Long-Term Datasets for the Understanding of Solar and Stellar Magnetic Cycles
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Asymmetry in Solar Torsional Oscillation

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Abstract. Solar torsional oscillations are migrating bands of slower and faster than average rotation, which are thought to be related to the Sun's magnetic cycle. We perform the first long-term study (16 years) of hemispherical asymmetry in solar torsional oscillation velocity using helioseismic data. We explore the spatial and temporal variation of North-South asymmetry using zonal flow velocities obtained from ring diagram analysis of the Global Oscillation Network Group (GONG) Doppler images. We find a strong correlation between the asymmetries of near-surface torsional oscillation with magnetic flux and sunspot number, with the velocity asymmetry preceding in both the cases. We speculate that the asymmetry in torsional oscillation velocity may help in predicting the hemispherical asymmetry in the sunspot cycle.

1. Introduction

Solar torsional oscillations are bands of slower and faster than average rotation that migrate from mid latitudes towards the equator and poles during the solar cycle. We study the long term variation in the North-South asymmetry of solar torsional oscillations. The zonal flow velocities obtained from ring diagram analysis of GONG Dopplergrams for a period of 16 years (July 2001 to March 2017) which are made available from the GONG ring diagram analysis pipeline is used for this work. We study the variation in hemispherical asymmetry of torsional oscillations with time, latitude and depth. Observations show that the migration of zonal flow and active region magnetic flux are strongly related. Here we do a correlation analysis of the hemispherical asymmetry in torsional oscillation with the asymmetry in sunspot flux and number. We observe that the asymmetry in velocity precedes the asymmetries in sunspot flux and number and there exist a significant correlation between the asymmetries with a time delay.

2. Data and Analysis

We use the zonal flow velocity data obtained from GONG ring diagram analysis pipeline for the period July 2001 to March 2017 (Corbard *et al.* (2003), Hill *et al.* (2003)). The systematic effects due to the variation in B_0 angle is corrected, following the procedure mentioned by Komm *et al.* (2015). The data are then smoothed over 1 year to remove random fluctuations, which remain even after the B-angle correction. A 11 year average over each latitude and depth is subtracted from the zonal flow velocity at the same latitude and depth to obtain the residual rotation rate (Figure 1). Hemispherical asymmetry in torsional oscillation velocity ($U_{\rm North} - U_{\rm South}$) at different depths and latitudes are calculated as a function of time.

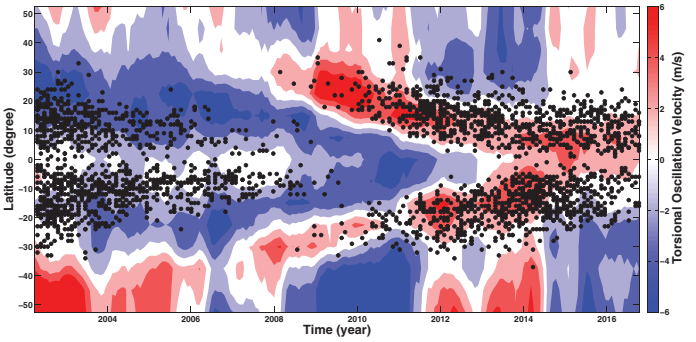

Figure 1. Contour plot of torsional oscillation (smoothed over 1 year) at a depth of 2 Mm from solar surface obtained from GONG ring diagram analysis as a function of latitude and time over-plotted with sunspot distribution (black circles). The zonal flow velocities are corrected for the effects due to B0-angle variation. A 11 year average is subtracted from the velocities at each latitude. The data covers the declining phase of cycle 23 and cycle 24 till 2016.

The sunspot data compiled by Royal Greenwich Observatory (RGO) and United States Air force/US National Oceanic and Atmospheric Administration (USAF/NOAA) are used for calculating the sunspot flux used in this study[(Sheeley 1966; Dikpati *et al.* 2006)]. The asymmetry in sunspot flux and number are quantified in the same way as that of torsional oscillation velocity. These asymmetries are correlated with the torsional oscillation asymmetry for a range of time delays (0 to 2.25 yars) with the velocity asymmetry preceding the sunspot cycle asymmetries.

3. Results

It is observed that there exist significant asymmetry between the torsional oscillation in both the hemispheres which varies temporally. Increase in asymmetry with depth and latitude is also observed. The northern branch of torsional oscillation is migrating faster than the southern branch for the present cycle. Significant correlation exist between the asymmetry in torsional oscillation velocity and the asymmetries in sunspot flux and number near the solar surface with the asymmetry in velocity preceding the sunspot cycle asymmetries. We speculate that it might be possible to use the asymmetry in torsional oscillations as a proxy for asymmetry in sunspot cycle.

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