Investigating Plasma Flows in Sunspots with Numerical Simulation Analysis

4 August 2010

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Our research has focused on the plasma flows observed in the penumbra and moat region of model sunspots in an effort to better understand the complex magnetic and thermal structure of these solar features. More specifically, numerical simulation analysis focused on azimuthally time-averaged radial velocities in the uppermost regions for 3 different sunspot models. The three models consisted of a stable sunspot with a penumbra and moat region, a model without a penumbra and a model without a penumbra and that was also decaying throughout its time-evolution. The velocities in both negative and positive vertical magnetic regions were calculated for each sunspot model. Our analysis showed a clear relationship between fast, outward flows in negative vertical magnetic field regions and slower, inward flows in positive vertical magnetic field regions. Because these models have a higher resolution than solar observing instruments, we reduced the resolution of our own data to allow observers to compare to our data. Essentially, the same relationships were found. We also used correlation-tracking methods to check that a similar relationship occurred between magnetic field regimes and average radial velocities. A similar trend was found, but with less strength than the previous results. To help explain these relationships, we have considered geometric effects of observing as well as the sum of the forces acting on plasma flows in positive and negative magnetic field regions within the sunspot models. It appears that the vertical convective flows in sunspots and the geometry of our analysis accounts for our results, although further analysis would help strengthen this conclusion. We also examined the believed connection between the horizontal outward flows in the penumbra (Evershed flow) and the MMF activity in the moat region of the sun. We found that type 3 MMFs--a fast moving, unipolar, opposite polarity moving magnetic feature--appear to have no connection to the Evershed flow.