Interpreting Solar Activity: Vorticity and Helicity Patterns Across Various Depths

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Introduction

Carrington Rotation: Carrington rotation is a unit of time measurement based on the Sun's rotation on its axis. One Carrington rotation equals approximately 27.2753 Earth days.

Vorticity: Measures the local spinning or rotational motion in a fluid flow.

Helicity: Measure of the intertwining or ‘knottedness’ of the flow patterns, the correlation between velocity and vorticity fields.

Objective: Uncover correlations between solar activity and fluid dynamics.

Importance: Understand the fluid dynamics of the Sun and the potential effects of solar phenomena.

Data Used

Source:

- The Solar Dynamics Observatory's Helioseismic and Magnetic Imager (SDO/HMI) offers uninterrupted, comprehensive observation of solar oscillations across the entire solar disk.

Horizontal flow velocities with 8 depth intervals (0 - 21 Mm)

- Depth ranges in Mm : 0 - 1, 1 - 3, 3 - 5, 5 - 7, 7 - 10, 10 - 13, 13 - 17, 17 - 21
- North-South (v_y) and East-West velocity (v_x) FITS files for calculating vorticity and helicity.
- Absence of radial flows.

Flow maps are obtained every 8 hours.

Horizontal spatial sampling of 0.12° per pixel.

Methodology: Mathematical Calculations

Vorticity : $\omega = \nabla \times \overline{v}$

Vorticity for a 2D flow: $\omega = \frac{\partial v_y}{\partial x} - \frac{\partial v_x}{\partial y}$

Helicity : $H = \int \overline{v} \cdot \overline{\omega}\, dV$

Mean Helicity: $H = \langle \overline{v} \cdot \overline{\omega} \rangle$

Helicity in the absence of radial flows:

- Given only horizontal velocities: v_x and v_y
- Estimate radial velocity using the divergence of horizontal flows: $v_z = \frac{\partial v_y}{\partial x} + \frac{\partial v_x}{\partial y}$

Methodology: Vorticity and Helicity Calculations

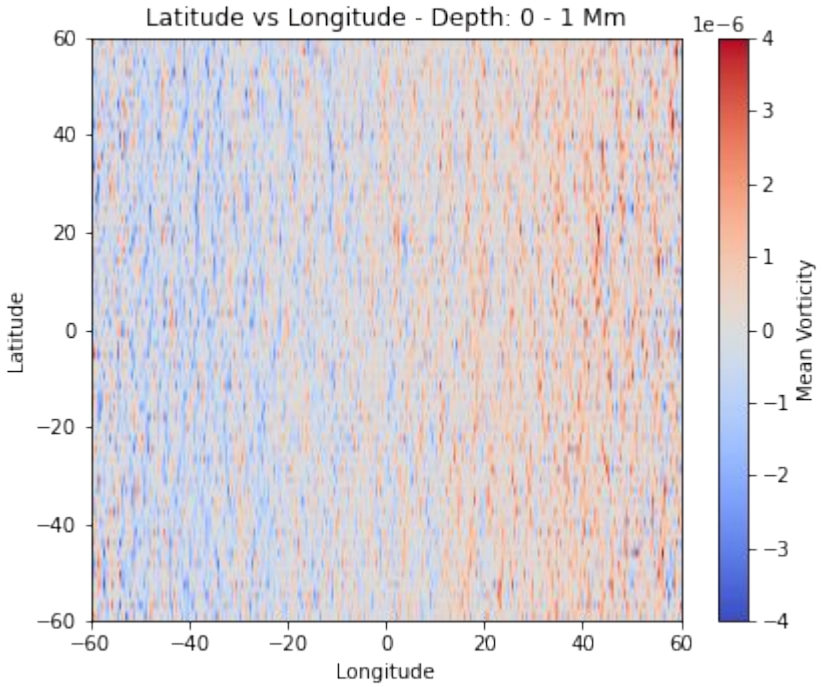
1. **Data Preparation:** Use Python's FITS handling capabilities to load horizontal and vertical velocity data across different solar depths.
2. **Pixel Size Calculation:** By using the known solar radius and the angular size of each pixel, we convert the pixel size from angular degrees to physical meters. This allows us to relate the data to real-world spatial measurements on the Sun.
3. **Depth-wise Calculations:** Perform vorticity and helicity calculations for the range of solar depths (0-21 Mm).
4. **Vorticity Calculation:** Derive vorticity by evaluating the difference between North-South and East-West velocity gradients.
5. **Helicity Calculation:** Compute helicity as a correlation between the velocity fields and vorticity, thereby assessing the 'knottedness' of the flow. In this case, we have to estimate the radial velocity using the divergence of flows.

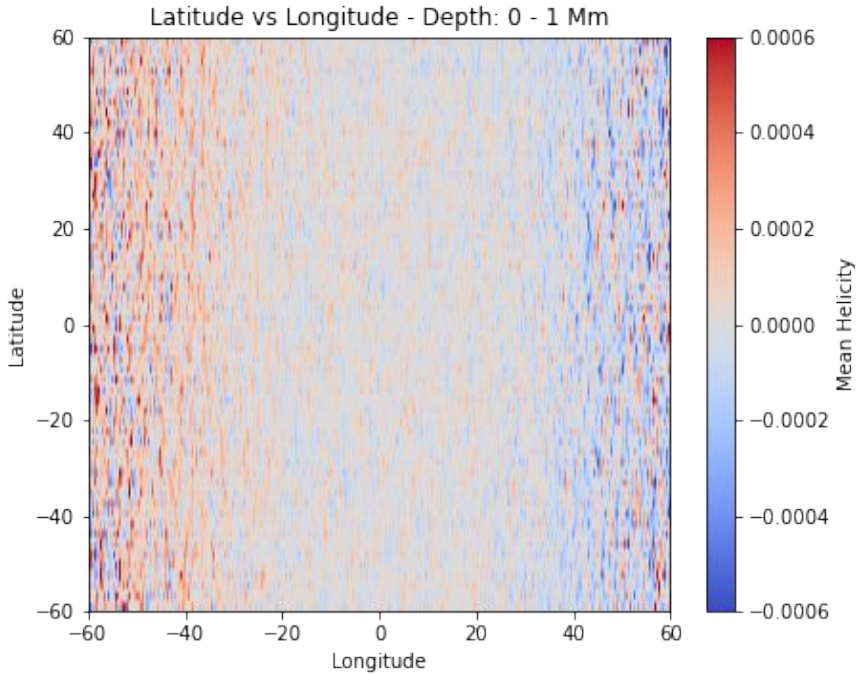
This set of steps forms the base of our methodology, where we load our data, process it, and finally visualize it to understand the patterns and correlations.

Methodology: Visualizing Results

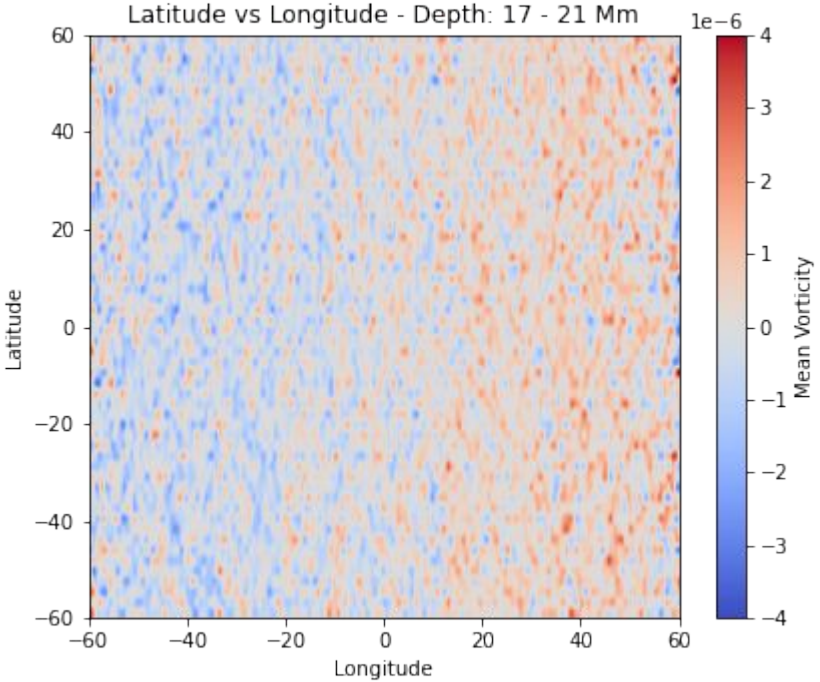
1. **Data processing:**
    a. Computation of vorticity and kinetic helicity maps.
    b. Create synoptic maps for vorticity and helicity showcasing 'Latitude vs Longitude' at varying solar depths.
    c. Investigate distribution with depth and time
2. **Data Visualization:**
    a. Use of Python package ‘matplotlib’ for creating visualizations.
    b. Application of color mapping techniques to showcase data variations.
    c. Incorporation of grid, labels, color bars, and legends to enhance data interpretation.

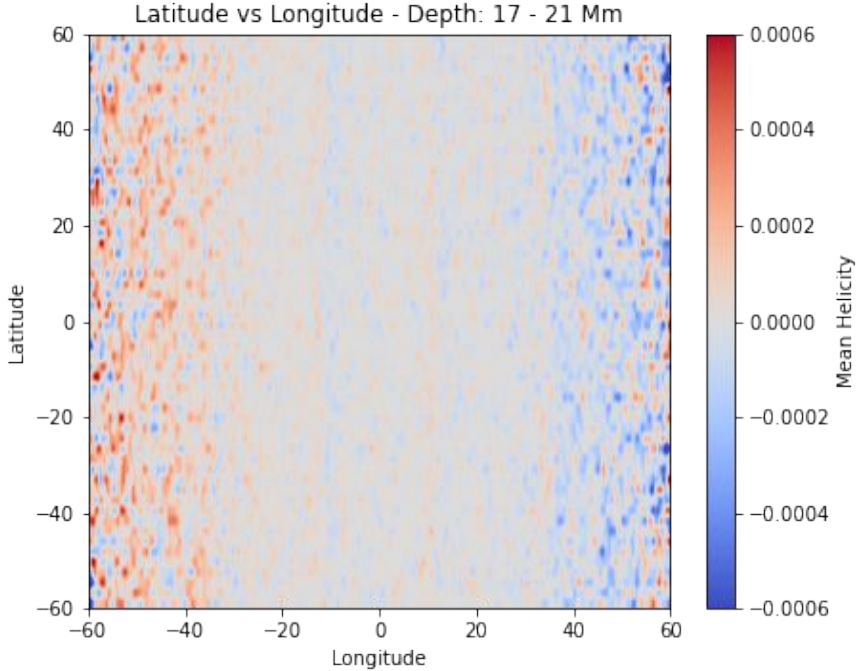
Mean Vorticity and Helicity: CR2096, 0-1 Mm



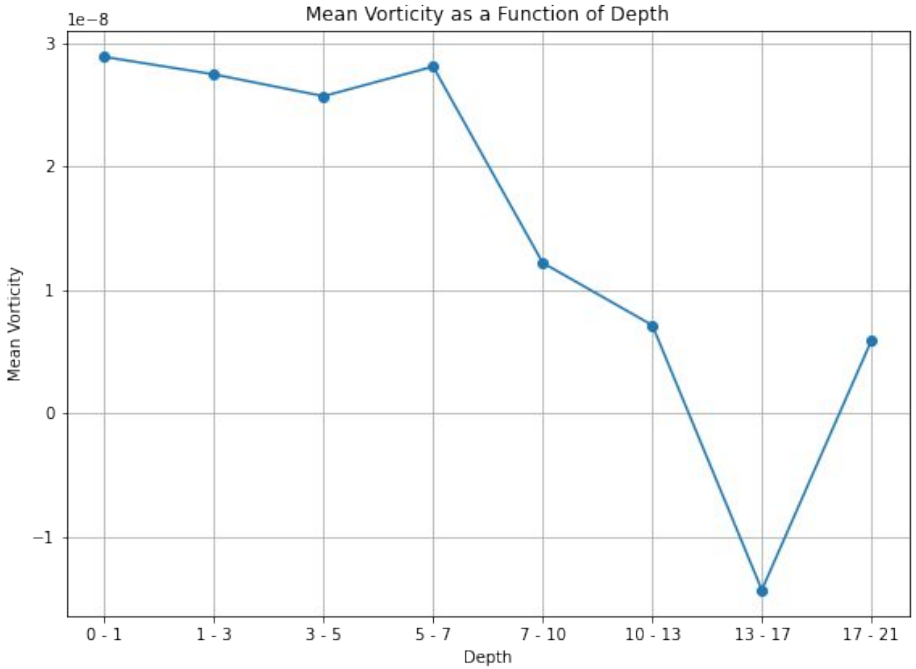


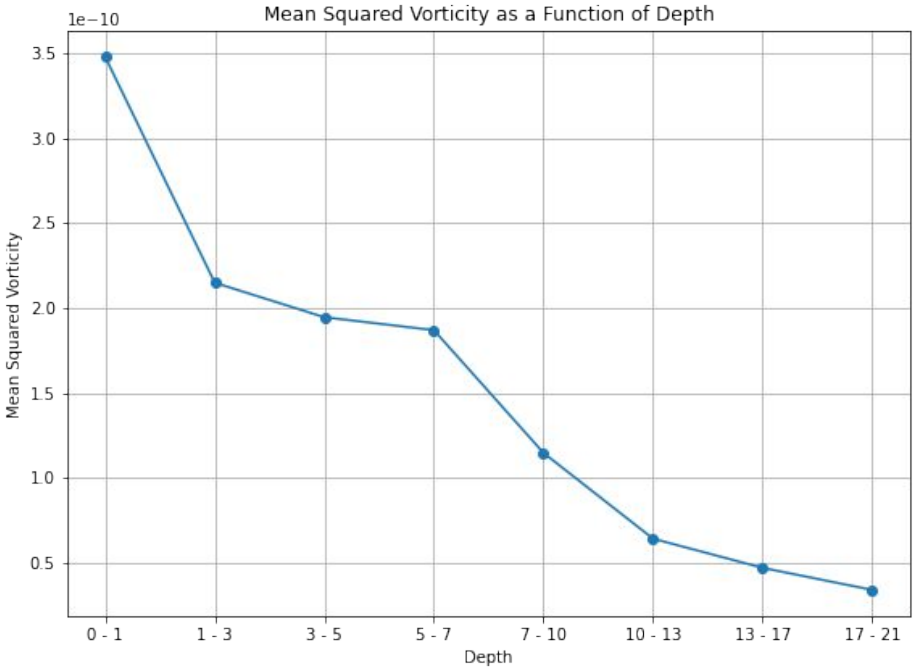
Mean Vorticity and Helicity: CR2096, 17-21 Mm



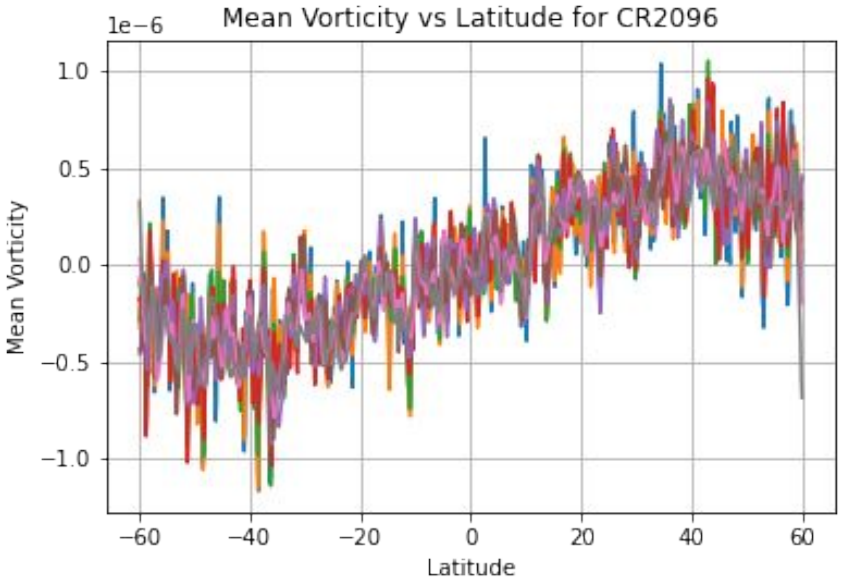


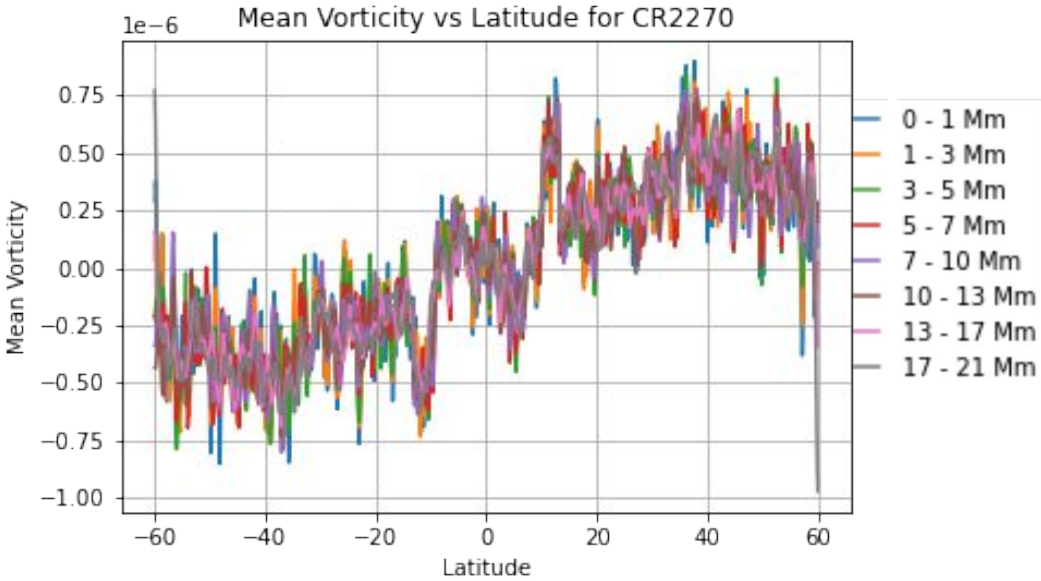
Vorticity as a Function of Depth: CR2096, May 1, 2010 at 04:00 UTC



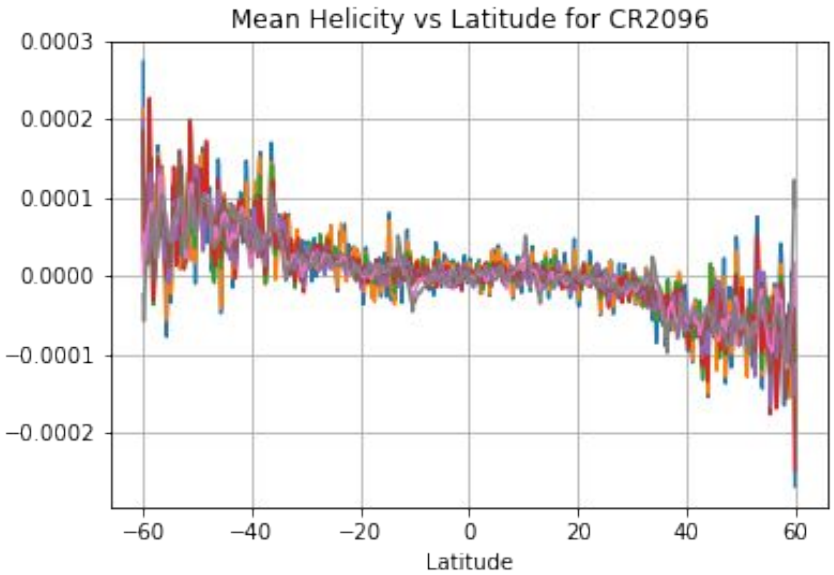


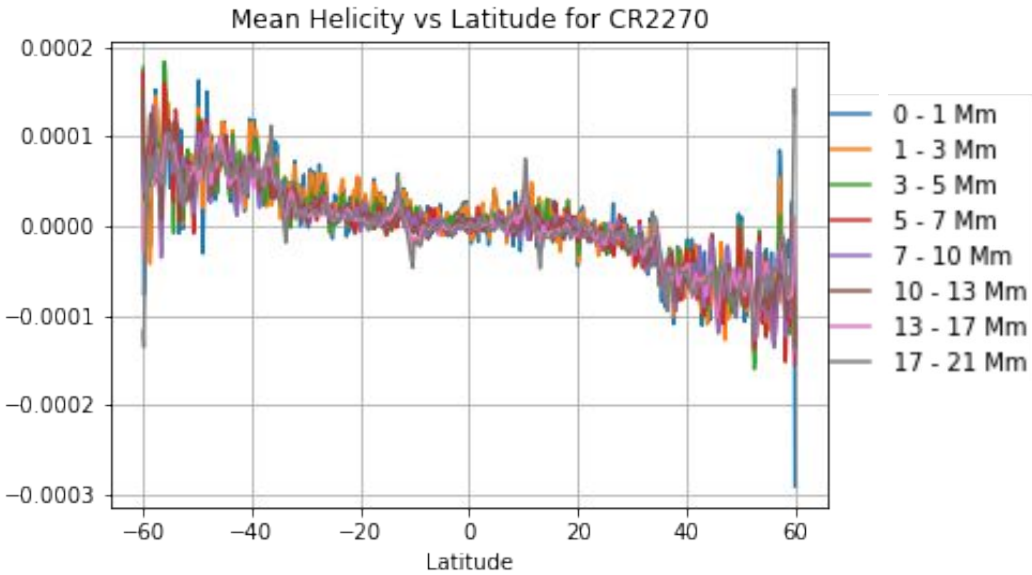
Mean Vorticity vs. Latitude: CR2096 & CR2270





Mean Helicity vs. Latitude: CR2096 & CR2270





Obstacles & Lessons Learned

Obstacles:

1. *Challenge with data* - Difficulties with handling large data sets, working with the NAS systems and transporting files
2. *Technical challenges* - Overall difficulties with coding, adapting standard helicity equations to accommodate data set constraints, and Issues with email communication affecting feedback and guidance.

Lessons Learned:

1. *Technical skills* - Improved Python coding skills, better understanding of cross-correlation methods, and visualization techniques
2. *Conceptual Understanding* - Deeper knowledge of solar physics, the importance of vorticity and helicity in helioseismology

Conclusion

1. Achievements:

- Developed coding proficiency to compute and visualize data.
- Produced visualizations, including various maps and plots of vorticity and helicity, to illustrate solar dynamics.
- Explored solar dynamics variations, gaining insights into solar phenomena.

2. Future Direction:

- Compute synoptic maps for the kinetic helicity and vorticity.
- Perform a 2D cross correlation analysis with a time lag, comparing magnetograms with vorticity and helicity maps.
- Anticipate discovering more nuanced correlations between vorticity and helicity.

3. Potential Impact:

- Enhanced efficiency in data processing.
- Provision of insights that could advance our understanding of solar dynamics.

Acknowledgements

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