Multi-wavelength analysis of active regions using ring-diagram technique

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Abstract. With the availability of high-cadence and high-resolution Doppler and intensity images from the *Solar Dynamics Observatory's* Helioseismic Magnetic Imager (HMI) and Atmospheric Imager Assembly (AIA), we analyze the characteristics of high-degree solar acoustic modes in active regions. We apply the ring-diagram technique to Doppler, continuum intensity measurements from HMI, and intensity images from AIA 1600 Å and 1700 Å passband to examine the high-degree mode parameters and sub-surface horizontal flows.

1. Introduction

Helioseismic studies using many different observables, which provides information at different heights in solar atmosphere, are important to determine the mode parameters precisely [1] as well as to characterize the systematic errors. With this goal in mind, we have previously analyzed [2] a few active regions using high-resolution observations of the Sun from Helioseismic Magnetic Imager (HMI). Here, we extend these analysis to include the intensity observations from Atmospheric Imager Assembly (AIA) on board *Solar Dynamics Observatory* (SDO) as well as the Doppler observations from Global Oscillation Network Group (GONG).

2. Data Analysis

The data used in this work consist of Doppler velocity (V) and continuum intensity (C) from HMI and 1600 Å and 1700 Å passband images from AIA with a cadence of 45 seconds and 48 seconds, respectively. For consistency checks, we also use GONG's Doppler (V_g) measurements where velocity observations are taken at a 1 minute cadence. It may be noted that the C, V, and V_g observables are formed around 20 km, 100 km, and 200 km while the AIA 1700 Å and 1600 Å bands are centered at 360 km and 480 km, respectively above the bottom of the photosphere [3].

The active regions that we select for this study consist of NOAA active regions (AR) 11092, 11093 and 11330 out of which the first two AR's consist of isolated and simple axisymmetric sunspots while the last AR is more complex consisting of many sunspots. The full disk images corresponding to these ARs are processed through the ring-diagram pipeline [4] where we select
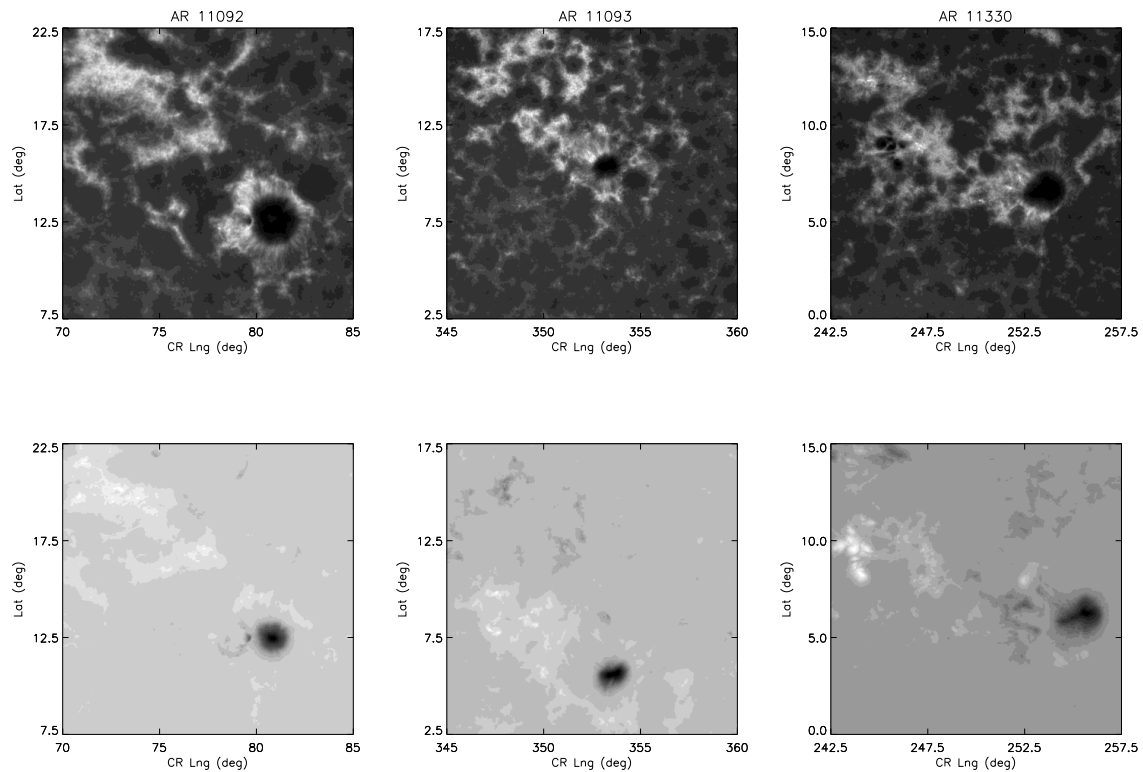
Figure 1. Mean values of active region data cubes as seen in AIA 1600 Å band (top panels) and HMI magnetograms (bottom panels).

Table 1. Details of the active regions used in this work. CR refers to the Carrington rotation. The values of the magnetic activity index (MAI) is provided by the HMI ring-diagram pipeline.

NOAA No.	CR No.	Latitude	Carrington Longitude	MAI in Gauss	Start Time in UT
11092	2099	15.0	077.5	40.78	2010.08.03_03:40
11093	2100	10.0	352.5	28.68	2010.10.08_13:57
11330	2116	07.5	250.0	91.00	2011.10.27_17:32

an area of 384 × 384 pixels around the active region and track it for 1728 minutes at the Carrington rate. Figure 1 shows the mean data cube of ARs as seen in the AIA 1600 Å band and the corresponding magnetic field data taken from HMI. More information on the data is summarized in Table 1.

The tracked cubes are then Fourier transformed in space and time to obtain the power spectra which are fitted to asymmetric profile model [5] to estimate the mode parameters. The fitted velocities are finally inverted to infer the depth dependence of horizontal flows [6].

3. Results
The frequency differences between modes obtained from different spectra are shown in Figure 2. We find that the differences are minimum between GONG and HMI Doppler observations while those between continuum and other observables are significantly large specially in the frequency
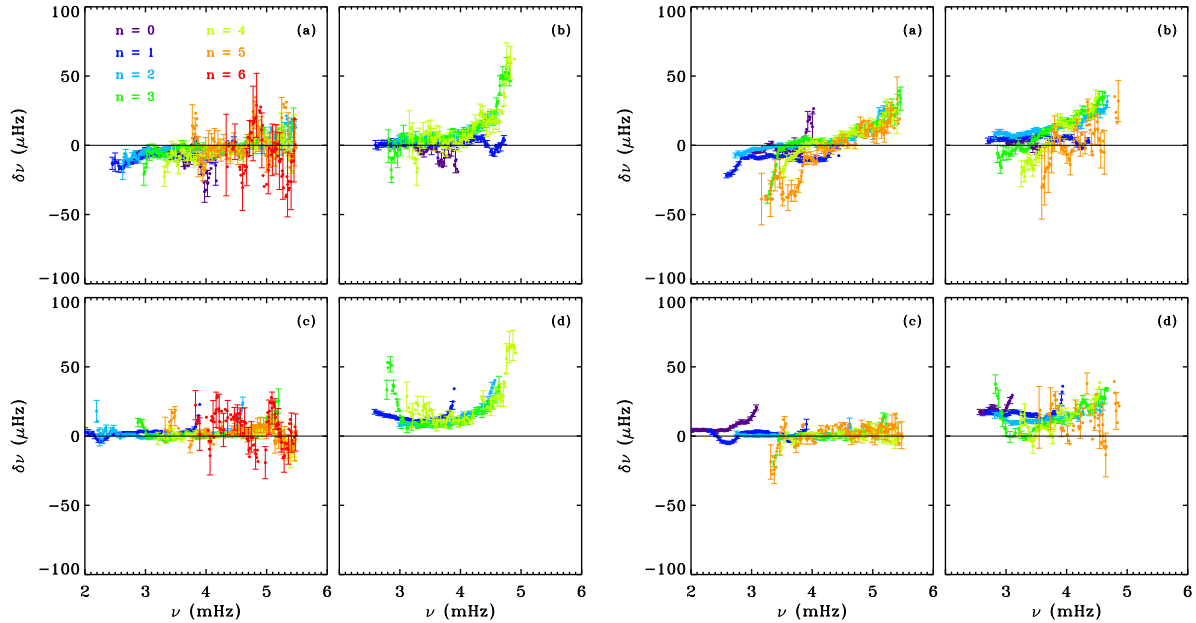
Figure 2. Frequency differences between different observables (a) HMI V - AIA 1600 (b) HMI C - AIA 1600 (c) HMI V - GONG V (d) HMI C - GONG V for AR 11092 (left) and AR 11330 (right)

range of $4.5-5$ mHz. From the study of quiet regions it is known that the frequency differences are significantly reduced when an asymmetric profile is used for fitting the spectra from different observables as compared to the use of a symmetric model profile [7]. However, a recent study using HMI and AIA data has shown that the frequencies measured from different observables in quiet regions do not agree with each other [8]. Thus there appears to be disagreement between results reported between [7] and [8] which used data from different instruments. Thus we postulate that the simplified asymmetry profiles used in ring-diagram studies do not adequately describe the correlation between the background power and peaks in active regions.

The horizontal and vertical components of the sub-surface flows for different ARs are shown in Figure 3. Each plot has 5 curves representing the flows from different observables. In general, the flow shows the two-layer structure increasing inward with depth. The flows near the surface are negative implying a retrograde motion while deeper down these are positive indicating prograde motion. These flows are consistent with measurements of flows in active regions made previously using Michelson Doppler Imager data [6] and our analysis using HMI data [2]. We also find that the zonal flows measured from different observables agree reasonably except for the one measured from AIA 1600 Å band. On the other hand, the meridional flows show larger variations between different observables and similar to the zonal flows, the discrepancy is largest for AIA 1600 Å band. We also find a large discrepancy for AIA 1700 Å band at greater depths for AR 11092.

4. Summary
The ring-diagram analysis of active regions using data from AIA and HMI observables show that the magnitude of the differences between mode frequencies computed from different spectra are significantly large at the higher end of the frequency range while the differences between the Dopplergrams from two different instruments are minimized. The sub-surface zonal flows, in
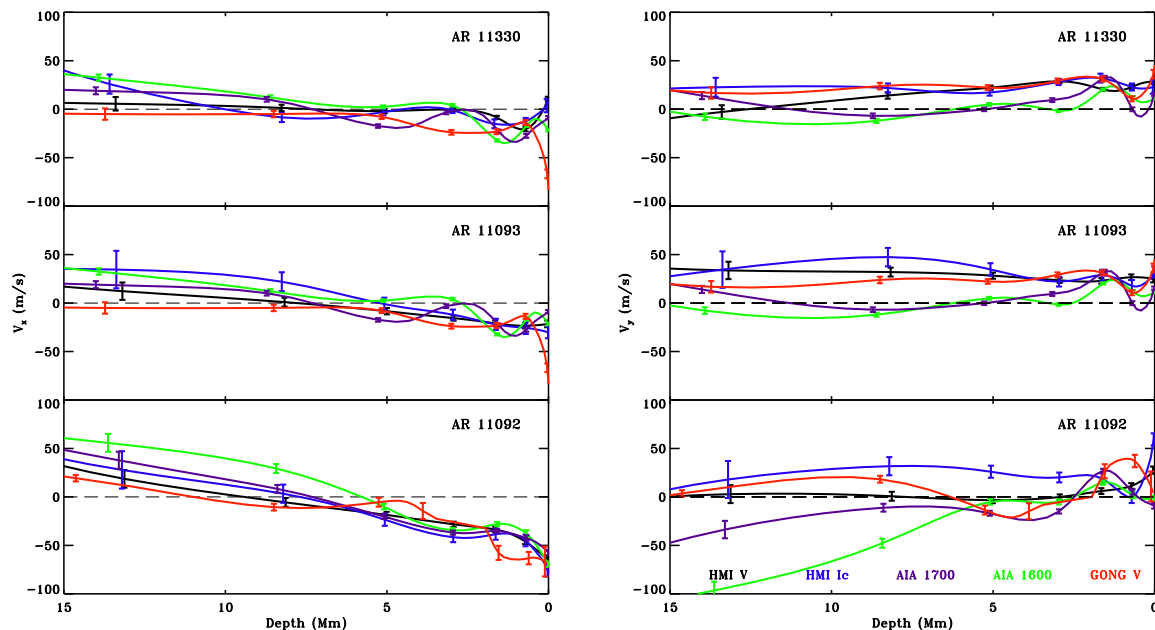
Figure 3. The horizontal velocity V_x (zonal) and V_y (meridional) for different observables and active regions as marked in the Figure.

general, are found to be consistent between different observables although the discrepancies are marginally larger for the meridional flows as compared to the zonal flows. Thus, it appears that the inference of sub-surface flows do not have a significant dependence on the choice of observables. A statistical study of many active regions is required to confirm these findings.

Acknowledgments

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