

INFERENCE OF SOLAR SUBSURFACE FLOWS BY  
TIME-DISTANCE HELIOSEISMOLOGY

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DOCTOR OF PHILOSOPHY

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I certify that I have read this dissertation and that, in my opinion, it is fully adequate in scope and quality as a dissertation for the degree of Doctor of Philosophy.

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# Abstract

The inference of plasma flow fields inside the convection zone of the Sun is of great importance. On the small scales, this helps us to understand the structure and dynamics of sunspots and supergranulation, and the connections between subsurface flows of active regions and coronal activity. On the large scales, it helps us to understand solar magnetic cycles and the generation and decay of solar magnetic fields. In this thesis, the flow fields in the upper convection zone are inferred on both large and small scales by employing time-distance helioseismology.

A detailed description of time-distance measurements is presented, together with the derivation of the ray-approximation kernels that are used in data inversion. Two different inversion techniques, the LSQR algorithm and Multi-Channel Deconvolution, are developed and tested to infer the subsurface sound-speed variations and three-dimensional flow fields. The subsurface flow field of a sunspot is investigated in detail, converging flows and downdrafts are found below the sunspot's surface. These flows are believed to play an important role in keeping the sunspot stable. Subsurface vortical flows found under a fast-rotating sunspot may imply that part of the magnetic helicity and energy to power solar flares and CMEs is built up under the solar surface. A statistical study of numerous solar active regions reveals that the sign of subsurface kinetic helicity of active regions has a slight hemispheric preference.

On the large scales, latitudinal zonal flows, meridional flows and vorticity distribution are derived for seven solar rotations selected from years 1996 to 2002 from SOHO/MDI Dynamics data, covering the period from solar minimum to maximum. The zonal flows display mixed faster and slower rotational bands, known as torsional oscillation. The residual meridional flows, after the meridional flow of the minimum

year is subtracted from the flows of each following year, display a converging flow pattern toward the active zones in both hemispheres. The global vorticity distribution is largely linear with latitude, mainly resulting from the solar differential rotation. In addition, a linear relation between the rotation rate of the magnetized plasma and its magnetic field strength is found: the stronger the magnetic field, the faster the plasma rotates.

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