Solar physics – overview

The sun contains turbulent velocity fields and strong magnetic fields that vary over many scales in space and time, and there are numerous physical phenomena at play that are closely coupled in nonlinear ways. Hence it is a system akin to many of those historically studied at the CTR. Furthermore, the sun is of immediate importance to life on earth and to space exploration through its effects on space-weather and its driving input of heat to earth's climate, making its study of prime importance to both NASA and the academic community. Many problems remain to be solved. The turbulent generator of the solar magnetic field, the solar dynamo, is not well understood or even satisfactorily characterized. The global solar velocity field is also not fully characterized or understood. These problems are difficult to study through observation because only the surface and atmosphere of the sun are directly observable; interior conditions must be inferred by indirect methods, such as theoretical modeling and helioseismology. The models contain many simplifying assumptions and need to be verified and refined by a combination of observation and simulation. Helioseismic deductions about the internal conditions depend on assumptions about those conditions, and self-consistency checking is therefore of paramount importance. A number of research topics concerned with these overall scientific questions were taken on by the summer visitors in collaboration with resident researchers.

Busse studied the Evershed flow in the penumbra of sunspots via a theoretical analysis in idealized conditions. This flow has been extensively studied at CTR by Kitiashvili using simulation. The physical situation is convective flow in a steeply inclined magnetic field. Busse found that oscillatory instabilities in convective rolls at low Prandtl number generate Reynolds and Maxwell stresses, and these in turn give rise to a shear flow similar to that believed to underlie the Evershed effect and also observed in the simulations.

Rogachevskii *et al.* studied the formation of compact magnetic structures in the upper solar convection zone using a new subgrid turbulence model which includes effects of subgrid motion on the Lorentz force. Magnetic flux tubes were found to spontaneously form when the initial magnetic field is above 100 G. They then compiled vertical profiles of the physical properties of this simulated magnetic structure.

Simitev, Busse, and Kosovichev simulated thin rotating shells to study convection-driven dynamos. These flows transition from a strong, non-oscillatory dipolar magnetic field structure to a weaker, regularly oscillating one. This transition was found to be mainly a result of the stress-free boundary conditions and only weakly dependent on the shell's inner-outer radius ratio.

Simitev and Busse simulated boundary-free convection by creating an unstable layer inside a stably stratified one, with no boundaries between them. Convection develops in the unstable inner layer and eventually results in a stable mean profile in the previously unstable region. However, convection continues to persist due to lateral temperature variations, and a new class of convective phenomena is expected to be present in such flowfields.

Yokoi *et al.* studied the generation and transport of cross-helicity (velocity-magnetic-field correlation) in several MHD flows. Cross-helicity contributes to the electromotive force in turbulent flows, and its role in dynamo field generation can be important. Generation of cross-helicity was studied in a Kolmogorov flow, in a rotating spherical shell, and in the vicinity of a simulated sunspot. In all cases, cross-helicity generation occurred. Comparison with kinetic helicity under magnetic reversal was done using the spherical shell as a solar convection-zone analog, and compressible vs. incompressible generation mechanisms were investigated.

Balarac *al.* studied eight models for the sub-grid-scale term in the filtered magnetic-field transport equation. They looked at *a priori* local accuracy of the modeled term as well as its energetic effects as compared to DNS in decaying isotropic turbulence. The main conclusion was that a mixed model based on the scale similarity model performs best, and that a dynamic formulation based on the divergence of the stress tensor improves results over those based on the full tensor.

Kitiashvili *et al.* studied spontaneous formation of concentrated magnetic structures and high-speed flows in the filamentary structure of sunspots. Details of the role of turbulent vortices was highlighted in the formation of pore-like magnetic field configurations and in the flows that comprise the Evershed effect in sunspot penumbae.

Parchevsky and Kosovichev simulated linear MHD waves in the solar-like conditions of strong density and pressure stratification combined with the non-uniform magnetic fields and background flows typical of sunspots. Excitation, propagation, and transformation of the waves were studied with the goal of producing artificial data to test and calibrate the helioseismic inversions used to analyze observational data. The ray-path approximation used to reconstruct sub-photospheric flows was found to be in good agreement with the simulations. Detailed analyses of wave transformation and distortion in a sunspot model were also performed.

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