Tracking of Large-Scale Atmospheric Waves in Comparison to Rossby Wave Theory

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Abstract

The Rossby wave theory claims smaller wavenumbers are associated with decreased amplitude and increased wave speed. This report examines the zonal winds, wavenumbers, amplitudes, and wave speeds in the northern and southern hemispheres from September 19th through November 19th to determine whether it agrees or disagrees with the Rossby wave theory. Results show that Rossby wave theory is confirmed in some cases but not all, potentially due to error and assumptions.

1. Introduction

Atmospheric waves play a role in our weather every day since they are a driving force for much of the weather that affects us. The evolution of wavelength (wavenumber), amplitude, motion, and zonal wind speeds were observed from the Iowa State Meteorological Weather Products website (http://www.meteor.iastate.edu/wx/data/) over the time period of September 19th – November 19th. The analysis of these parameters are used to explain how rapidly wave patterns move, how long a pattern lasts, how rapidly waves change in amplitude, how zonal wind evolves through the period, whether there is a relationship between zonal wind speed and wave propagation, and whether there is a relationship between zonal wind speed and wave growth/decay. These results will then be compared to various facets of Rossby Wave Theory to determine the real world accuracy of the theory.

2. Data and Methodology

The data for this report was taken from animations located at the Iowa State Weather Products page, which contains continually updated, real-time weather products. Products viewed included the northern hemisphere 500 hPa heights, southern hemisphere 500 hPa heights, and global zonal average zonal winds. The following parameters were recorded every day for each hemisphere from September 19th through November 19th:

a) Wavenumber (N)

In the northern hemisphere, the wavenumber was recorded by counting the number of times the 5580m contour <u>crossed</u> the 50° N latitude, and then divide that number by two. This resulted in a whole number as the wavenumber. In the southern hemisphere, the wavenumber was recorded by counting the number of times the 5280m contour <u>crossed</u> the 50° S latitude, divided by two.

b) Amplitude (A)

The amplitude was estimated by the maximum and minimum wave heights around each hemisphere. For each wave, the maximum and minimum height around the 50° N were recorded, and averaged respectively. Once averaged, the average minimum height was subtracted by the average maximum height, and divided by two. This value gave the amplitude in units of meters. The same procedure was done for the southern hemisphere, using the waves around 50° S for a given day.

$$A = (Zmax - Zmin)/2$$

$$A = (AveMaxima - AveMinima)/2$$

c) Wave speed (C)

Wave speed, or motion, was estimated by tracking the movement of a wave. This was done by recording the longitude of a target contour one day prior and one day after the date being recorded. The longitude of the day prior was then subtracted from the longitude of the day after, and divided by two. This value gave the wave speed in unites of degrees/day. This was done in both hemispheres.

$$C = \{LON(day+1) - LON(day-1)\} /2$$

d) Zonal winds

The zonal wind plot is read with the South Pole beginning on the left axis, and the North Pole beginning on the right axis, with the equator in the middle, and the pressure decreasing from bottom to top. Zonal wind parameters are taken at 50° latitude in both hemispheres. The (U500) parameter was found by recording the maximum zonal wind speed at 500 hPa over 50° for each hemisphere. The (Uupper) parameter was found by recorded the maximum zonal wind speed between 300 hPa and 150 hPa over 50° for each hemisphere. (Fig 1)

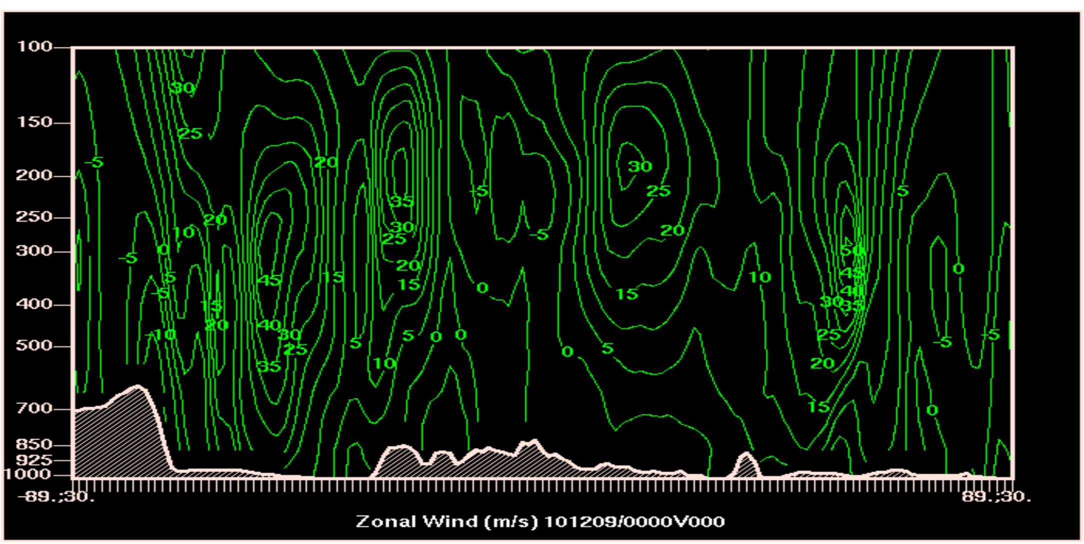

Figure 1. Zonal Wind Plot

3. How Rapidly Waves Move

In the Northern Hemisphere, waves move around the globe at an average speed of 7.83 degrees per day. The maximum speed that a wave moved around the globe in the north was 15 degrees per day while the minimum was 2.5 degrees per day. In the Southern Hemisphere, the waves moved faster than in the north. This is due to more land mass in the northern hemisphere which causes more friction. This slows the waves down in the north and allows the waves in the south to move more freely. The Southern Hemisphere saw waves moving at an average speed of 11.92 degrees per day. There was a maximum of 35 degrees per day and a minimum of 5 degrees per day.

4. Relationship Between Zonal Wind Speed and Wave Propagation

Waves move toward the east in both hemispheres. In the northern hemisphere, waves rotate counter clockwise around the North Pole; in the southern hemisphere, waves move clockwise around the South Pole. Travel is faster in the southern hemisphere because it has less land mass. This is lessens the friction and allows the waves to move faster. The northern hemisphere has more land mass which increases friction and slows the wave speed down. The average speed in the north was 7.83 degrees per day. In the southern hemisphere it was 11.92 degrees per day. In the northern hemisphere it takes around 45.6 days to circle the globe. In the southern hemisphere it takes around 29.9 days to circle the globe. This seems to agree with the fact of how rapidly waves move in each hemisphere.

By viewing the graph below, it seems that wave speed does not vary much with zonal wind speeds at 500 hPa. According to Rossby wave theory, as the zonal wind increases, the wave speed should increase as well. This is not the case in the graph below which is for the Northern

Hemisphere or Southern Hemisphere. It showed that as zonal wind increased, the wave speed decreased. This contradicts Rossby wave theory. The overall average of U(500 hPa) in the Northern hemisphere is 16.7 degrees per day. The average wave speed was 7.8 degrees per day. This is less than the U(500 hPa) and does not agree with Rossby wave theory. In the Southern Hemisphere, the average of U(500 hPa) was 31.1 degrees per day. This was greater than the average wave speed in the southern hemisphere which was 11.9 degrees per day. This reinforces that our data did not agree with Rossby wave theory. (Fig 2)

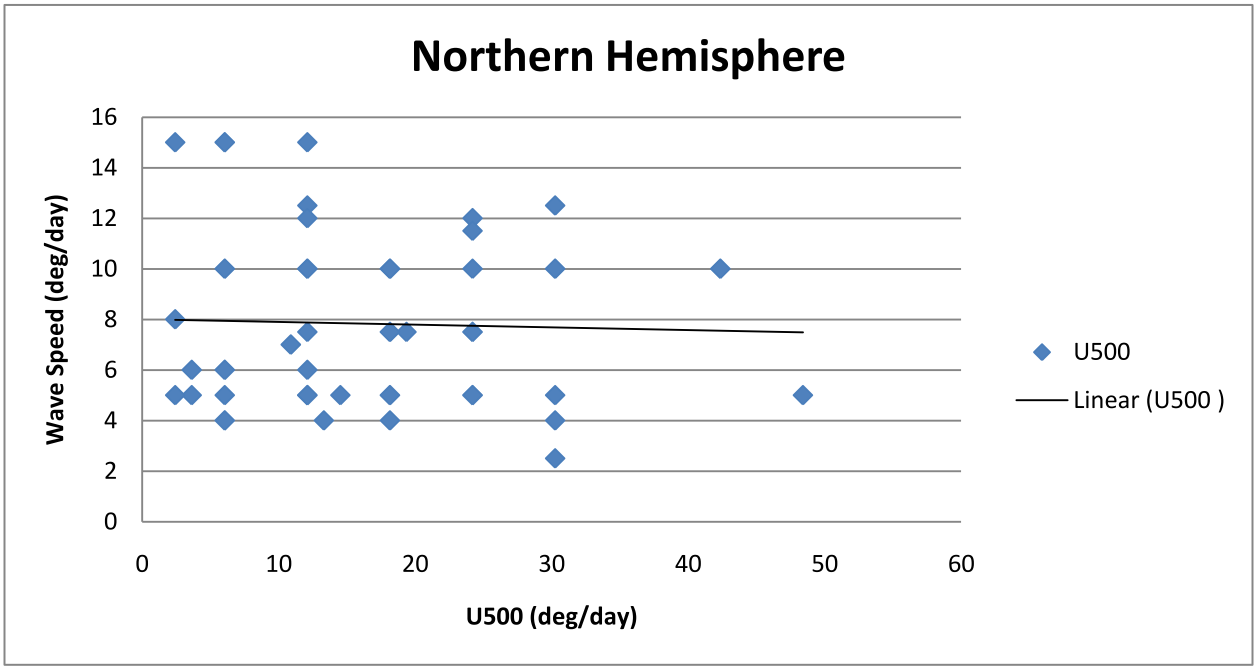

Figure 2

In regards to U upper wind speed, in the Northern Hemisphere, our data did agree with Rossby wave theory. As the zonal wind speed increased, the wave speed increased as well. In the southern hemisphere, our data did not agree with Rossby wave theory. In the Northern Hemisphere, our graph does show a dependence on upper air wind speed. A high upper zonal wind increases the wave speed. (Fig 3, 4)

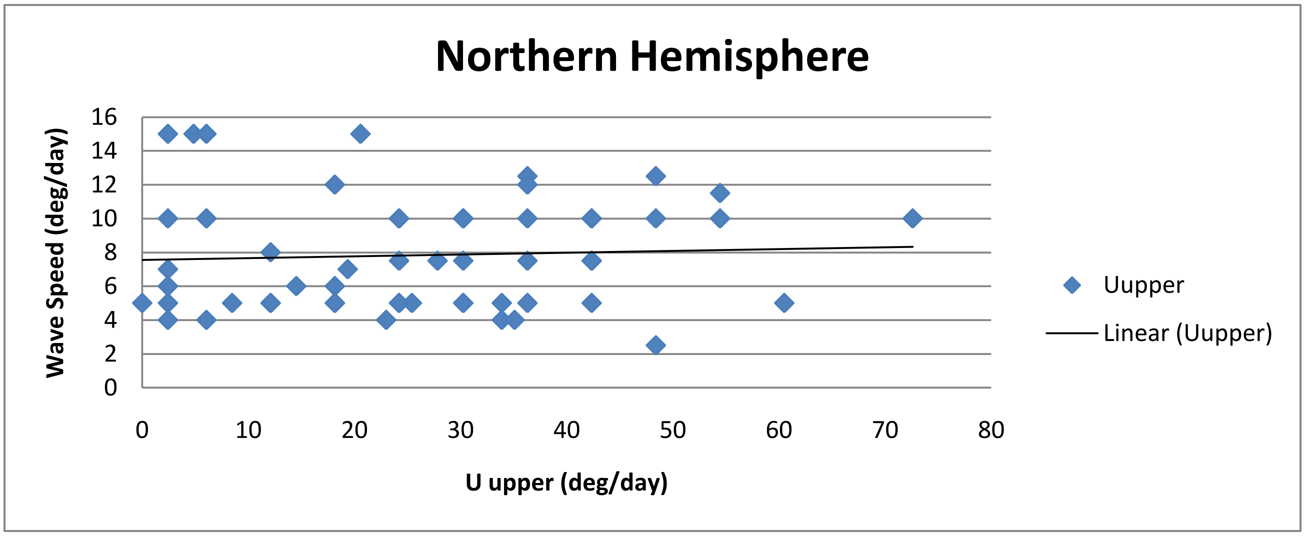

Figure 3

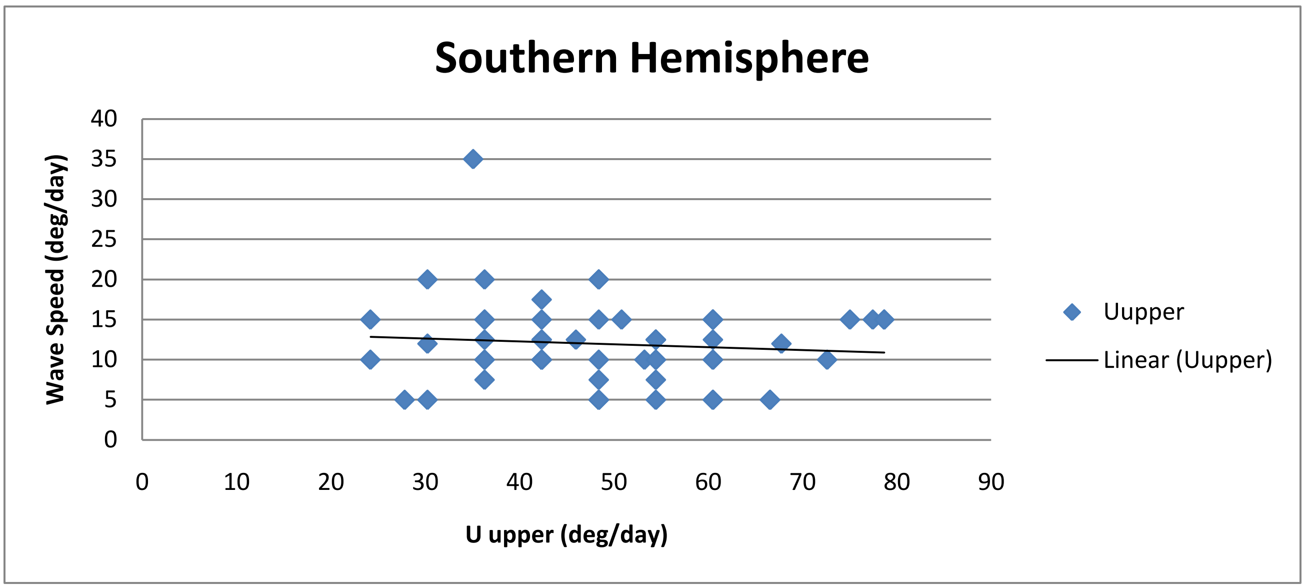

Figure 4

According to our data, as wave speed increases, the wave number also increases. This agrees with Rossby wave theory. Short waves travel faster than longwaves around the globe. A larger wavenumber indicates shorter waves moving around the globe. This means that the wave speed will increase as wavenumber increases since there are shorter waves. In the graphs below, we show that our data in both the northern and southern hemisphere agrees with the theory. (Fig 5, 6)

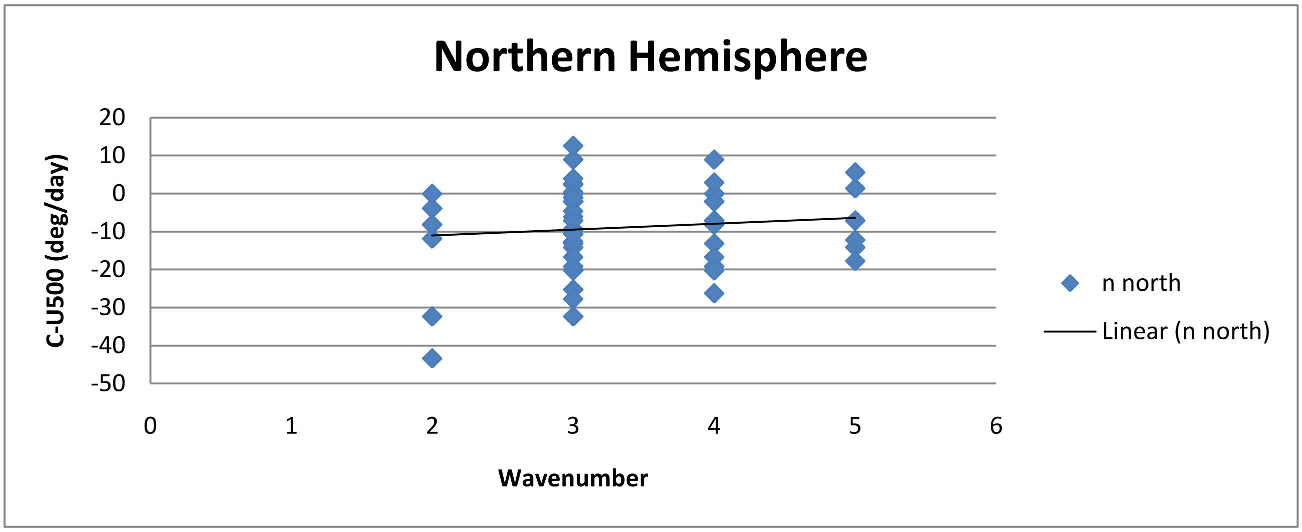

Figure 5

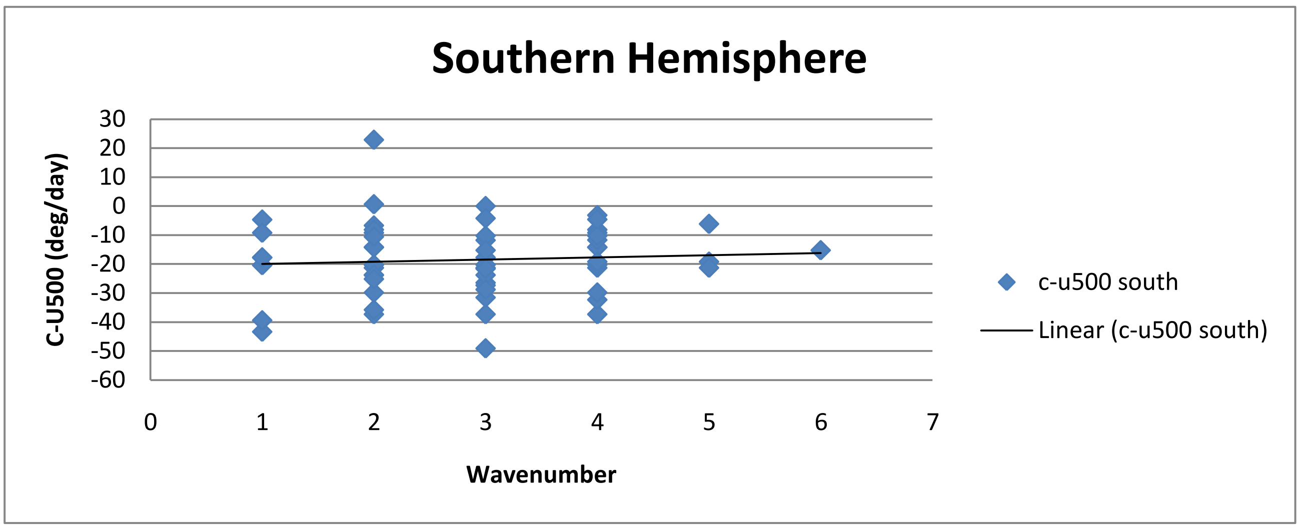

Figure 6

5. How Long One Identifiable Pattern Lasts

a. Wavenumber

The northern hemisphere wavenumber has no identifiable pattern the first week, September 19th – September 26th. There is a short period of less than a week following September 26th through September 30th where the wavenumber is a persistent wavenumber 5, but then it jumps back down to lower wavenumbers and is inconsistent for a several weeks until

October 5th. From October 9th – October 21st the wavenumber appears consistent, staying +1/- 1 integer wavenumber 4. The last week of October and first week of November have very inconsistent wavenumbers, similar to the middle of September. The time period finishes strong with a very consistent pattern from November 4th – November 18th of wavenumber 3.

The longest consistent wavenumber pattern in the northern hemisphere appears to be twelve days, as seen from October 9th – October 21st, and November 4th – November 18th. This pattern is much longer than the typical synoptic scale pattern which is roughly 3-5 days. (Fig 7)

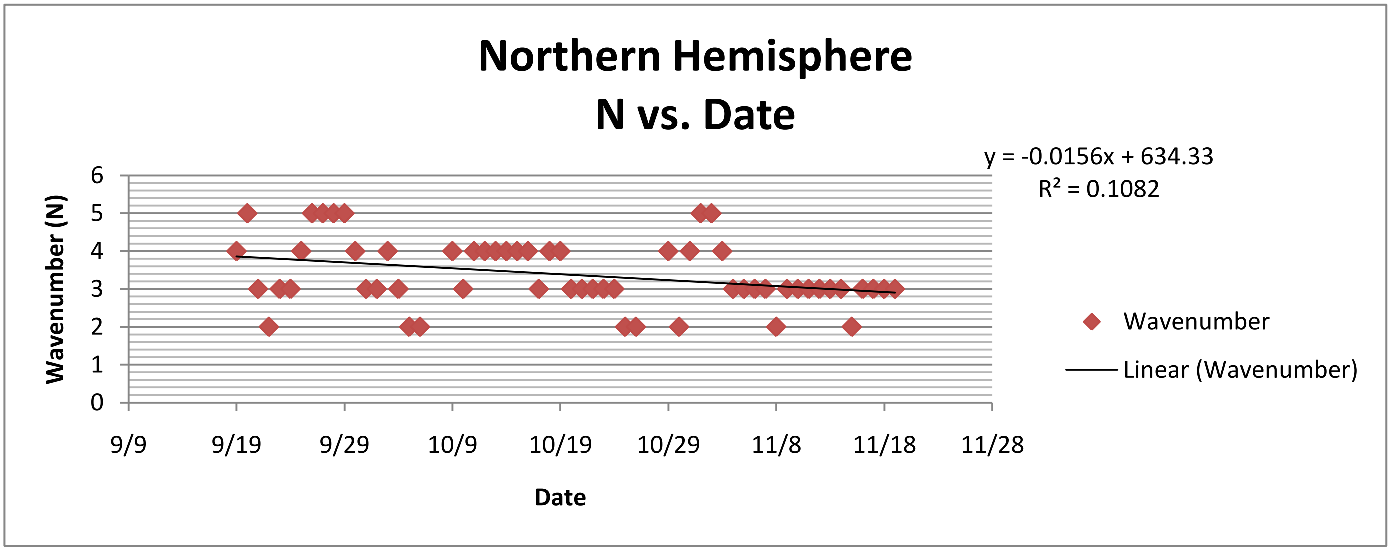

Figure 7

The first week of the period, the southern hemisphere has four consistent days at wavenumber 3. The following few days through September 26th, the wavenumbers are inconsistent from wavenumber 4 to wavenumber 6. The next week and a half are somewhat consistent, ranging between wavenumbers 2 and 4. From October 16th – October 19th, there is a pattern between wavenumber 3 and 4. Then there is a persistent pattern of wavenumber of 1 and 2from October 30th – November 6th. The wavenumber then jumps up to 3 and 4 and is persistent from November 8th – November 14th. The period finishes off quite inconsistent ranging between wavenumber 1, 2, and 3.

The longest consistent wavenumber pattern in the southern hemisphere appears to be 4-7 days, as seen by the October 30th – November 6th and November 8th – November 14th periods. This pattern is one to two days longer than the typical synoptic scale pattern. (Fig 8)

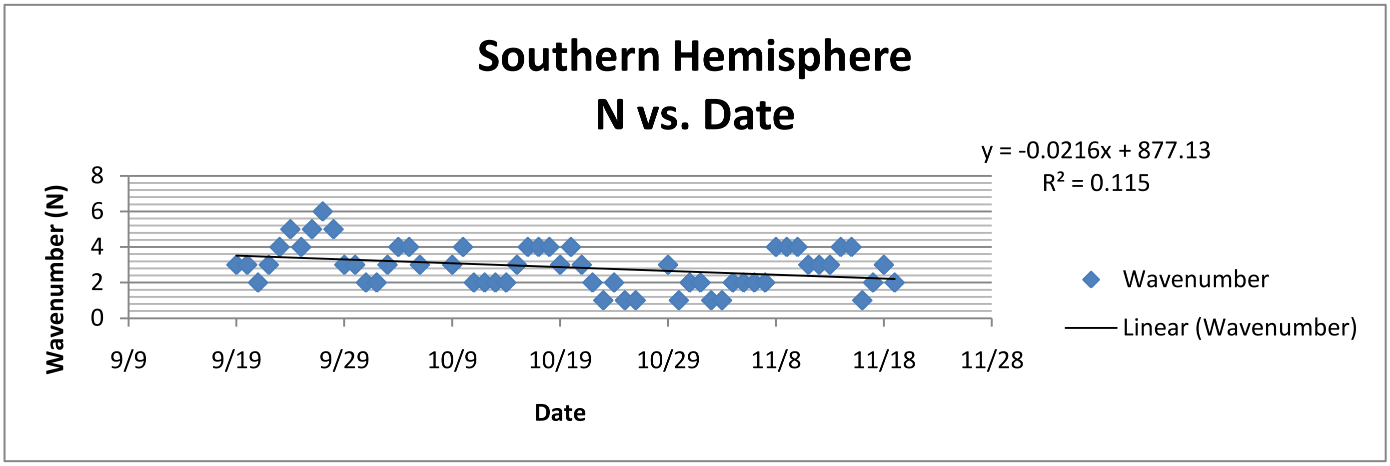

Figure 8

The southern hemisphere consistency seems much smaller than the northern hemisphere, with its longest wavenumber pattern being around one week as opposed to the northern hemisphere's two weeks. This may be due to the different seasons the two hemispheres are experiencing at the moment. This may also be due to the fact that the northern hemisphere has more land mass than the southern hemisphere, therefore there is more friction in the northern hemisphere than the southern hemisphere.

b. Amplitude

The northern hemisphere plot of amplitude versus wavenumber seems to be almost symmetrical. It is very difficult to identify either an increasing or decreasing trend in the northern hemisphere data. Wavenumbers 2 and 5 have the same high amplitude values, and wavenumbers 3 and 4 also have the same high amplitude values. Wavenumber 2 has the highest low amplitude value, implying the lower the wavenumber, the higher the amplitude. When a trend line is fit, there appears to be a negative slope, implying the higher the wavenumber, the lower the amplitude. (Fig 9)

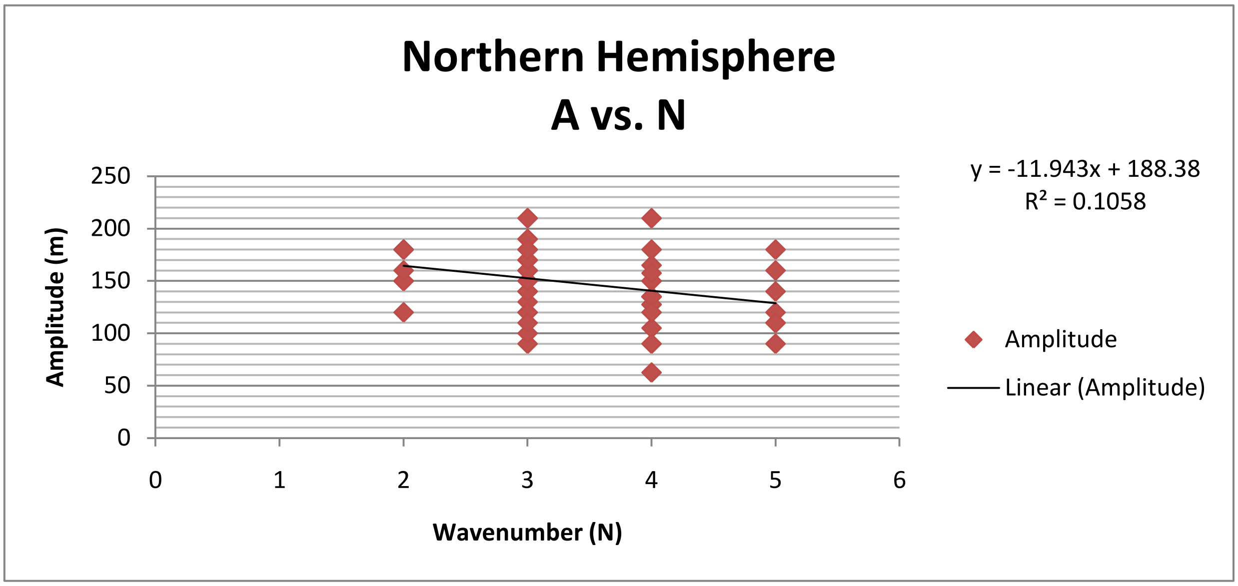

Figure 9

The southern hemisphere has a wider range of wavelengths, from wavelength 1 to wavelength 6. The amplitude versus wavenumber graph clearly shows a relationship between high wavenumbers and lower amplitudes. Wavenumber 1 has the highest amplitude; wavenumber 2 has the second highest, and so on down to wavenumber 6. The trend line fit for the southern hemisphere also shows a decreasing slope, which implies that higher wavenumber is congruent with smaller amplitude. (Fig 10)

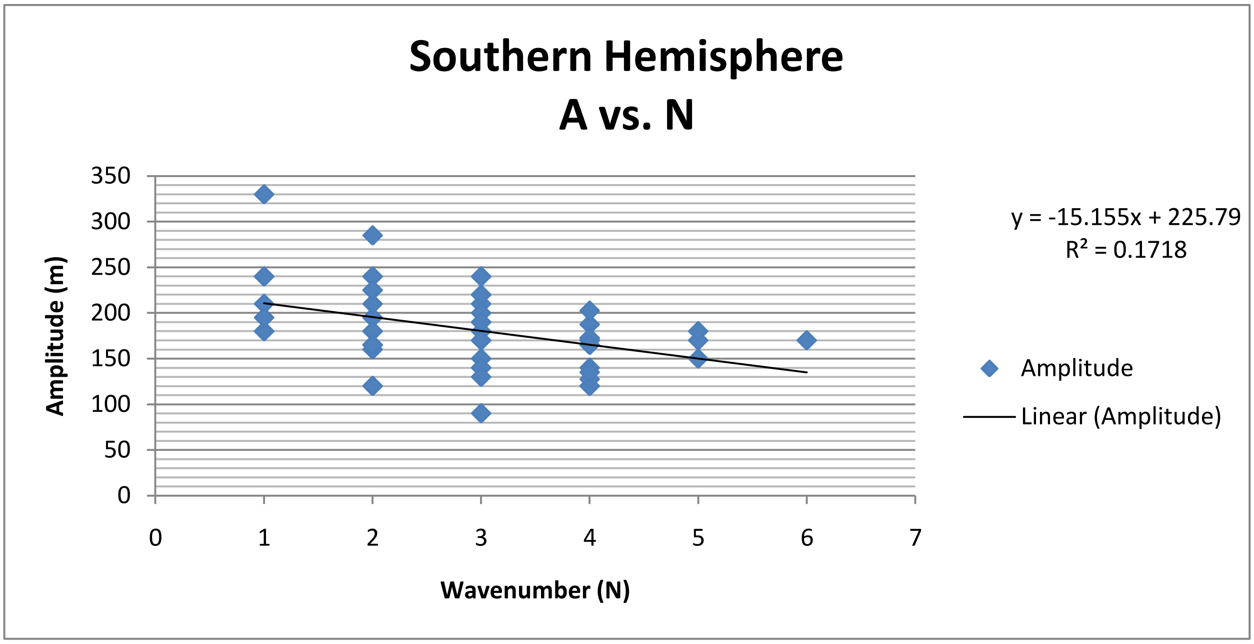

Figure 10

The graphs and analysis done show that both the northern and southern hemispheres oppose Rossby wave theory which states that decreased wavenumbers are congruent with decreased amplitude. Both hemispheres exhibited lower wavenumbers and higher amplitudes, opposite of what theory states.

6. How Rapidly Waves Increase or Decrease in Amplitude

The northern hemisphere shows no signs of an overall increase throughout the period of September 19th – November 18th. The amplitude fluctuates throughout the period; however there seems to be an increasing trend the first ten days, September 20th – September 30th, where the amplitude reaches a maximum of 210 meters. Following, there is a two week period through October 23rd, where the amplitude has no distinct increasing or decreasing trend. There is a large drop in the amplitude to 105 meters on October 29th, followed by a distinct increasing period from November 2nd – November 19th. The northern hemisphere amplitude exhibits a negative trend of -.089 over the September 19th – November 19th period. (Fig 11)

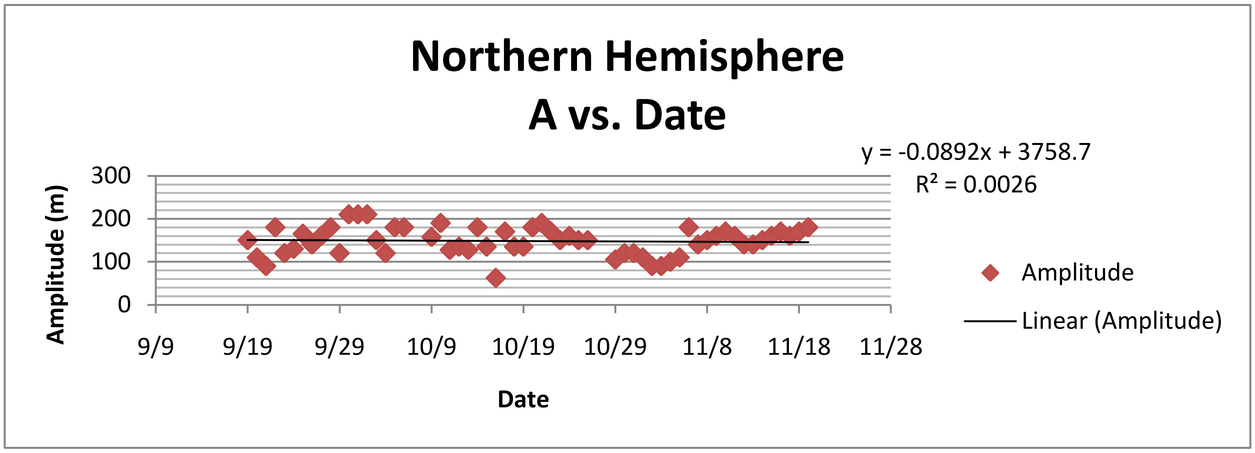

Figure 11

The southern hemisphere has a slight overall bell-shaped trend over the two month period. The amplitude begins high at 240 meters, and then quickly drops to 160 meters where it fluctuates slightly for two weeks until it begins to gradually rise reaching a peak of 285 meters on October 14th. From there, the amplitude drops and stays steady from October 15th – October 29th. The amplitude begins a gradual decline October 31st – November 13th after a maximum amplitude peak of 330 meters on October 30th. There is a distinct increasing period is from October 2nd – October 14th, and a distinct decreasing period is from October 30th – November 13th.The southern hemisphere amplitude exhibits a negative trend of -.0043 over the September 19th – November 19th period. (Fig 12)

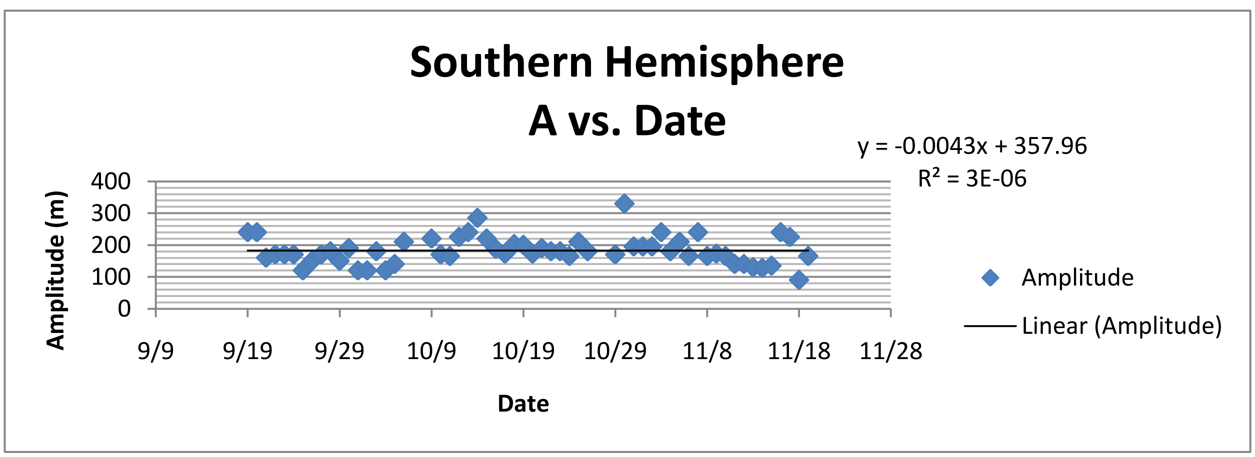

Figure 12

7. How the Zonal Wind Evolves through the period

Zonal winds at the latitude 50 both north and south were measured at 500 hPa using the maps on the ISU Meteorological Weather Products website. At the same latitude in both hemispheres the maximum zonal wind in the layer 300 hPa to 150 hPa were also recorded. The average of the zonal wind at 500 hPa was 11.57 m/s in the northern hemisphere and 25.71 m/s in the southern hemisphere. Then for the maximum in the 300 hPa to 150 hPa layer the average is 20.95 m/s in the northern hemisphere and 41.26 m/s in the southern hemisphere. This makes sense because the northern hemisphere has more land than the southern hemisphere and because of this it has more friction because land provides more friction than ocean does. This added friction makes a wind in the southern hemisphere faster than a wind in the northern hemisphere with the same conditions.

As seen in figure 13, 14, 15, and 16, the linear line of best fit for the zonal wind at 500 hPa and maximum zonal wind in the 300 hPa to 150 hPa layer for both hemispheres all have an obvious slope. The same trend is noticed in both the 500 hPa and 300 hPa to 150 hPa maximum for both hemispheres so the trend does not have to do with the level of the atmosphere. The trend is increasing zonal wind in the northern hemisphere and decreasing zonal wind in the southern hemisphere. This is due to the changing of seasons from summer to winter in the north and winter to summer in the south. The northern hemisphere should have a harder time making this change due to the friction discussed above but it does not. This is likely due to the outliers such as the last four data point which seems to go against the trend in both hemispheres.

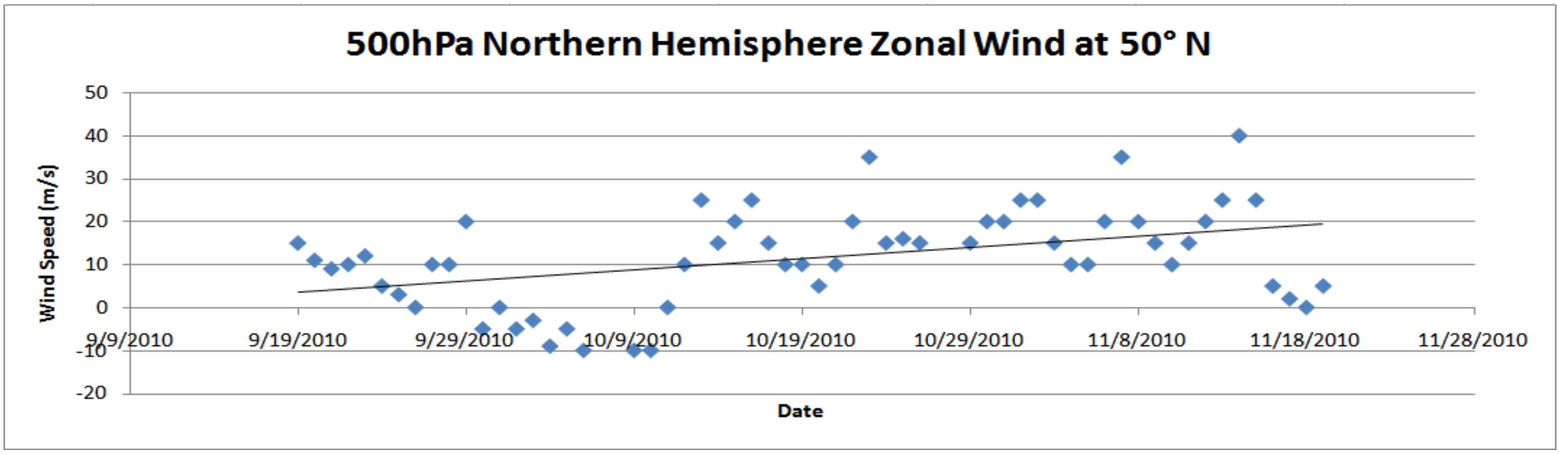

Figure 13

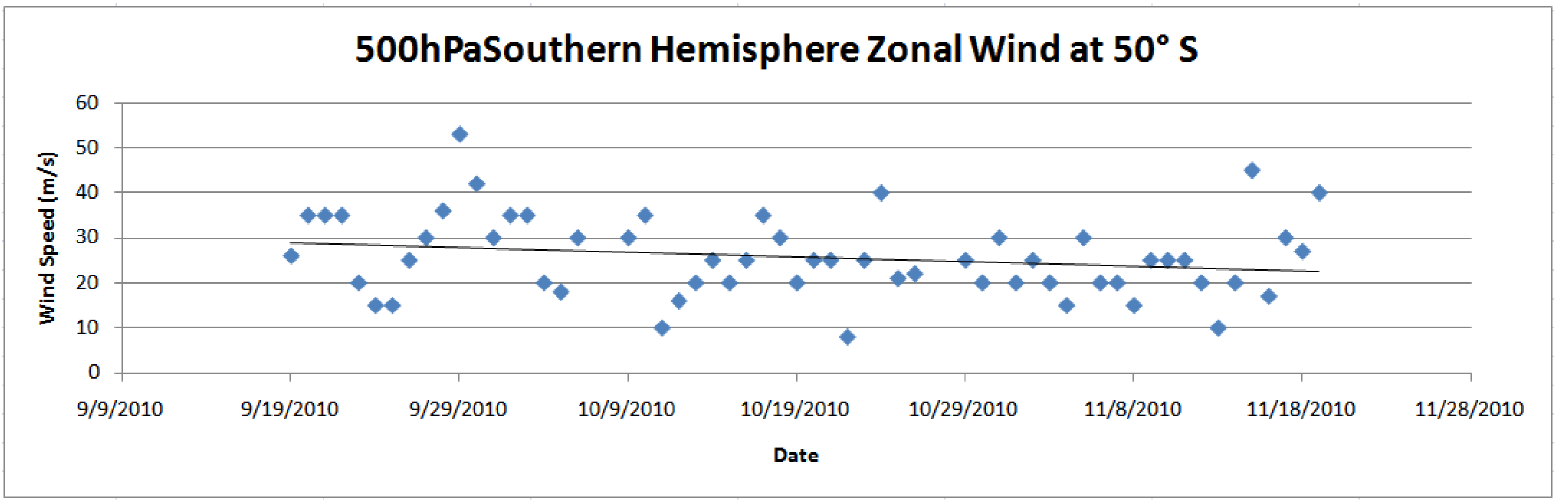

Figure 14

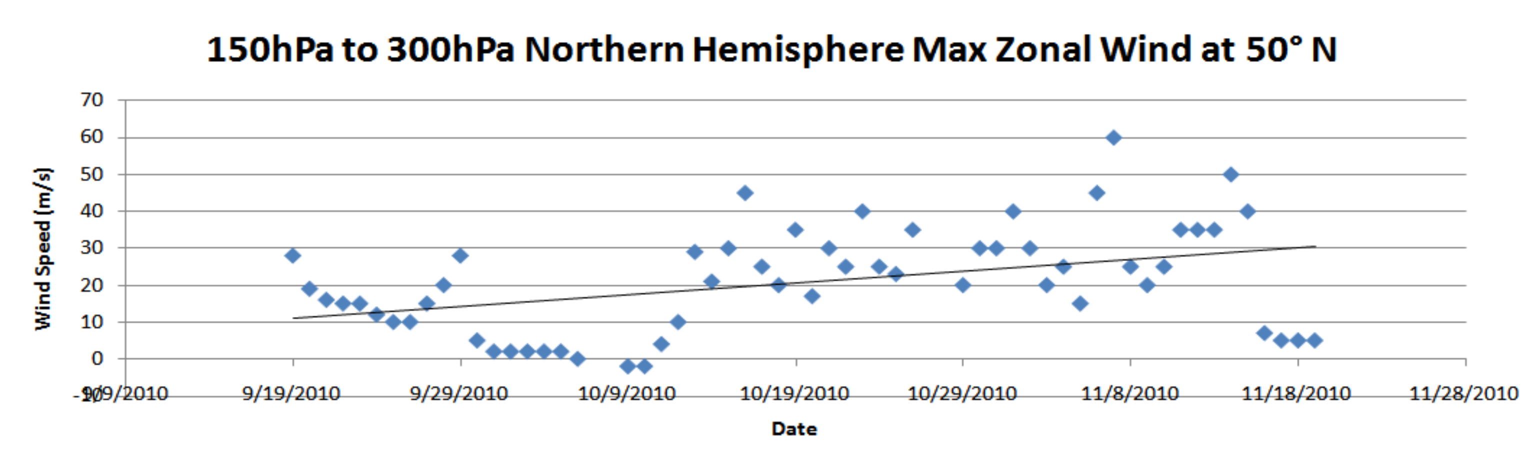

Figure 15

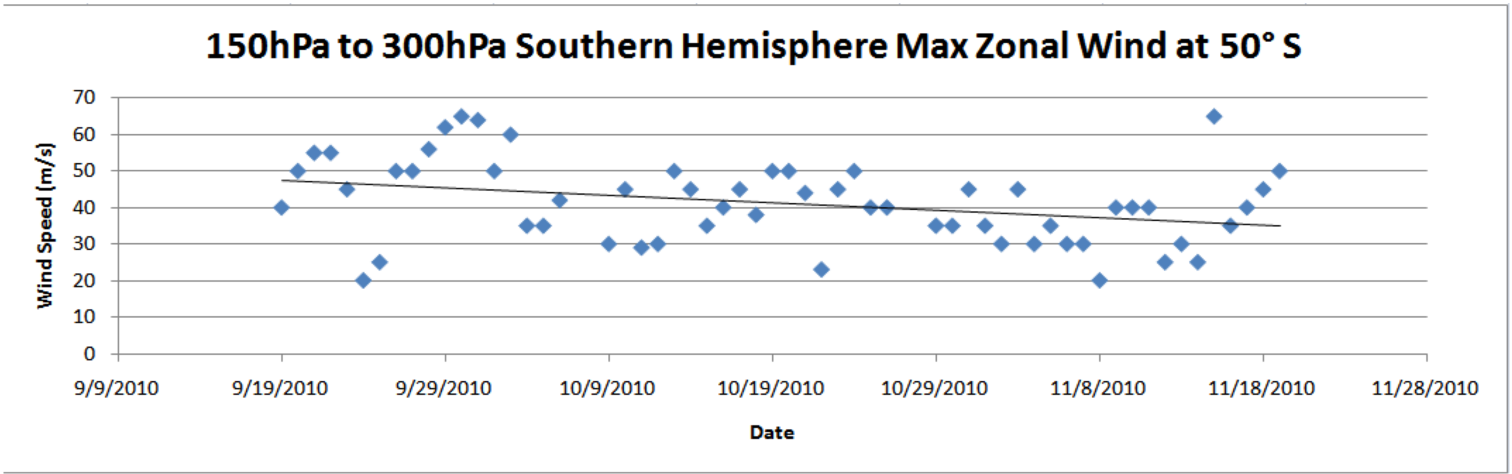

Figure 16

8. The Relationship Between Zonal Wind Speed and Wave Growth and Decay

The relationship between zonal wind speed at 500 hPa and amplitude is shown in figures 17 and 18, with linear fits. For the northern hemisphere the amplitude does not have a strong trend associated with it but the linear fit is very slightly decreasing and the zonal wind is increasing through as winter approaches. For the southern hemisphere the amplitude once again does not show a very strong trend but this time it seems to be slightly increasing its value with time and the zonal wind is decreasing as summer approaches. A relationship noticed in the graphs is that when the zonal wind at 500 hPa is increasing most of the time the amplitude does the opposite and decreases. This agrees with Rossby wave theory because longer waves have lower amplitudes and longer waves have more zonal flow thus a larger zonal wind. So an inverse relation is expected and shown for most of the results.

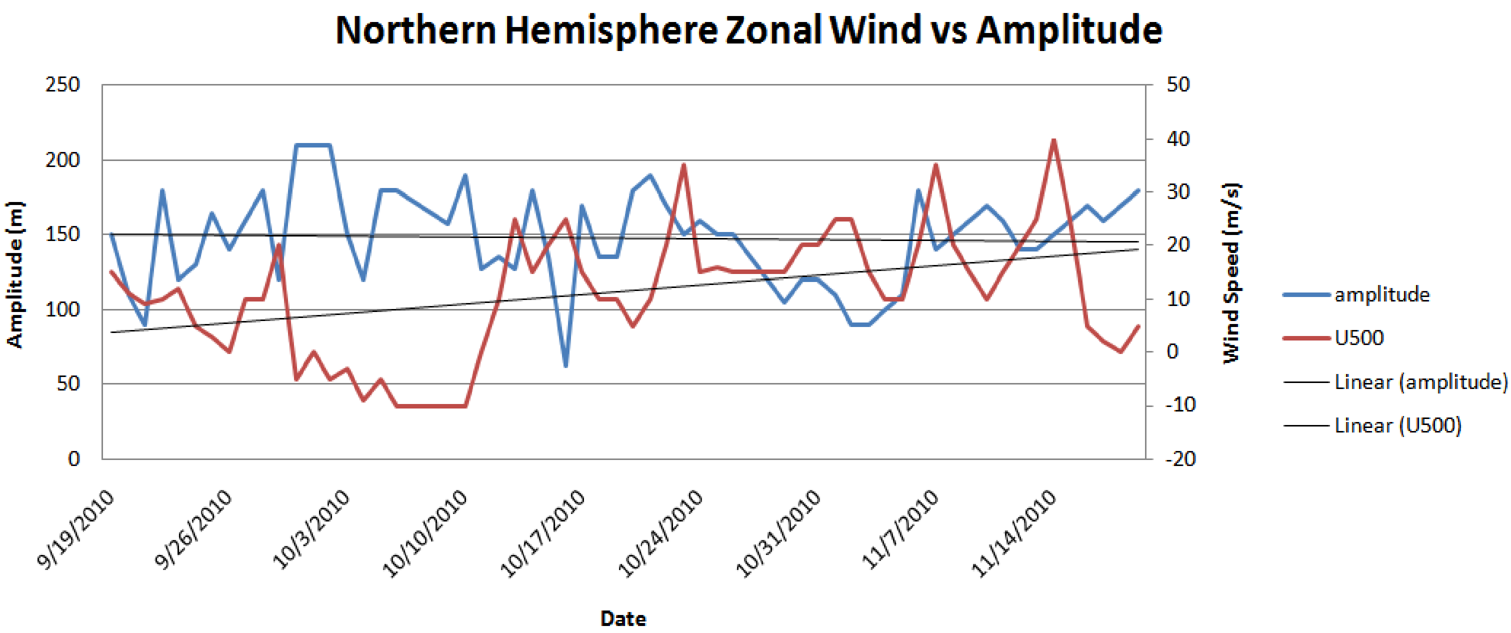

Figure 17

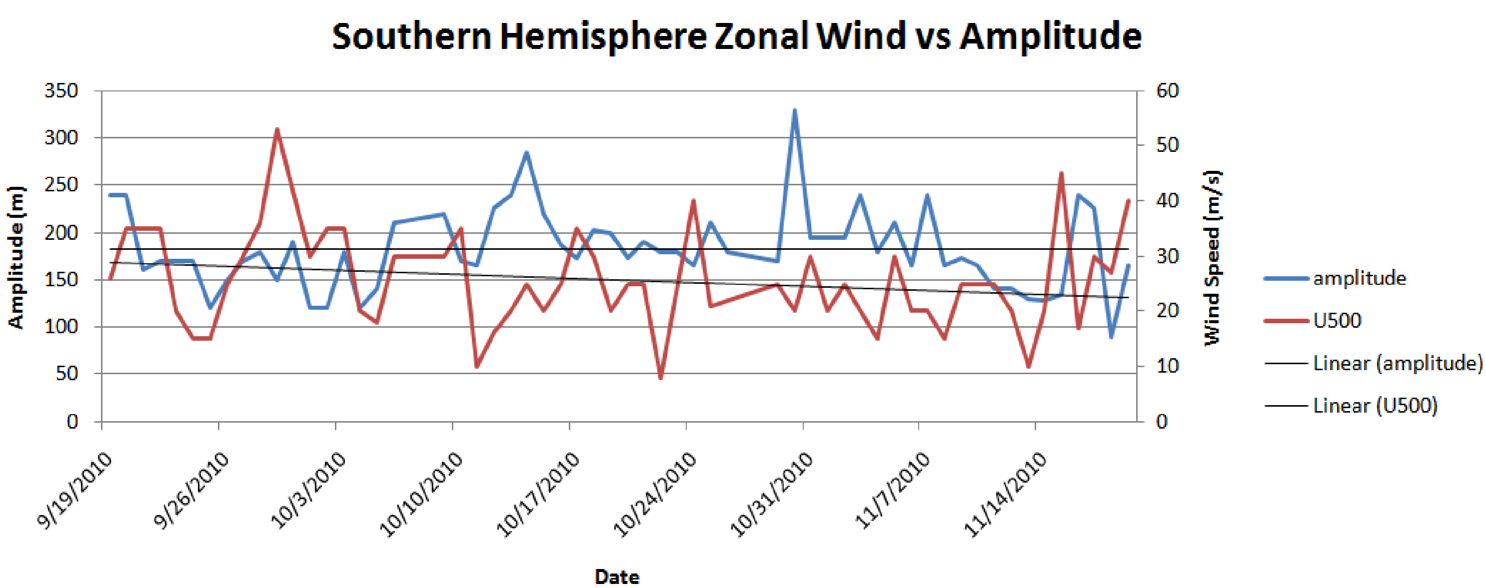

Figure 18

9. Conclusion

Rossby wave theory agreed with our results in some cases but in many it did not agree. In regards to the relationship between wave speed and zonal flow at 500 hPa in both hemispheres, our data did not agree with Rossby wave theory. Looking at zonal wind flow in the upper atmosphere, our data did agree with Rossby theory in the northern hemisphere. Looking at the wave speed in regard to wave number, our data did agree with Rossby wave theory in both hemispheres. Amplitude results indicate that the southern hemisphere's amplitudes increase as the wavenumbers decrease, and the northern hemisphere's amplitudes overall stay constant as the wavenumbers decrease. This opposes Rossby theory which states that smaller wavenumbers have decreased amplitudes. Rossby wave theory agreed with the inverse relationship between zonal wind and amplitude. The results found in this report may be skewed due to many assumptions made, such as: all waves will track along 50° N and S, the assumption of barotropic flow (the conservation of absolute vorticity), the limitations of the source data, and human error in calculation.