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Editorial: Connecting solar flows and fields to understand surface magnetism

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Editorial on the Research Topic
Connecting solar flows and fields to understand surface magnetism

Our understanding of the plasma motion below the solar surface and various phenomena occurring above the surface has advanced significantly in last couple decades. This has led to many new discoveries by expanding our knowledge of how the solar interior and atmosphere are interconnected. At the same time, they have raised many new challenges to our understanding of interior dynamics and magnetic field generation. For example, we do not have precise understanding of when and where active regions will emerge. Studies indicate puzzling and contradictory results regarding the cell structure of meridional circulation (Gizon et al., 2020). Furthermore, observations covering the last two deep and extended periods of low magnetic activity raise several additional questions about our understanding of the solar dynamo (Jain et al., 2022). Do we have precise knowledge that can be applied to forecast the strength and timing of future solar cycles with some confidence (Pesnell, 2020)? Uninterrupted full-disk high-spatial resolution observations from Global Oscillation Network Group (Harvey et al., 1996), Michelson Doppler Imager (Scherrer et al., 1995), and Helioseismic and Magnetic Imager (Scherrer et al., 2012) for more than two solar cycles have played a crucial role in addressing these questions, however many unsolved problems remain that require better understanding of both observational and theoretical aspects.

In this Research Topic, our aim was to provide researchers an opportunity to present their work focusing on a) how recent observations enriched our understanding of solar flows and fields; b) the links between interior and atmosphere of the Sun; c) the processes responsible for magnetic field generation, transport of dynamo-generated magnetic flux, flux emergence to the surface and its global distribution; d) the hidden problems in the understanding of various solar phenomena and interpreting observations; and (e) how solar flows and fields can provide new insight into solar activity forecasting, e.g., strength of the forthcoming cycle, emergence of active regions, precursors of eruptive events and space weather.

The availability of quarter-century time series opens the possibility of carrying out detailed analyses of temporal changes occurring in different layers below and above the surface. However, this remains challenging in both global and local helioseismic studies due to the complicated mode fitting procedures. Studies based on fitting contemporaneous observations from different instruments or pipelines employing different approaches often produce inconsistent results. Korzennik compares mode characteristics from the fitting of global time series of all three instruments using the same methodology. The author also investigates the precision and systematic errors in each case, which are important for reconciling the inferences from multiple data sources.

The key aspects of the convection zone dynamics are Sun's axisymmetric flows, which are the principal drivers of the solar activity cycle. These flows are crucial components in solar dynamo models. While the shearing motions of differential rotation stretches north-south and radially oriented magnetic field in the azimuthal direction to generate sunspot-producing fields, from which bipolar active regions manifest at the surface, the meridional circulation transports magnetic field to the poles that reverses the polar fields at cycle maximum. The polar fields undoubtedly play a crucial role in determining the strength of the next solar activity cycle. Hathaway et al. discuss variations of these flows in the near-surface shear layer over last two and a half solar cycles using magnetic pattern tracking on magnetograms. The authors provide evidence that the meridional flows tend to disappear above about 80° latitude, consistent with *ad hoc* assumptions in some surface flux transport models.

Komm determines the radial gradient of the solar rotation rate in the near-surface shear layer using local helioseismic techniques applied to Doppler observations. The rotation rate shows a local maximum near 0.950 R_{Sun} and decreases toward the solar surface. A precise understanding of such a shear layer is pivotal for solar dynamo. The author finds that the amplitude of the radial gradient increases rapidly toward the solar surface in a thin layer between 0.986 R_{Sun} and 0.998 R_{Sun} but it starts decreasing slowly with greater depth below this range. The radial gradient also varies with the solar cycle and has opposite behaviour at the locations of high- and low-magnetic activity. These results may be crucial in constraining solar models.

The precise understanding of the interaction of magnetic field with acoustic waves has been a topic of debate in recent years. Both global and local helioseismic studies have significantly contributed to our knowledge on this topic however, studies involving sunspots and active regions are extremely challenging. Despite an abundance of clues from observations at the solar surface and the applications of helioseismic techniques, theories about the formation, subsurface structure, and thermal properties of active regions remain controversial. Tripathy presents various aspects of this intriguing puzzle and reviews its future prospects. The author further discusses possible observational and theoretical scenarios that may provide important clues for solving this continuing conundrum.

Important recent developments involve the application of helioseismic and magnetic-field measurements to predict space weather. These include the detection of active regions on the unobserved far side of the Sun and the forecasting of extreme space weather events such as solar flares and coronal mass ejections. Increasing space exploration and the applications of modern technology demand reliable forecasting of such energetic events. Though this is an emerging area of research and still limited by analysis techniques, encouraging results have been obtained. Lekshmi et al. explore the correlation between the fluid dynamics descriptors, e.g., the flow divergence, vorticity, and kinetic helicity, that are derived from the subsurface flow measurements and corresponding magnetic field parameters several days prior to flaring events. The authors show that strong vorticity and kinetic helicity lead to greater active region twisting, presumably generating high-intensity flares.

In conclusion, the connection between solar flows and the magnetic fields has rich potential for advancing our understanding of the solar dynamo and forecasting space weather with new and improved data analysis tools, methodologies and models.

Author contributions

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References

Gizon, L., Cameron, R. H., Pourabdian, M., Liang, Z.-C., Fournier, D., Birch, A. C., et al. (2020). Meridional flow in the Sun's convection zone is a single cell in each hemisphere. *Science* 368, 1469–1472. doi:10.1126/science.aaz7119

Harvey, J. W., Hill, F., Hubbard, R. P., Kennedy, J. R., Leibacher, J. W., Pintar, J. A., et al. (1996). The global oscillation Network Group (GONG) project. *Science* 272, 1284–1286. doi:10.1126/science.272.5266.1284

Jain, K., Jain, N., Tripathy, S. C., and Dikpati, M. (2022). What seismic minimum reveals about solar magnetism below the surface. *Atrophy. J. Letts.* 924, L20. doi:10.3847/2041-8213/ac3de9

Pesnell, W. D. (2020). Lessons learned from predictions of solar cycle 24. *J. Space Weather Space Clim.* 10, 60. doi:10.1051/swsc/2020060

Scherrer, P. H., Bogart, R. S., Bush, R. I., Hoeksema, J. T., Kosovichev, A. G., Schou, J., et al. (1995). The solar oscillations investigation - Michelson Doppler imager. *Sol. Phys.* 162, 129–188. doi:10.1007/BF00733429

Scherrer, P. H., Schou, J., Bush, R. I., Kosovichev, A. G., Bogart, R. S., Hoeksema, J. T., et al. (2012). The helioseismic and magnetic imager (HMI) investigation for the solar dynamics observatory (SDO). *Sol. Phys.* 275, 207–227. doi:10.1007/s11207-011-9834-2