TRACKING MOVEMENT OF CORONAL HOLES USING MCINTOSH ARCHIVE DATA

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Why Tracking Solar Features are Important

- Tracking solar features will help us better understand how the sun's magnetic field works.
- Finding the rotation rates of these features, will help us make deductions of phenomena in the sun's interior.
- This will help us learn more about solar weather and possibly help us make better predictions.
- This could help us prepare for potentially dangerous solar storms and help keep our planet safe.
Mapping Sun's Magnetic Features

- In 1964, Patrick McIntosh, a former scientist at NOAA's Space Science Center, started creating hand-drawn maps of the sun's magnetic features.

- Over the course of his life, he made over 45 years (about 4 solar cycles) worth of maps.

- This data gave us a unique record of solar activity and the evolution of the sun's magnetic field.

- Recently, he passed away, and his life's work was in danger of being lost.

- Thankfully, NOAA and NCAR, under the funding of the NSF, have made it their goal to digitalize all these in the McIntosh Archives.
SYNOPTIC MAPS:
WHAT ARE THEY?

◦ Map of sun's solar features
◦ Coronal holes
◦ Filaments
◦ Magnetic polarity
◦ Sunspots
◦ Polarity Inversion Lines
Coronal Holes

- Coronal holes are regions in Corona that are cooler and less dense than the surrounding plasma.
- They can easily be seen in extreme ultraviolet and soft x-ray images.
- These regions are created from open magnetic field lines from the sun.
- Because the field is open more particles from the corona are free to escape as solar wind, which is why these regions are less dense.
Filaments

- Filaments are large regions of plasma lifted above the photosphere by the sun's magnetic field.
- Since this plasma is cooler and less dense than the plasma at the photosphere it also looks dark from a bird's eye view.
- However, if seen from an angle you can see large loops of plasma that rise far above the photosphere.
- These are called Prominences.
- Filaments tend to form on magnetic inversion lines.
Sunspots

- Sunspots are regions on the photosphere that are cooler than the surrounding plasma.
- These regions are created by intense magnetic flux that prevents convection from occurring.
- Seeing sunspots are more common during solar minimum and less common during solar maximum.
- The number of sunspots increases and decreases through an average cycle of 11 years.
HOW WE TRACK CORONAL HOLES
Calculating the Centroids of Coronal Holes

- Before we can find the slopes of the coronal holes, we must first calculate the centroids of the coronal holes in the stack plots.
- I developed a new method to do this and used Mathematica to implement this method.
- The method can be broken down into a simple two step process.
  1. Mathematically represent the coronal holes.
  2. Use Integration to calculate the x and y coordinates of the coronal holes.
PARAMETRIZING ANYTHING
How These Equations are Made

- Images of the stack plots are put through a color filter to isolate the positive and negative coronal holes.
- Each stack plot image is split into smaller images, showing the latitude bands during each Carrington rotation.
- Mathematica then extracts the pixel coordinates at the edges of each of the coronal holes and performs Fourier transformations on these points.
- This creates pairs of trigonometric equations for the x and y values.
- Together these equations create curves that model the contours of the coronal holes.
Calculating Centroids Using Line Integration

- To calculate the centroid of 2-D objects it is common to use double integration.
- However, these integrals are not compatible with parametric equations.
- Fortunately, it is possible to use line integrals as a substitute.
- All we need to do is convert between the two.
- This can be done with using Greens Theorem.
Calculating Centroids Using Line Integration

\[ \bar{x} = \frac{M_y}{m} \rightarrow \frac{\iint_{R} x \rho(x,y) \, dA}{\iint_{R} \rho(x,y) \, dA} = \frac{\rho(x,y) \iint_{R} x \, dA}{\rho(x,y) \iint_{R} dA} = \frac{1}{A} \iint_{R} x \, dA \]

\[ \bar{y} = \frac{M_x}{m} \rightarrow \frac{\iint_{R} y \rho(x,y) \, dA}{\iint_{R} \rho(x,y) \, dA} = \frac{\rho(x,y) \iint_{R} y \, dA}{\rho(x,y) \iint_{R} dA} = \frac{1}{A} \iint_{R} y \, dA \]

\[ \oint_{C} \vec{F} \cdot d\vec{r} = \oint_{C} P \, dx + Q \, dy = \iint_{R} \text{curl} (\vec{F}) \, dA = \iint_{R} \frac{\partial Q}{\partial x} - \frac{\partial P}{\partial y} \]

Converting \( \bar{x} \) to a line integral.

- For what force field does \( \frac{\partial Q}{\partial x} - \frac{\partial P}{\partial y} = \bar{x} \)

- If \( \frac{\partial Q}{\partial x} = \bar{x} \) and \( \frac{\partial P}{\partial y} = 0 \) then the force field \( \vec{F} = \left(0, \frac{1}{2}x^2\right) \)

- So \( \bar{x} = \frac{1}{A} \oint_{C} \frac{1}{2} x^2 \, dy = \frac{1}{2A} \oint_{C} x^2 \, dy \)
Calculating Centroids Using Line Integration

- Converting $\bar{y}$ to a line integral.
  - For what force field does $\frac{\partial Q}{\partial x} - \frac{\partial P}{\partial y} = y$
  - If $\frac{\partial Q}{\partial x} = 0$ and $\frac{\partial P}{\partial y} = -y$ then the force field $\vec{F} = \left(-\frac{1}{2} y^2, 0\right)$
  - So $\bar{y} = \frac{1}{A} \phi_c - \frac{1}{2} y^2 \int dx = -\frac{1}{2A} \phi_c y^2 \int dx$
- So the two line integrals
  - $\frac{1}{2A} \phi_c x^2 \int dy$ and $-\frac{1}{2A} \phi_c y^2 \int dx$ calculate the x and y component of the centroid point $(\bar{x}, \bar{y})$ respectively.
Problems with Centroid Method

- Most of the time the centroid method is accurate.
- However the x or y values of the centroids are sometimes way off and not even on the coronal hole.
- This seems to happen for small coronal holes.
- Fortunately, this doesn’t happen very often and there are plenty of coronal hole pattern to observe at each central latitude.
Finding the Slopes

- After the centroids of the coronal holes were calculated the coordinates the x values were converted to longitude.
- The longitudes were then plotted on a Longitude vs. Time graph.
- Then to get the slopes we found the line of best fit.
- For four central we chose a long-lived coronal hole pattern to find the slope of.
- Ideally if we had more time we would have found more for each latitude and took the average.
RESULTS: CARRINGTON ROTATION RATES VS DIFFERENTIAL ROTATION
Conclusions

- Seeing how much the rotational rates of these coronal holes differs from the differential rotation will tell us how much its movement is being influenced by other phenomena.

- One of the biggest causes of coronal hole movement other than the differential rotation is Rossby waves.

- After we get more and better data of the coronal holes rotation rates at different latitudes, this will be the focus of our research.

- Learning more about these waves could possibly help us make better predictions of coronal mass ejections.

- Better predictions, would help us better prepare for natural disasters caused by these events.
QUESTIONS