Dynamics in the Upper Solar Convection Zone

by

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Dynamics in the Upper Solar Convection Zone

Thesis directed by Professor Juri Toomre

The differential rotation of the sun, as deduced from helioseismology, exhibits a prominent layer of radial shear near the top of the convection zone. This shearing boundary layer just below the solar surface is composed of convection possessing a broad range of length and time scales, including granulation, mesogranulation, and supergranulation. Such turbulent convection is likely to influence the dynamics of the deep convection zone in ways that are not yet fully understood. We seek to assess the effects of this near-surface shear layer through two complementary studies, one observational and the other theoretical in nature. Both deal with turbulent convection occurring on supergranular scales within the upper solar convection zone.

We characterize the horizontal outflow patterns associated with solar supergranulation by individually identifying several thousand supergranules from a 45°-square field of quiet sun. This region is tracked for a duration of six days as it rotates across the disk of the sun, using full-disk ($2''$ pixels) SOI-MDI images from the SOHO spacecraft of line-of-sight Doppler velocity imaging the solar photosphere at a cadence of one minute. This time series represents the first study of solar supergranulation at such high combined temporal and spatial resolution over an extended period of time. The outflow cells in this region are observed to have a distribution of sizes, ranging from 14–20 Mm across, while continuously evolving on time scales of several days. Such evolution manifests itself in the form of cell merging, fragmentation, and advection, as the supergranules and their associated network of convergence lanes respond to the turbulent convection occurring a short distance below the photosphere.

We have also conducted three-dimensional numerical simulations of turbulent compressible convection within thin spherical shells located near the top of the convection zone. Vigorous fluid motions possessing several length and time scales are driven by imposing the solar heat flux and differential rotation at the bottom of the domain. The convection patterns form a connected network of downflow lanes in the surface layers that break up into more plume-like structures with depth. The regions delineated by this downflow network enclose broad upflows that fragment into smaller structures near the surface. We find that a negative radial gradient of angular velocity Ω is maintained against diffusion in these simulations by the tendency for the convective motions to partially conserve their angular momentum in radial motion. This behavior suggests that similar dynamics may be responsible for the decrease of Ω with radius as deduced from helioseismology within the upper shear layer of the solar convection zone.

Dedication

To my parents, Pete and Cindy, and to my sister Lisa.

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