

Tracking Movement of Coronal Holes from Long Term McA Data

Jacob Harris¹, Ian M. Hewins², Mausumi Dipakti², Sarah E Gibson²,
¹ Arizona State University; ² National Centers for Atmospheric Research, High Altitude Observatory;

Summary

Features on the surface of the Sun and other layers of the atmosphere are constantly changing, due to its magnetic field. In 1964, Patrick McIntosh, a scientist at NOAA's Space Environment Center, began creating hand-drawn synoptic maps of the sun's magnetic features and gathered nearly 45 years' (about four solar cycles) worth of these maps. To prevent these maps from being lost, most of these maps have been digitalized in the McIntosh Archives (McA). This summer, we processed years' worth of this data to create stack plots, which are essentially plots of latitude bands stacked in time. This allows us to track the movement of solar features, particularly coronal holes. We calculated the centroids of the coronal holes at successive Carrington rotations, and estimated the slopes of these patterns as the coronal holes evolve. To calculate the centroids, we developed a new method using an algorithm and numerical tools in Mathematica. This method utilizes the Fourier Transform to find an approximation of any outline of coronal holes with a series of sinusoids in parametric form. These parametric equations are then plugged into line integrals to calculate the centroids. Our method of centroid calculations is accurate except when the coronal holes are too small. By estimating their velocities from these slopes, we found that the velocity is more prograde when the coronal holes are at low latitudes, and more retrograde at high latitudes, which isn't surprising due to the differential rotation. The velocity became zero at a lower latitude than expected based on where the Carrington rotation rate is defined at the photosphere. This implies, that the movement of coronal holes are being influenced by deeply rooted magnetic field lines below the surface. By superimposing differential rotation on coronal hole migration velocities and estimating the difference between the two, we can investigate what other factors influence coronal hole movement, such as Rossby waves. Learning more about these waves will tell us more about other forms of solar weather and could help us predict CMEs. This information could not only advance solar physics but also help keep our planet safe.

Figure 4

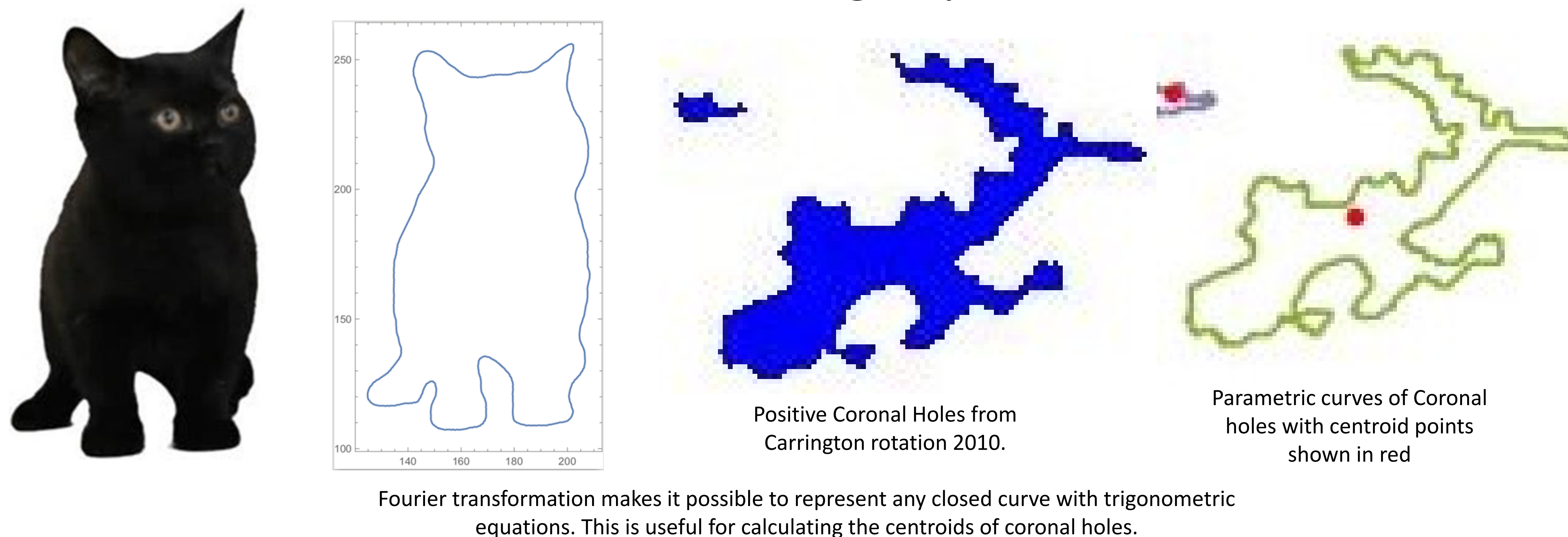


Figure 5

Centroid Calculation

- A common method of calculating the centroids of two-dimensional objects is double integration.
- These integrals, however, require functions in cartesian or polar coordinates.
- Unfortunately, it is very difficult to represent complicated shapes, like coronal holes, as elementary functions.
- However, there is a way to get around this.
- If we convert the double integrals to line integrals, which are compatible with parametric equations, we can avoid using functions altogether.
- It can be shown by Greens Theorem that the following line integrals are equivalent to the double integrals

$$\frac{1}{2A} \oint_C x^2 dy = \frac{1}{A} \iint_R x dA$$

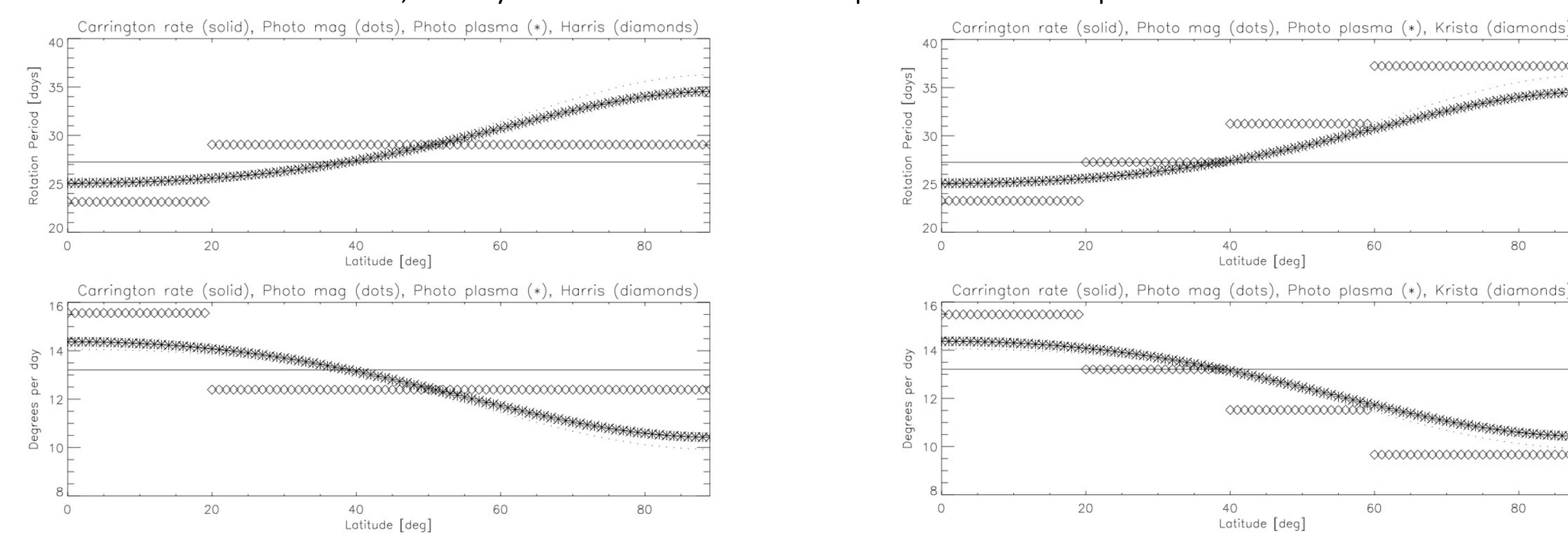
$$-\frac{1}{2A} \oint_C y^2 dx = \frac{1}{A} \iint_R y dA$$

- Using the parametric equations we found for the coronal holes, we can use these integrals to calculate the centroids.

Figure 6

Results

After all centroids were calculated, we found slopes for four coronal hole patterns each at different latitudes. Ideally, we would have wanted to find the slopes of more patterns for each latitude and take the average, however, due to time constraints we only did one for each. With these slopes, we then found the rotation rates of the coronal holes at these latitudes. Afterward, we compared this to the differential rotation rates of the photospheric plasma at the corresponding latitudes. We did this by plotting the coronal hole rates and differential rotation rates together on a latitude vs. rotation rate plot and a latitude vs. degrees plot. We found that at higher latitudes the movement becomes retrograde, however we also found that this retrograde slope started decreasing at even higher latitudes. Based on stack plot observations and previous research from HAO scientist Lariza D. Krista the two slopes at the higher latitudes do not appear to be accurate. The lower latitude slopes however do seem to match up well with observations and Krista's plot, below. If we calculated more slopes for each of the latitudes or calculated more accurate centroids, we may find that the results match up more with Krista's plot.



Conclusions:

As we continue this research, next summer we will find a more conclusive answer of how coronal rotation rates compare to the differential rotation. Finding how much these rotation rates differ will help us uncover how other solar phenomena influence the movement and evolution of coronal holes. One of biggest known influences on the movement of solar features other than differential rotation is Rossby waves, localized waves in the sun's interior. This is what will be our focus as our research continues. Learning more about these waves could potentially help us learn more about other kinds of solar weather such as coronal mass ejections and consequently allow us to make better predictions about when events like this will happen. This could not only advance our understanding of solar physics but also help us be prepared for dangerous solar weather.



Figure 1 McIntosh Archive Synoptic Map at two selected Carrington Rotations (CR1964 and CR2061) to present two characteristic solar cycle phases, namely solar maximum (left) and minimum (right).

Features:

- During solar minimum (right panel) polar Coronal Holes are prominent (see the extended red and blue patches near the North and South poles respectively)
- At solar maximum (left panel) all Coronal Holes are lower latitudes (i.e. nonpolar)
- Lower latitude CHs show the effect of differential rotation (see the curvature of the blue/positive and red/negative Chs)

Our goal is to utilize this McA data to analyze the evolution of coronal holes over time and extract features of Coronal Holes as well as other solar features. One efficient way is to make "stackplots" and derive the movement of CHs and other features. Figure 2 shows some sample stackplots. These are created by taking a band of latitudes of a chosen range from several Carrington rotations and stacking them on top of each other. By calculating the slopes of the patterns the coronal holes make in these plots, we can accurately track their movement over time.

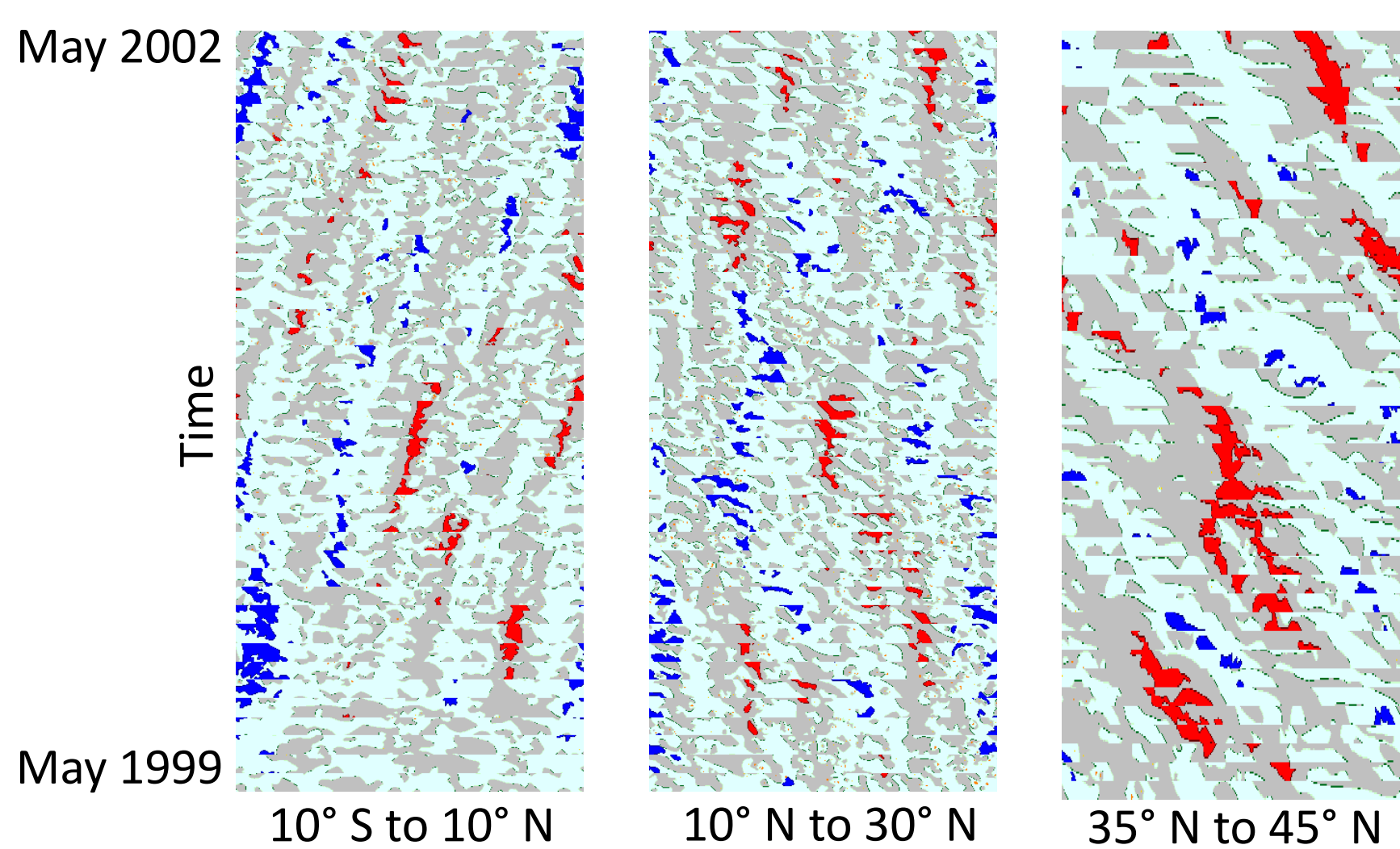


Figure 2: Stack Plots from McA data

Several features are revealed from these stackplots.:

- ✓ The CHs show prograde movement when they are at low latitudes (left)
- ✓ They move at a rate close to at the Carrington rate when they are around 30-degrees.
- ✓ Note that Carrington rate is defined at 38-degrees latitude at the surface. The CHs show that movement rate at a slightly lower latitude, implying they are governed by deep-rooted magnetic fields below the surface.
- ✓ Right panel shows retrograde movement of CH when they are higher latitudes (higher than Carrington latitude)

In order to estimate the movement of CH more accurately, we employ a technique to compute their centroids and plot in a Hovmoller-type diagram (longitude-time plots).

- To calculate the centroids, we must mathematically represent the outlines or contours of the coronal holes.
- An example of this is shown in Figure 4.
- This is done with pairs of parametric equations that represent the x and y values, respectively.
- These equations are created by extracting points from the edges of the coronal holes and performing a Fourier Transform.
- Due to the nature of the Fourier Transform all equations are series of sines and cosines.
- After the equations are created these equations can be plugged into two line integrals x and y values for each centroid (Figure 5).
- Then we estimate the coordinates of the centroid of the closed curve/outline of a CH
- Then we plot them in a longitude-time diagram for selected latitudes
- We can thus estimate their movements more accurately

Figure 3: How Slopes are Calculated