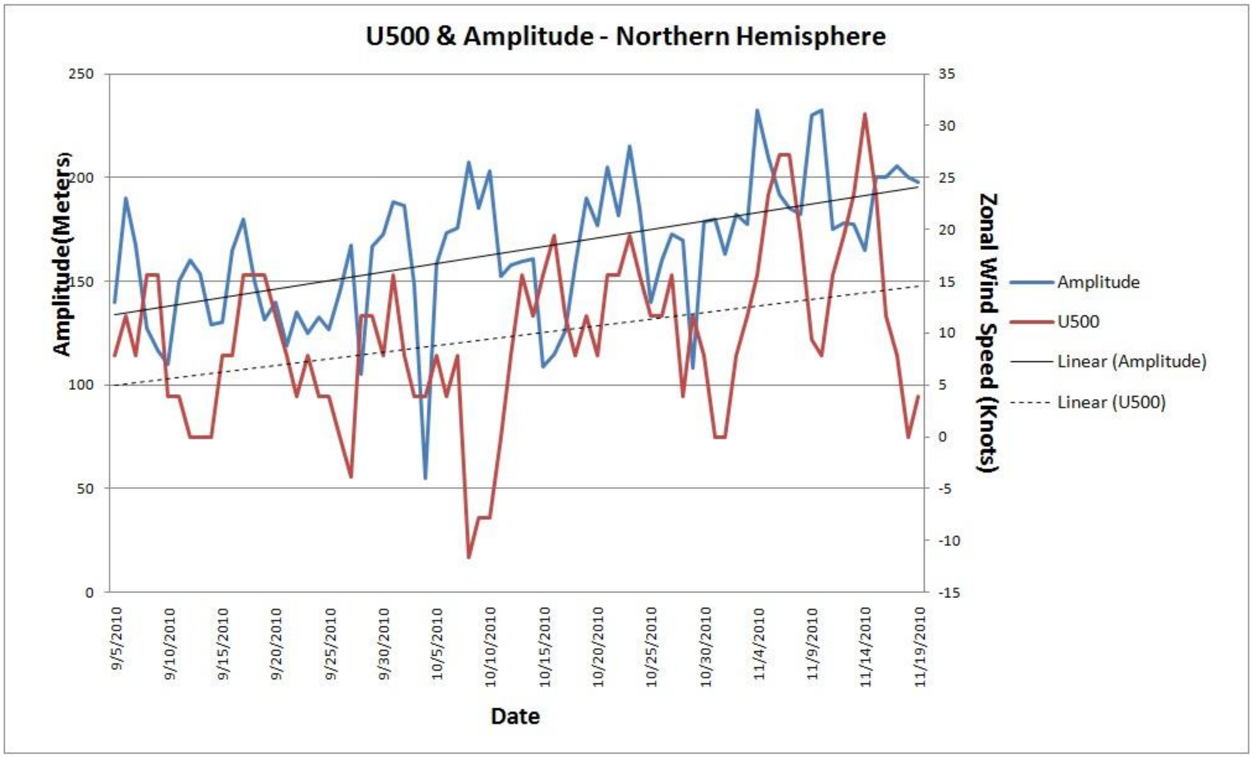

Figure 13

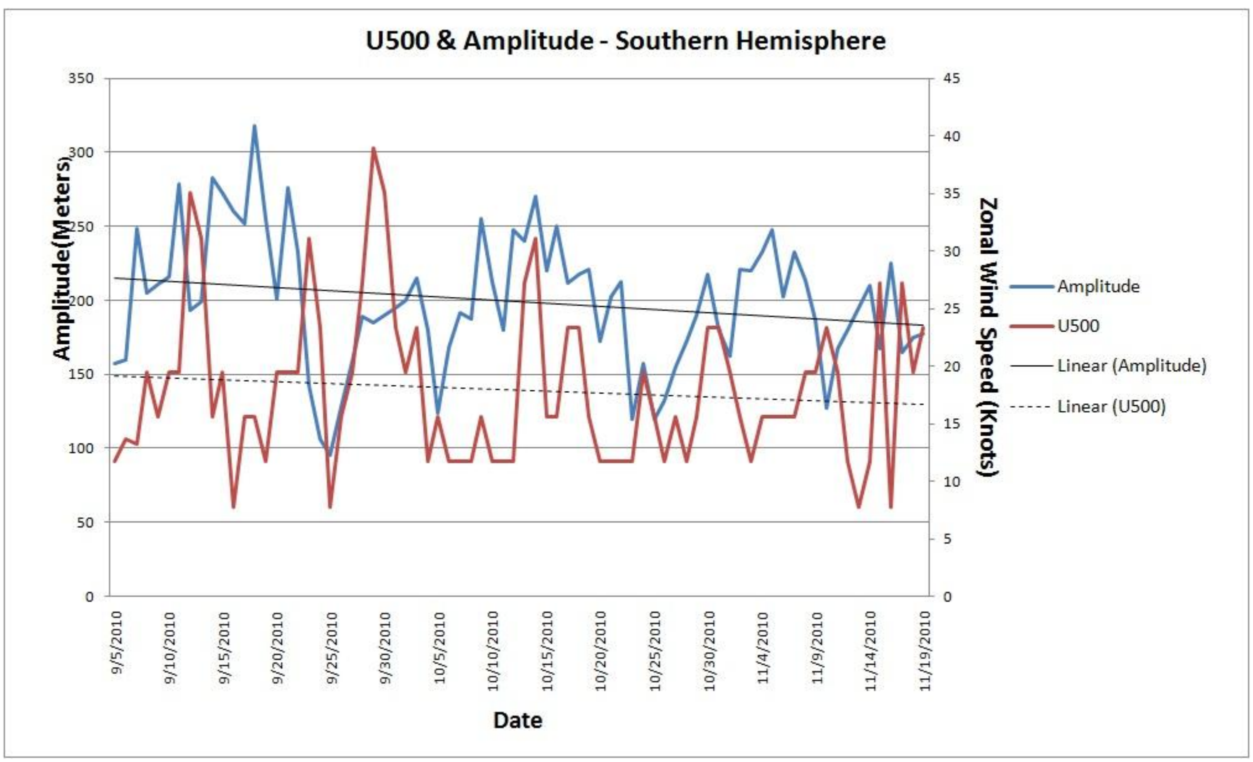

Figure 14

F) Is there a relationship between zonal wind speed and wave growth/decay?

Figures 13 and 14 also show the relationship between the zonal wind speed and amplitude during the study period for both the Northern and Southern Hemispheres respectively. By simply glancing at these two graphs we can generally deduce that during most periods with increasing amplitude occur at approximately the same time as 500 hPa zonal winds increase (same relationship for decreasing trends). There are some instances where this relationship is not followed however. Overall linear trend lines for both the 500 hPa zonal wind and amplitude correlate well with each for both hemispheres. In the Northern Hemisphere 500 hPa zonal wind speeds increase as amplitude also increases over the seventy-five days, while in the Southern Hemisphere 500 hPa zonal wind speeds decrease slightly as do amplitude values.

4. Conclusion

The group observed the 500 hPa height field as well as the global zonal wind average in the Northern and Southern Hemisphere from September 5, 2010 through November 19, 2010. Based on the results we obtained, the group found evidence that both supports and declines Rossby's Wave Theory in the Atmosphere. Perhaps reasoning for the theory not being completely supported in this study was due to lack of statistical significance with the data collected. Another source of error could be because of only focusing on the 50 degree latitude line which was not a total survey of the atmosphere as a whole. A better analysis could be done if a longer monitoring period took place rather than just seventy-five days.