Tracking of Large Scale Waves

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ABSTRACT

Large scale wave motions are important in our understanding of weather and forecasting. In this study, large scale wave motions were observed between August 28, 2012 and November 7, 2012 for both the northern and southern hemispheres. Data was obtained for wave number, wave amplitude, wave speed, zonal wind speed at 500 mb, and zonal wind speed in the region from 150-300 mb. This data was plotted in comparison to each other as well as out in time and to Rossby Wave Theory. The study found the southern hemisphere seems to agree much more with Rossby Wave Theory then the northern hemisphere. This may be due to factors such as the relatively short data set, measurement errors, or assumptions made through Rossby Wave Theory.

1. INTRODUCTION

Large scale waves in the atmosphere are an important influence on our everyday weather. The large scale waves can deviate from their normal zonal flow pattern through a series of troughs and ridges which ultimately form the large scale wave pattern. Typically, these troughs and ridges are types of long waves, which have wavelengths that are greater than 1000 kilometers (km), and have a profound influence on weather patterns. In general, troughs are areas of lower pressure and tend to influence clouds and precipitation. The clouds and precipitation usually associated with troughs can be found on the east side of a trough where through dynamic forcing, air is rising. As an air parcel rises it cools and condenses forming clouds and precipitation. On the west side of a trough the opposite is true. Downward motion causes air parcels to sink which inhibits clouds and precipitation. Waves can also influence weather on a smaller scale. These smaller waves, known as short waves, affect areas less than 1000 km and induce rising motion which creates precipitation, just on a much smaller scale than that of long waves.

Variables important in describing the large-scale flow include wavelength, amplitude, wave motion, and the environment in which the waves are embedded. Wavelength, which can also be described by the wave number, describes the number of large-scale trough and ridge patterns present. Amplitude is a measure of the wave's energy with larger values of amplitude corresponding to more energy. Wave motion can be described by the wave speed and Rossby Wave Theory. The environment in which waves are embedded can be studied by looking at the zonal wind. If 500 mb atmospheric waves conform to Rossby Wave Theory, then results drawn from data collected will exhibit trends that follow Rossby Wave Theory.

2. DATA AND METHODS

a. Atmospheric Waves

Wave data for this project was taken from the ISU Meteorological Weather Products page. Data was recorded from August 28, 2012 to November 7, 2012 in both the Northern (NH) and Southern (SH) Hemispheres. 500 millibar (mb) height fields were observed to find the wavenumber, amplitude, and wave speed for both hemispheres. This data was found at a specific location in the both hemispheres which was at roughly 50 degrees latitude. A target contour was then chosen to accurately and consistently record the data. The target contour in the NH was the 5580 meter height contour which separates the orange and yellow color zones. In the SH, the 5280 meter height contour was chosen which is in between the blue and green color zones.

The wavenumber, k, was found by determining how many times the target contour crossed the 50 degree latitude line and then dividing by two. This study states that the average amplitude, A, is:

$$(1)\ A = (Zmax - Zmin) / 2$$

where Zmax is the maximum height for the wavelength, k, and Zmin is the minimum height. Since there are many waves present in the atmosphere, finding the amplitude this way can be difficult. In this study, the average amplitude was estimated for each of the wavelengths by averaging all the local maximums and local minimums by taking:

(2) AveMaxima = average of the N local height maxima

(3) AveMinima = average of the N local height minima

$$(4)\ A = (AveMaxima - AveMinima) / 2$$

Wave speed, C, was found by approximating how fast a wave moved from day to day. This speed was estimated by one half the longitude change between the day after to the day before. The speed, C, is given by:

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

b. Zonal Wind

Zonal wind data was determined by estimating the wind at 500 mb (U500) and the maximum value in the 150-300 mb (Uupper) region. Since the maximum wind speeds are located in the jet stream, 50 degrees latitude was used in both hemispheres to determine the zonal wind since the jet stream is usually found around this latitude. Data for the zonal wind was collected from August 28, 2012 to November 7, 2012 in both hemispheres.

c. Limitations

There were many limitations and potential errors that occurred when recording the wave data. For example, if the 5580 meter height contour in the Northern Hemisphere didn't quite reach 50°N then the wave would not be counted in the data set even if there was a distinct wave present. Also, cut off lows in the wave pattern presented a problem at times. The cut off low in many cases would be south of 50°N and would not be counted.

Calculating the wave speed was also very problematic at times. Waves patterns move at different speeds as they circulate around the world. Following only one wave would not give nearly as accurate results as averaging all wave speeds. Wave speeds also change dramatically when closed low pressure systems develop off the main flowing patterns. This ultimately causes the waves to slow down as wave blocking patterns set up from the cut off low pressure systems.

Zonal wind collection did not have many limitations as the recording of data was explicit. Any problems that may have occurred were a result of not having the x axis labeled with the degrees of latitude. 50° latitude had to be estimated which caused error at times. On occasion, there were extreme gradients present in the zonal wind plots which made the contours hard to read allowing for errors to be caused.

3. RESULTS

a. Wave Propagation

The waves included in this study may be analyzed based on the properties of Rossby waves. Table 1 shows the average speed at which these waves propagate along with the wind speeds at the atmospheric levels of interest. Without accounting for the effects of the 500 mb zonal wind, wave propagation is to the east in both hemispheres with an average velocity of 11.83 longitudinal degrees per day in the NH and an average velocity of 15.87 longitudinal degrees per day in the SH. After removing the effects of the 500 mb zonal wind, which for the NH and SH averaged 15.31 and 29.61 longitudinal degrees per day respectively, we see that the wave propagation switches direction with average wave speeds of -3.44 longitudinal degrees per day for the NH and -13.56 longitudinal degrees per day for the SH. These results support the Rossby wave theory which states that these waves propagate westward. It is the influence of the zonal winds at 500 mb which give the appearance of eastwardly propagating waves.

	Wave Speed, C (deg/day)	U500 (deg/day)	Uupper (deg/day)	C - U500 (deg/day)
NH	11.83098592	15.30986111	31.00625	-3.438873239
SH	15.87323944	29.61138889	54.06347222	-13.55873239

Table 1: 500 mb wave speed, 500 mb zonal wind speed, 150 - 300 mb max zonal wind speed and 500 mb wave speed with the effects of the 500 mb zonal wind removed. All values are averages over the entire period and units are longitudinal degrees per day.

Figure 1 is a plot of the 500 mb wave speed versus the 500 mb zonal wind speed in the NH and Figure 2 is the same for the SH.

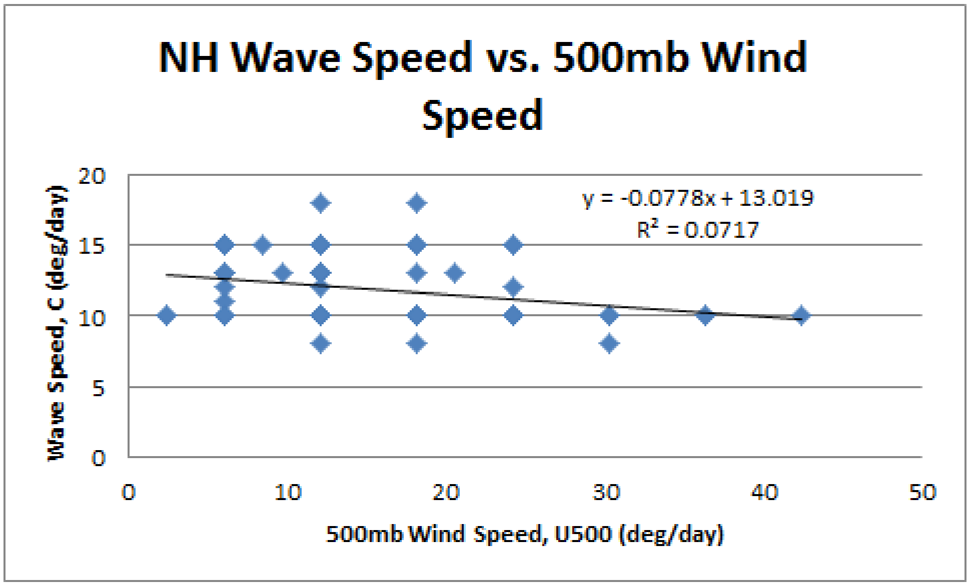

Figure 1: Speed of 500 mb waves compared to 500 mb zonal wind speeds in the NH. Both measurements are in longitudinal degrees per day.

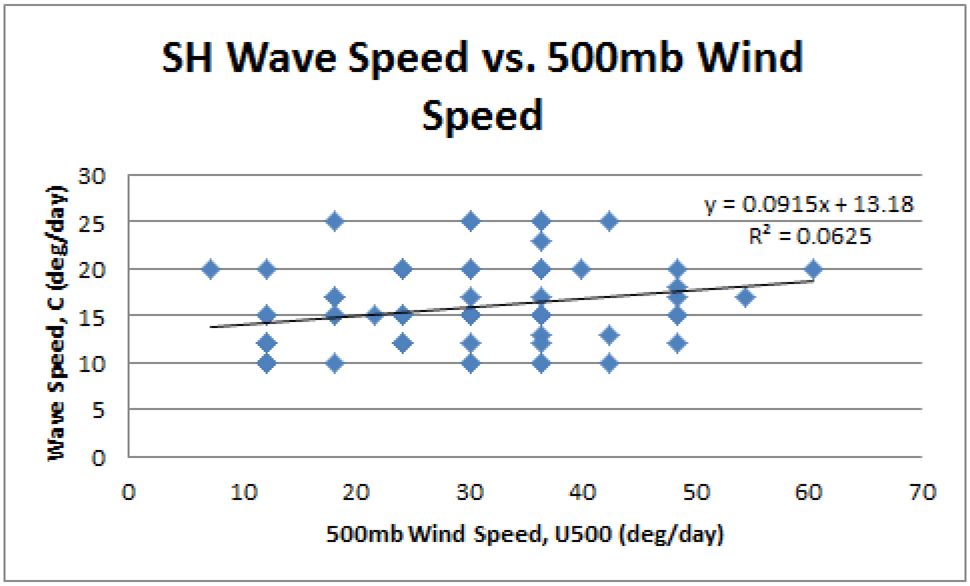

Figure 2: Speed of 500 mb waves compared to 500 mb zonal wind speeds in the SH. Both measurements are in longitudinal degrees per day.

Results for the NH do not support Rossby wave theory in that the trend is as 500 mb zonal wind speed increases, 500 mb wave speed decreases. With an R^2 value of 0.0717, the correlation between wave speed and zonal wind speed is very low meaning these results are not definitive. One source of error in this data set is the lack of data with larger values for 500 mb wind speed. There are only a few data points with wind speeds of 30 longitudinal degrees per day or greater which may skew the trendline. In the SH, results support Rossby wave theory. As the 500 mb zonal wind speed increases, 500 mb wave speed increases. As in the NH, the correlation between wave speed and zonal wind speed is weak with an R^2 value of 0.0625, but still supports the theory.

Looking at the jet stream winds, 150 - 300 mb max zonal wind speed, a correlation with 500 mb wave speed may be seen, a bit weaker than that with 500 mb wind speed.This is because the winds in the jet stream have a slight effect on the winds at 500 mb due to friction. Figure 3 is a plot of the 500 mb wave speed versus the jet stream wind speed for the NH. As in Figure 1, the relation exhibited does not support Rossby theory. With an extremely low correlation, R^2 value of 0.006, the plot indicates that as jet stream wind speeds increase, 500 mb wave speed decreases. As with 500 mb wind speed, there is limited data at higher jet stream wind speeds, skewing the trendline. In the SH, the relation between 500 mb wave speed and jet stream wind speed, Figure 4, follows the same trend that it did for the relation with 500 mb wind speed. As in the NH, the correlation is even weaker than before, R^2 value of 0.0343. Even though the correlation is very weak, the results support Rossby wave theory showing that the wind speeds in the middle and upper troposphere affect the propagation of waves at 500 mb.

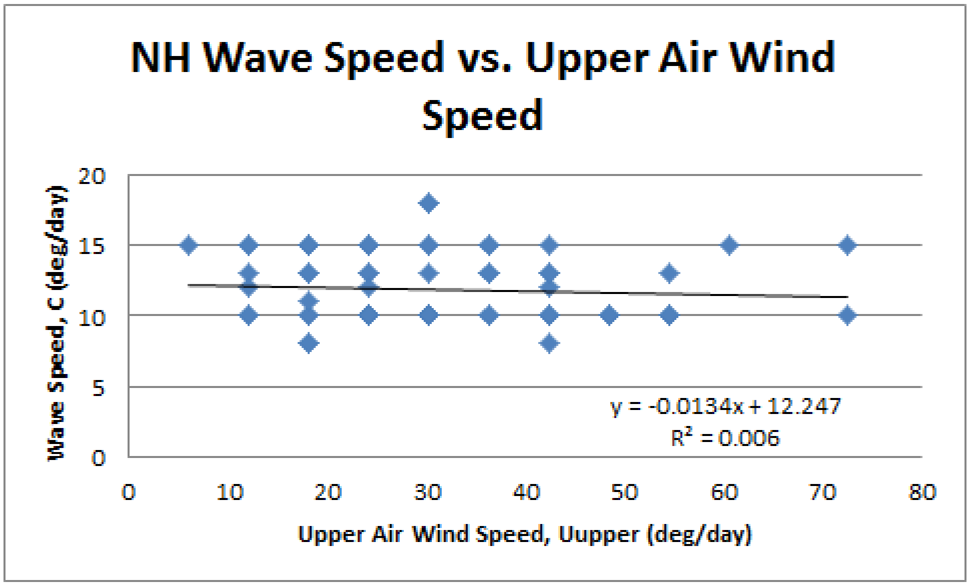

Figure 3: Speed of 500 mb waves compared to 150 - 300 mb max zonal wind speeds in the NH. Both measurements are in longitudinal degrees per day.

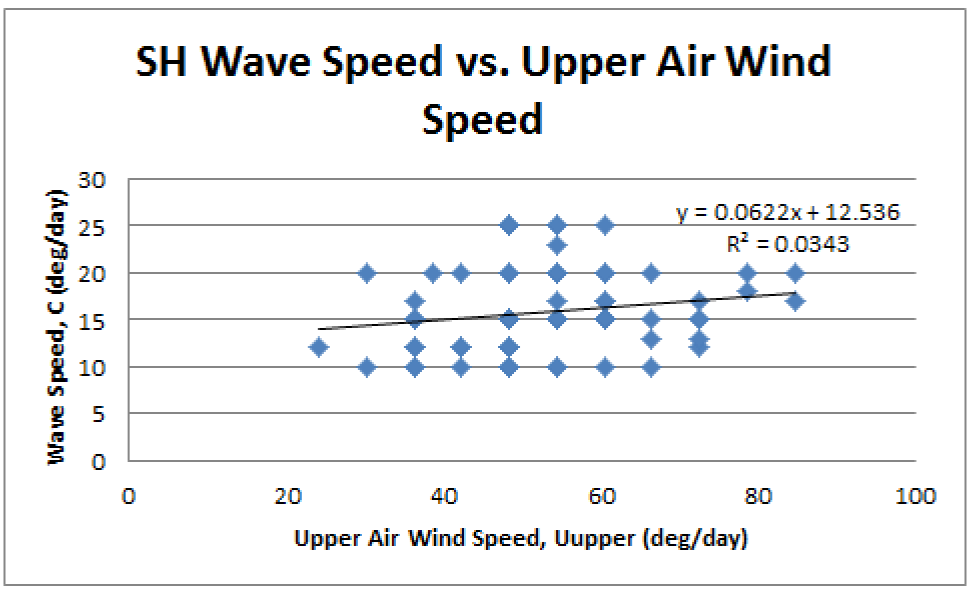

Figure 4: Speed of 500 mb waves compared to 150 - 300 mb max zonal wind speeds in the SH. Both measurements are in longitudinal degrees per day.

b. Wavenumber

According to Rossby wave theory, wave speed is dependent on wavelength and thus wavenumber through the equation:

$$(6)\ C - \bar{u} = -\beta/K^2$$

where K^2, given by:

$$(7)\ K^2 = k^2 + l^2$$

is the total horizontal wavenumber squared (Holton, 2004). By removing the effects of the 500 mb zonal wind, a plot can be made of the adjusted 500 mb wave speed, the left-hand side of equation (6), versus the wavenumber, the right-hand side of equation (6). According to the theory, as wavenumber increases, wave speed must decrease. This is due to the fact that Rossby waves are dispersive, meaning the wave speed is dependent on wavelength. Figure 5 has this relationship plotted for the NH. The data from the NH for this study does not support this relationship. There is no correlation, R^2 value of 0.00005, for adjusted wave speed and wavenumber.

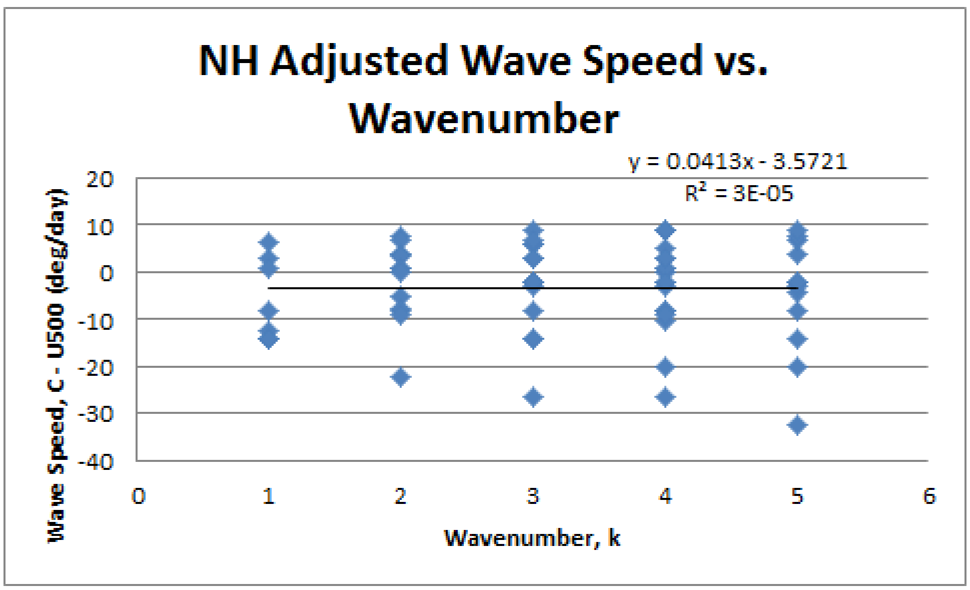

Figure 5: Measured speed of 500 mb waves with the effects of the 500 mb zonal wind removed, in longitudinal degrees per day, plotted against the integer wavenumber for the NH.

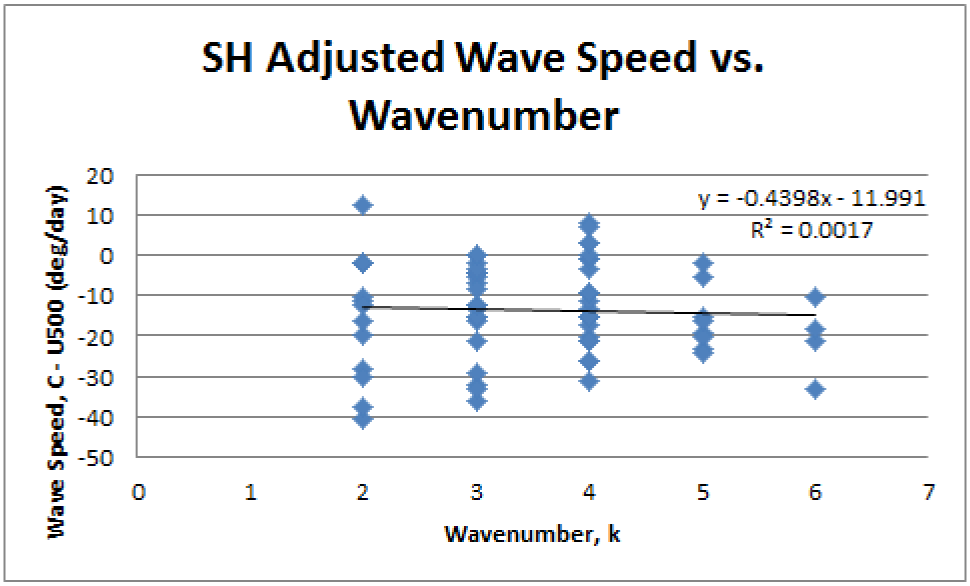

Figure 6: Measured speed of 500 mb waves with the effects of the 500 mb zonal wind removed, in longitudinal degrees per day, plotted against the integer wavenumber for the SH.

For the SH, Figure 6, there is a slight negative correlation exhibited in the data. As wavenumber increases, adjusted wave speed decreases supporting Rossby theory. The correlation between the two is relatively weak with an R^2 value of 0.0017 but still present nonetheless. One source of error that could cause the low correlation is the wave speed for a given day was estimated by finding how far wave features traveled from the previous day to the following day. This estimation was hindered by the fact that the maps only have longitude lines every 10 degrees thus making it impossible to be very accurate.

Looking at the evolution of 500 mb waves on the synoptic time scale, Figures 7 and 8 show how the wavenumber changes with time in both the NH and SH respectively. Average wavenumber for the NH was 3.21 and 3.56 for the SH. Individual synoptic features, like storm systems, caused by upper level troughs last for roughly one week before breaking apart. In the NH, wavenumber typically stays consistent only changing by one or none over days 3 through 8. This is consistent with the synoptic time scale as variations can be explained by the fact that individual waves are building and decaying at different times. The constant evolution of individual waves may cause wavenumber to change by one or two in a day. Another possible way wavenumber may change rapidly is individual waves may not reach the 50 degree latitude line, thus excluding them from the count for a given day.

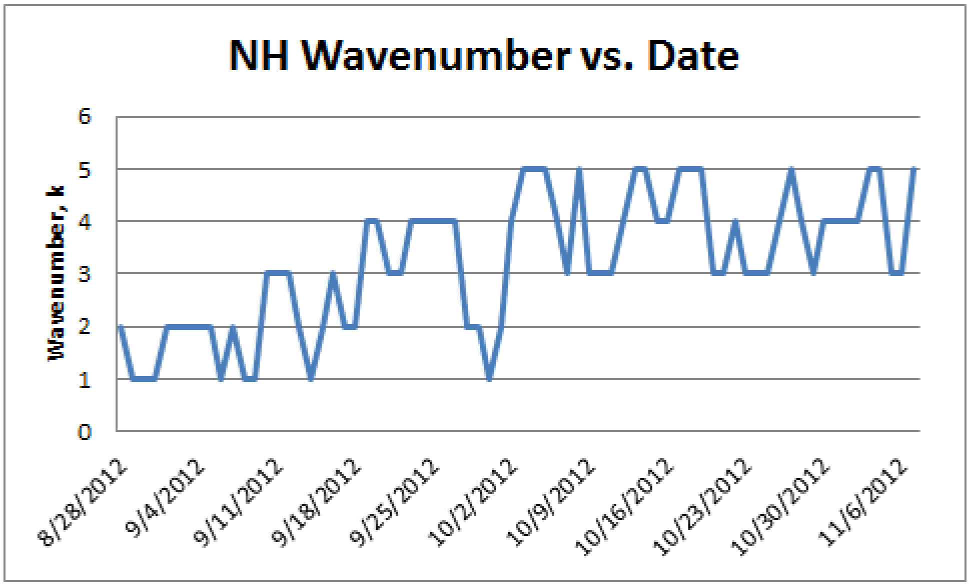

Figure 7: 500 mb integer wavenumber plotted by date for the NH.

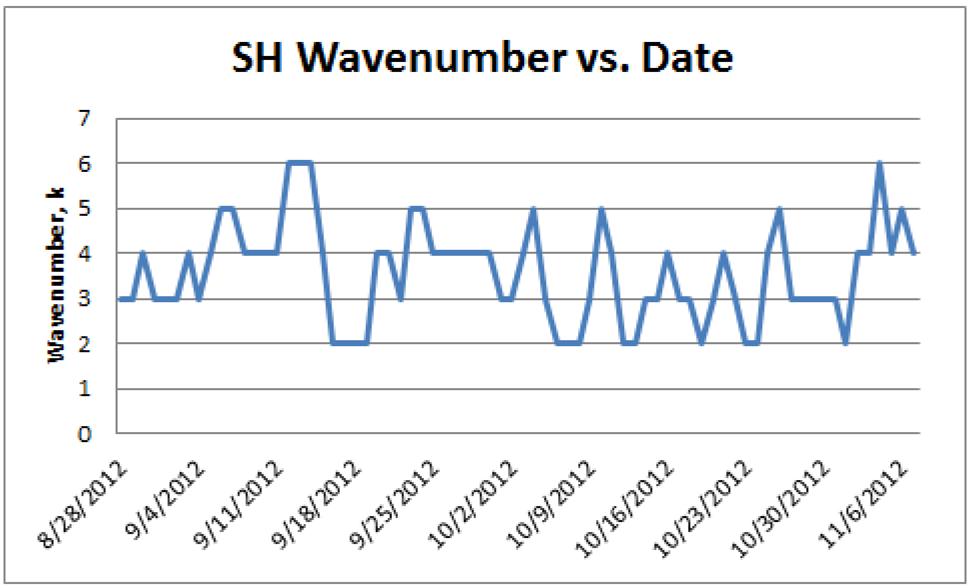

Figure 8: 500 mb integer wavenumber plotted by date for the SH.

The SH exhibits the same trend. Wavenumber stays consistent for 3 to 10 days, with one stretch from September 25 to September 30 where the wavenumber remains constant at 4. There are many times where wavenumber stays constant for 3 days or more, 9 in the NH and 7 for the SH. The fact that this occurs numerous times through the period, lends support to the idea that these waves are synoptic features.

c. Wave Amplitude

A relationship between wavelength and wave amplitude exists such that longer waves typically have smaller amplitudes. Figures 9 and 10 have 500 mb wave amplitude plotted against wavenumber. Due to the relationship between wavelength and wavenumber, we can deduce that waves with a lower wavenumber should have a smaller amplitude. The graphs for both hemispheres suggest the opposite relationship in higher wavenumber waves have smaller amplitude.

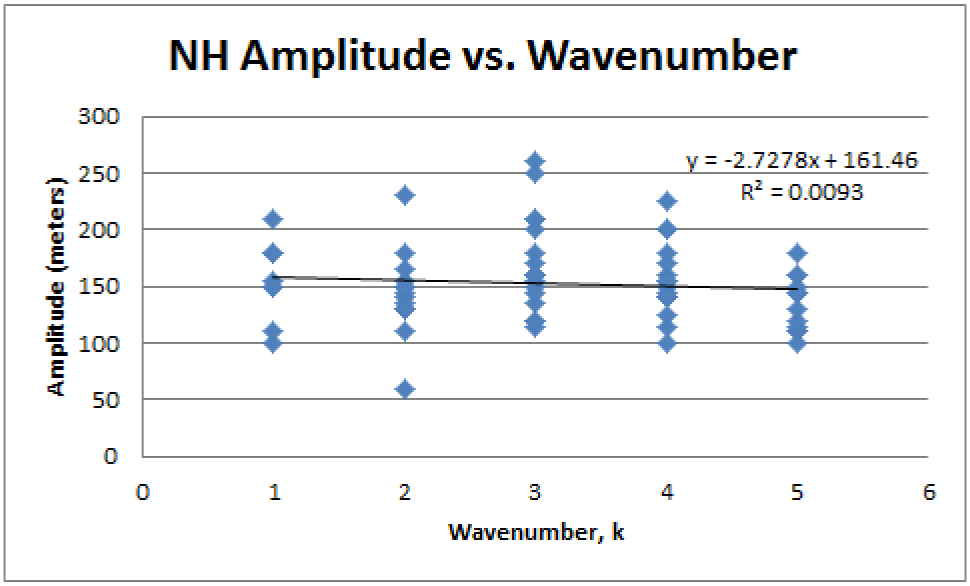

Figure 9: 500 mb wave amplitude, in meters, plotted for integer wavenumber for the NH.

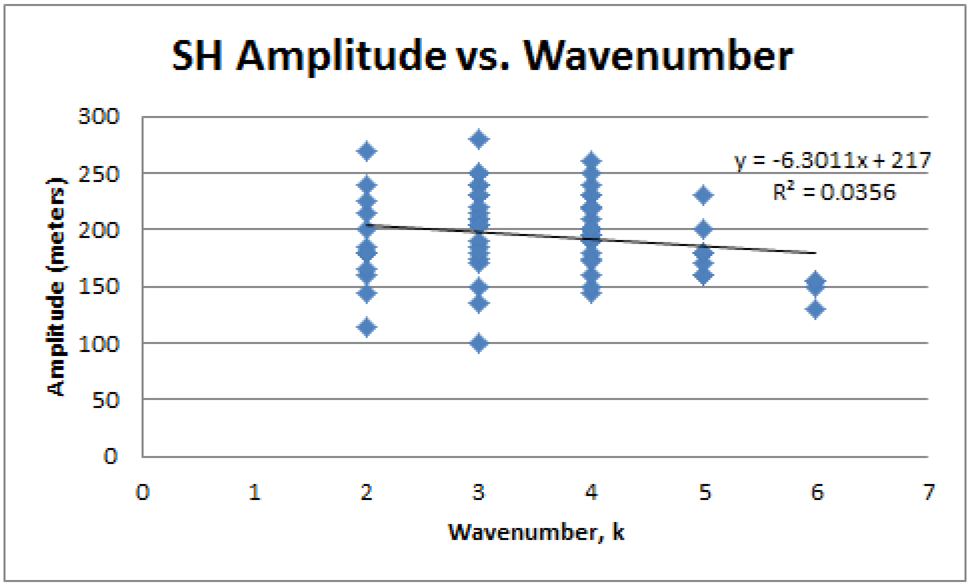

Figure 10: 500 mb wave amplitude, in meters, plotted for integer wavenumber for the SH.

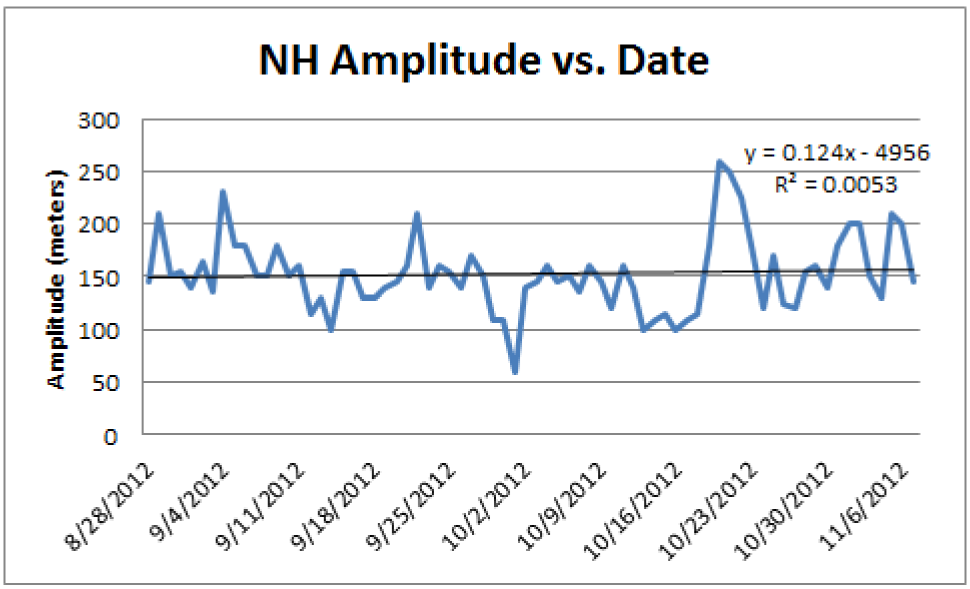

Figure 11: Amplitude of 500 mb waves, in meters, plotted by date for the NH.

In both hemispheres, as wavenumber increases amplitude decreases. Another interesting observation is the variation in amplitude readings for a given wavenumber decreases as wavenumber increases. This could be caused by the fact that there are more wave amplitudes being averaged to find the amplitude plotted for the given day. With each additional wave, individual waves with large amplitudes may be masked by other waves with smaller amplitudes. With smaller wavenumbers, individual waves with very large or very small amplitudes will not be lessened because there are fewer waves to average out their effects.

Plotting amplitude by day shows a slight increase in amplitude for both hemispheres as the period progressed. Figure 11 shows the values of amplitude for the NH where the R^2 value was 0.0053. Figure 12 shows the amplitude for the SH where the R^2 value was 0.0029. Although the trendlines for both hemispheres suggest an increase, the increase is so slight that it can be viewed as a constant meaning that amplitude in both hemispheres varies around a constant value. The average amplitude in the NH was 152.71 meters and the SH average amplitude was slightly higher at 194.60 meters. This study suggests that 500 mb wave amplitudes in the SH are greater than those in the NH.

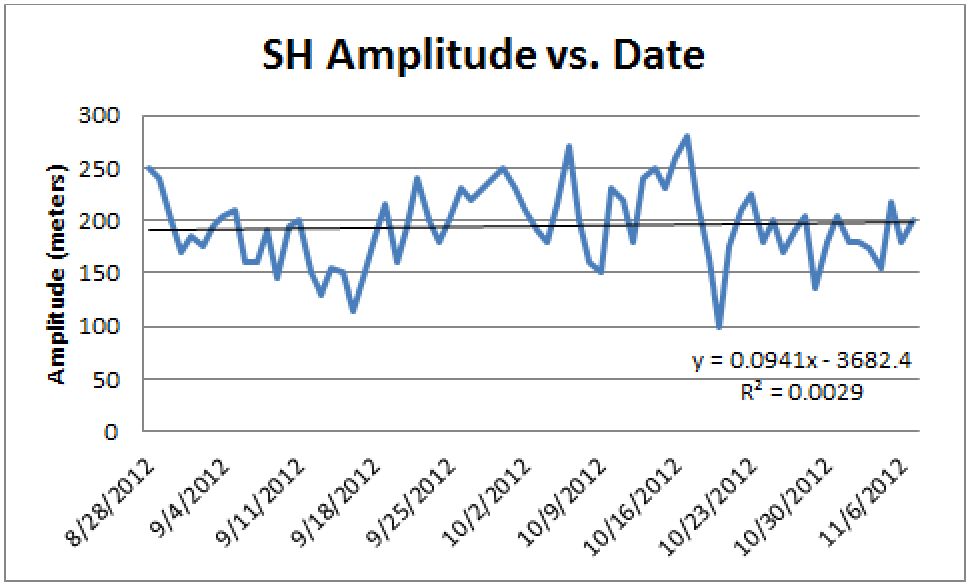

Figure 12: Amplitude of 500 mb waves, in meters, plotted by date for the SH.

d. Zonal Wind

Continuing on the discussion earlier involving zonal wind speeds, there are some observations that can be made by comparing the 500 mb zonal wind speed and the jet stream speed, the 150 - 300 mb max zonal wind. Figure 13 has these winds plotted by day for the NH. The easiest observation to make is the jet stream wind speeds are almost always higher than the 500 mb wind speeds. This is because the jet stream is located in the tropopause where the highest winds are located. From there, downward winds decrease due to frictional forces from the surface. Both winds increased as the period progressed, showing the transition to Winter.

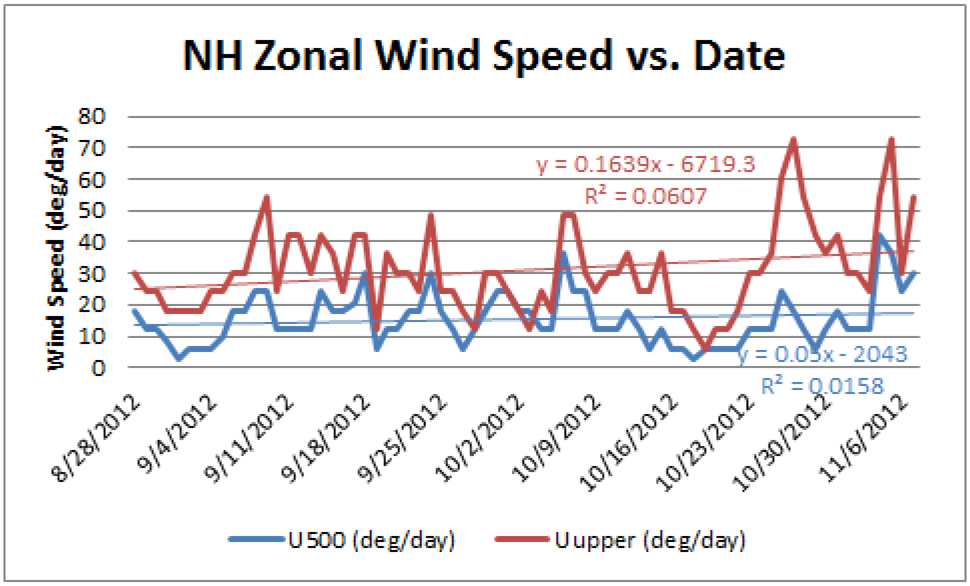

Figure 13: 500 mb zonal wind speed and 150 - 300 mb max zonal wind speed, in longitudinal degrees per day, plotted by date for the NH.

Figure 14 shows these same values for the SH. As with the NH, jet stream winds are higher than the 500 mb wind speeds. The difference between the NH and the SH arises in the evolution of the winds with time. As the period progressed, winds in the SH decreased, which is opposite of what happened in the NH. This is due to the SH transitioning into Summer.

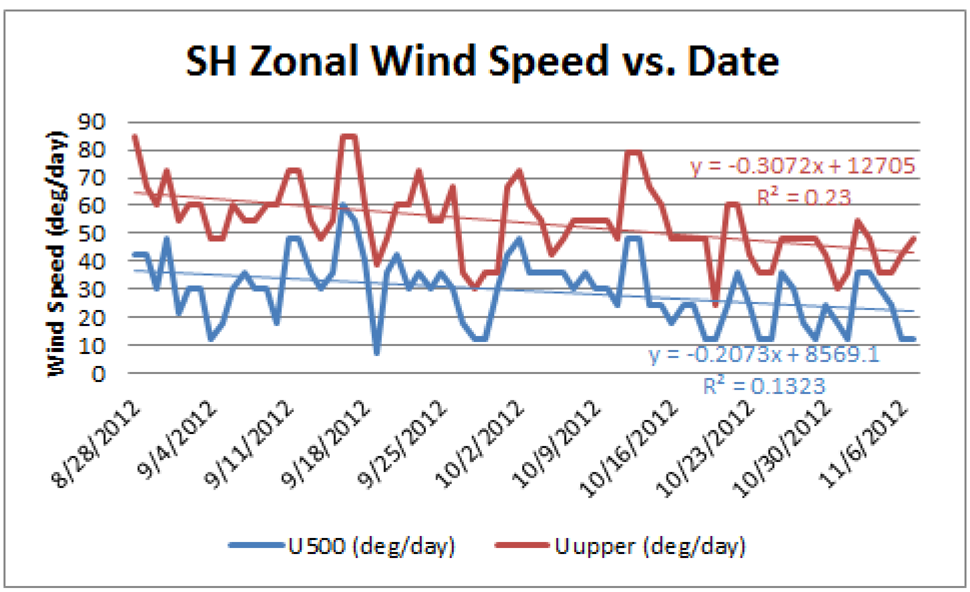

Figure 14: 500 mb zonal wind speed and 150 - 300 mb max zonal wind speed, in longitudinal degrees per day, plotted by date for the SH

Plotting the 500 mb wind speed and the wave amplitude by date shows a relationship between the two. Looking at Figures 15 and 16, it is possible to see as the amplitude of 500 mb waves decreases, 500 mb wind speeds typically increases. The opposite is also noticeable, as the amplitude of waves increase, 500 mb wind speeds tend to decrease. One of the best occurrences of this may be seen in the SH, Figure 16, during the period between September 25 and October 2. Here there is a clear decrease in 500 mb wind speed while there is an increase in 500 mb wave amplitude.

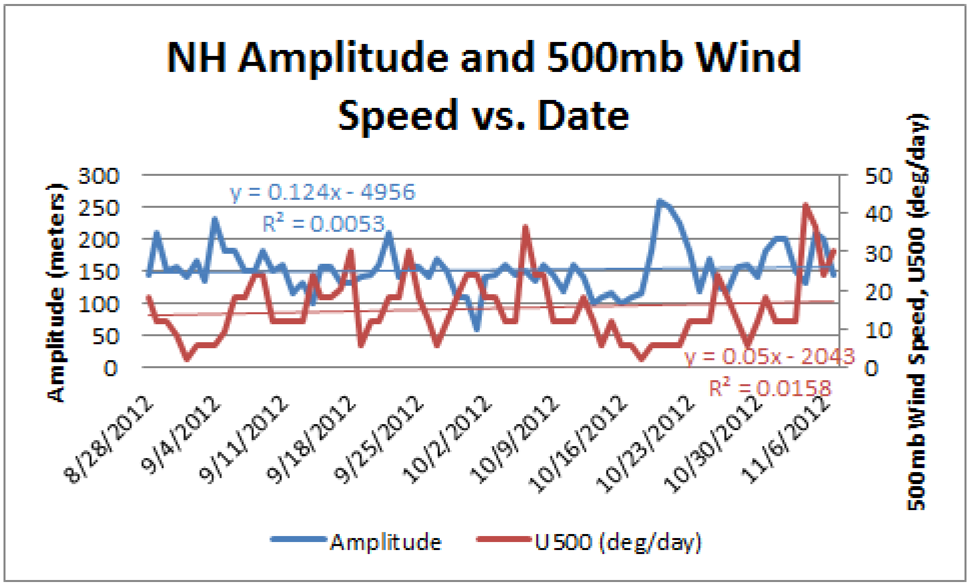

Figure 15: Amplitude of 500 mb waves, in meters, and 500 mb zonal wind speeds, in longitudinal degrees per day, plotted by date for the NH.

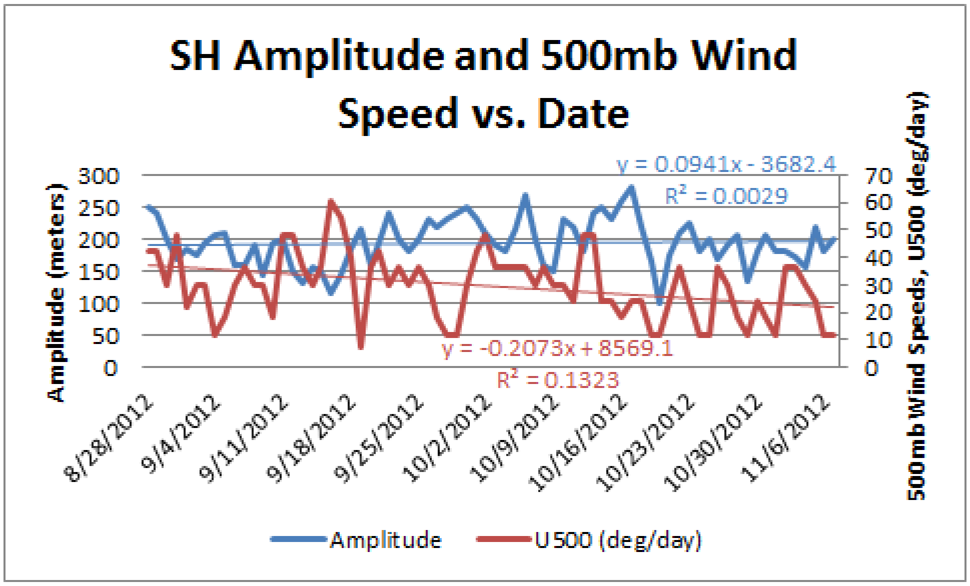

Figure 16: Amplitude of 500 mb waves, in meters, and 500 mb zonal wind speeds, in longitudinal degrees per day, plotted by date for the SH.

4. CONCLUSIONS

In conclusion, the results from this study tend to agree with Rossby Wave Theory in relation to wave propagation without zonal wind in both hemispheres, SH wave speed vs. 500 mb zonal wind speed, SH wave speed vs. upper wind speed, and SH wave speed vs. wave number. The results disagreed in relation to NH wave speed vs. 500 mb zonal wind speed, NH wave speed vs. upper wind speed, and NH wave speed vs. wave number. When looking at zonal wind speeds over time it is observed that in the NH they are increasing and in the SH they are decreasing. This result agrees with what should occur during the transitioning seasons. Finally, it is observed that 500 mb wind speeds are greater in the SH than in the NH. 500 mb wind speeds and wave amplitudes are also inversely related in both hemispheres. It is difficult to draw any conclusive results from this data however, it seems that while the results were variable, a stronger agreement with Rossby Wave Theory seems to exist in the SH than in the NH. This result may be due to the relatively short length of data observed, observation error in the method used, or various other factors not accounted for when using Rossby Wave Theory.

REFERENCES

Holton, James R. An Introduction to Dynamic Meteorology Fourth Edition. Burlington: Elsevier Inc., 2004. Print.