Long-Term Datasets for the Understanding of Solar and Stellar Magnetic Cycles
Proceedings IAU Symposium No. 340, 2018
D. Banerjee, J. Jiang, K. Kusano & S. Solanki, eds.

doi:10.1017/S1743921318001242

22 Year Solar Magnetic Cycle and its relation to Convection Zone Dynamics

Kiran Jain[1], **Sushanta Tripathy**[1], **Rudolf Komm**[1], **Frank Hill**[1] **and Rosaria Simoniello**[2]

[1]National Solar Observatory, 3665 Discovery Drive, Boulder, CO 80303, USA
email: kjain@nso.edu, stripathy@nso.edu, rkomm@nso.edu, fhill@nso.edu

[2]Geneva Observatory, University of Geneva, Geneva, Switzerland
email: rosaria.simoniello@unige.ch

Abstract. Using continuous observations for 22 years from ground-based network GONG and space-borne instruments MDI onboard *SoHO* and HMI onboard *SDO*, we report both global and local properties of the convection zone and their variations with time.

Keywords. Sun: activity, Sun: helioseismology, Sun: oscillations, Sun: interior

1. Introduction

The dynamics of the convection zone plays a crucial role in understanding the activity cycles and to predict the strength of the next solar cycle. The solar dynamo, which governs the solar activity, is believed to be seated in a thin layer called the *tachocline* located at the base of the convection zone. It can only be studied by using the techniques of helioseismology, where propagating acoustic waves are used to infer the properties of the region they travel through. The availability of continuous Dopplergrams at high-resolution and high-cadence allow us to map this region over a complete Hale magnetic cycle. Here, we present some important results from our ongoing investigations.

2. Data and Results

The data used here are from a ground-based network, Global Oscillation Network Group (GONG), and the space-borne instruments Michelson Doppler Imager (HMI) onboard *SoHO* and Helioseismic and Magnetic Imager (HMI) onboard *SDO*.

The oscillation frequencies vary in phase with the solar activity cycle and display a strong correlation between them. However, un-interrupted observations for complete solar cycles suggest that the correlation changes when the individual phases of the solar cycle are considered (Figure 1), in particular it decreases significantly during the minimum phase (Jain *et al.* 2009). In addition to the variation on a solar-cycle time scale, the oscillation frequencies also have a periodicity of approximately two years (Simoniello *et al.* 2013). Further, similar to the magnetic activity on the solar surface, the oscillation frequencies also display the hemispheric asymmetry (Tripathy *et al.* 2015) as well as the latitudinal progression of the solar cycle in the convection zone (Simoniello *et al.* 2016).

The Dopplergrams are also used to map the flows in convection zone at different latitudes as well as hemispheres. The zonal flow has bands of faster and slower rotations, the patterns commonly known as the torsional oscillations (Komm *et al.* 2014). The meridional flows are poleward with a peak amplitude of about 16 to 20 m/s depending on the depth at about 40° latitude (Komm *et al.* 2015). These continuous observations

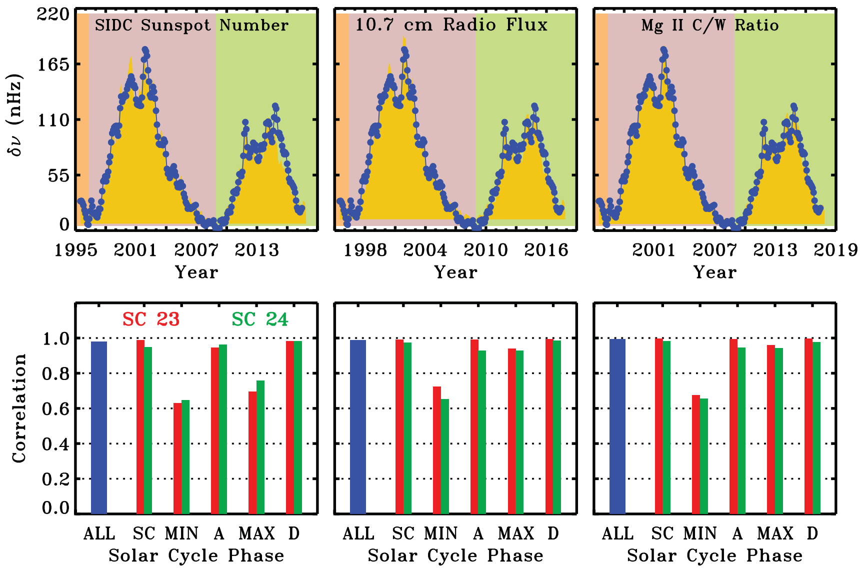

Figure 1. (Upper panels) Temporal variation of frequency shifts ($\delta\nu$) for common modes in all GONG data sets. Errors in calculated shifts are smaller than the size of the symbols. Filled areas show the variation of solar activity indices. (Lower panels) The Pearson's linear correlation for different phases: minimum (MIN), ascending (A), maximum (MAX), and descending (D).

further allow us to study the subsurface characteristics of active regions (ARs) (e.g., Jain *et al.* 2017, and references therein). Using GONG Dopplergrams, we have investigated the plasma flow beneath AR 10486 and AR 12192. These were the biggest ARs of their respective solar cycles and produced several high M- and X-class flares but with different CME productivity. We find that these ARs had unusually large horizontal flow amplitude with distinctly different directions. While meridional flow in AR 12192 was poleward, it was equatorward in AR 10486 (Jain *et al.* 2017). The flow patterns produced strong twists in horizontal velocity with depth in AR 10486 that persisted throughout the disk passage, as opposed to AR 12192, which produced a twist only after the eruption of the X3.1 flare that disappeared soon after.

In summary, the observations spanning two solar cycles have significantly advanced our understanding of the different layers below the surface. However, there are still many areas where the results are inconclusive due to large discrepancies between different methods and also between data from different instruments. Hence, long-term observations for many more cycles are essential to fully understand the dynamics of the convection zone.

Data were acquired by GONG instruments operated by NISP/NSO/AURA/NSF. *SoHO* is a mission of international cooperation between ESA and NASA. *SDO* data courtesy of *SDO* (NASA) and the HMI and AIA consortium.

References

Jain, K., Tripathy, S. C., & Hill, F., 2009, *ApJ*, 695, 1567
Jain, K., Tripathy, S. C., & Hill, F., 2017, *ApJ*, 849, 94
Komm, R., González Hernández, I., Howe, R., & Hill, F., 2015, *Sol. Phys.*, 290, 3137
Komm, R., Howe, R., González Hernández, I., & Hill, F., 2014, *Sol. Phys.*, 289, 3435
Simoniello, R., Jain, K., Tripathy, S. C., *et al.*, 2013, *ApJ*, 765, 100
Simoniello, R., Tripathy, S. C., Jain, K., & Hill, F., 2016, *ApJ*, 828, 41
Tripathy, S. C., Jain, K., & Hill, F., 2017, *ApJ*, 812, 20

https://doi.org/10.1017/S1743921318001242 Published online by Cambridge University Press