CHANGES IN HIGH-DEGREE MODE CHARACTERISTICS WITH MAGNETIC ACTIVITY

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ABSTRACT

We compare mode frequencies and other characteristics as determined from ring-diagram analysis of selected small regions of the Sun exhibiting strong variations in magnetic activity. These regions were observed with the Michelson Doppler Imager (MDI) on SOHO in its high-resolution mode during several years from solar minimum to maximum. To better understand the systematic uncertainties in fitting the ridges to the high-resolution data, we compare our results with those for the same regions concurrently observed in the MDI full-disc mode. We find that the the properties of high degree p-modes are different in active and quiet regions and that the magnitude of the changes depend on the activity level.

Key words: helioseismology; ring-diagrams; mode parameters; solar magnetic activity.

1. INTRODUCTION – ANALYSIS

Ring-diagram analysis affords us the opportunity to determine the effect of surface magnetic activity on the propagation and generation and absorption of near-surface helioseismic modes by isolating the regions studied (Hindman et al., 2000). In order to improve the spatial isolation of active regions, and also to incorporate information on very high-degree modes near the surface, we have chosen to analyze data taken with the high-resolution (1.3 arc-sec) mode of MDI. In order to compare the results with those achieved in the normal mode, we have selected data from the few intervals during which concurrent full-disc and high-resolution Doppler data. The available data are limited to the periods 13–19 June and 30 June–14 July in 1997, 5 Mar.–10 Apr. 1998, and 14–28 May 2001. Spatial coverage is restricted by the high-resolution field of view and telemetry limitations to a 1024×600 pixel (11×6.5 arc-min) subraster of that field. The regions studied are shown in Table 1.

Table 1. Locations of regions analyzed.

Date	CR	Lon.	Lat.	MAI
1997.06.15	1923	040	+10.0	0.336
			+20.0	1.912
1998.04.07	1923	100	+5.0	0.068
			+15.0	0.960
1998.05.04	1923	100	+5.0	0.481
			+15.0	0.415
2001.05.16	1976	230	+10.0	56.370
			+17.5	46.350
2001.05.18	1976	205	+10.0	1.802
			+17.5	1.945
2001.05.24	1976	130	+10.0	88.177
			+17.5	24.297

Regions of diameters 15° heliographic centered on the target locations have been mapped and tracked for 4096 minutes, which is about the maximum length of time a point on the Sun remains in the MDI high-resolution field of view, using the procedures described in Bogart et al. (2000). The spatial-temporal $k-\omega$ power spectra of the tracked data are then fit to the 13-parameter spectral model

$$P(k,\omega) = \Big\{\exp\Big[A_0+(k-k_0)A_1+A_2(\frac{k_x}{k})^2+A_3\frac{k_xk_y}{k^2}\Big] \times[S^2+(1+Sx)^2]\Big\}(x^2+1)^{-1}+\frac{e^{B_1}}{k^3}+\frac{e^{B_2}}{k^4}$$

where

$$x = \frac{2\pi\omega - ck^p - U_xk_x - U_yk_y}{w_0 + w_1(k-k_0)}$$

using the method described in Basu and Antia (1999). (k_0 is a fitting target, and $k^2 = {k_x}^2 + {k_y}^2$.)

For purposes of selection and comparison we have defined a local Magnetic Area Index, whose values for the individual tracked regions are given in the

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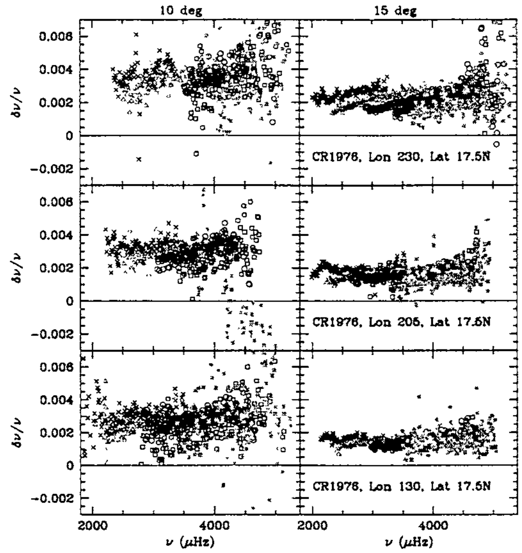

Figure 1. Comparison of mode fits for regions of diameter 10° *(left) and* 15° *(right) for three regions (two active and one quiet) of CR1976 (May 2001). The differences between the frequencies of the fits from the data in the high-resolution field and the data in the same areas from the full-disc field are plotted as a function of frequency. The values are symbol coded by mode order as follows:* $n = 0$*: crosses;* $n = 1$*: open triangles;* $n = 2$*: open circles;* $n = 3$*: open squares;* $n = 4$*: filled squares.*

table. The Index is calculated by mapping similar regions to the tracked Doppler data (but using an azimuthal equal-area projection rather than Postel's projection) from the MDI full-disc magnetograms taken during the tracking interval, and averaging the absolute values of all field values greater than or equal to 50 gauss, which is several times the standard deviation of the normally-distributed core of quiet-sun values.

We attempted to analyze smaller regions (10° diameter) for better isolation of the active sites. When the regione sizes were reduced even from 15° to 10° diameter, however, we were unable to determine sufficiently complete mode sets (see Figure 1). Nevertheless, the high-resolution data do allow for the incorporation of higher-degree modes, but there are still uncertainties due to the unknown and varying scale ratio between the high-resolution and full-disc observing modes. We thus focus here on comparisons of parameters for the modes that can be fit in both high-resolution and full-disc data at the same scale.

2. RESULTS

When we compare mode frequencies for the same regions in the full-disc and high-resolution observing modes, we see that there is a consistent and substantial offset at higher latitudes that is not present at lower latitudes (Figure 2). We attribute this to uncorrected position-dependent scale errors in the high-resolution field. Not surprisingly, we see similar effects in the fit parameters U_x and U_y representing the response to transverse flows (Figure 3). These location-dependent effects dominate any possible effects associated with the difference between the magnetically active regions in CR 1976:230 and the quiet regions.

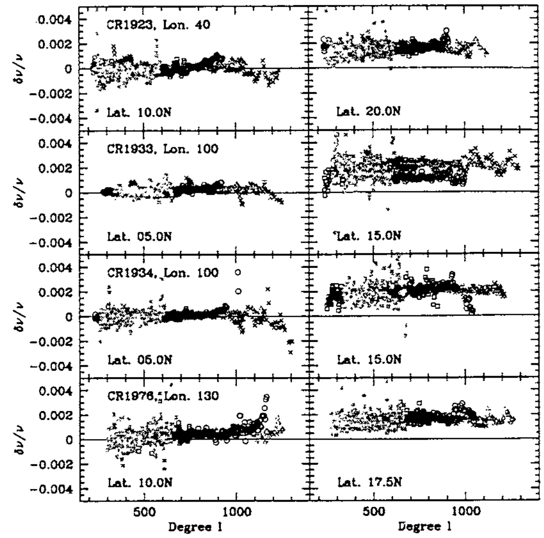

Figure 2. Frequency differences between full-disc and high-resolution observations for selected locations Fractional frequency differences for the same modes, coded as in the previous figure, are shown as a function of degree.

In order to isolate the magnetic activity effects on oscillations, we have compared results for two quiet regions during Carrington Rotation 1976 (May 2001) with four very active areas at the same latitudes seen in the high resolution field a few days before and after the quiet longitude. When we do so, we see that there is a significant increase in frequency (of the order 0.1positive frequency dependence, and at least a suggestion that the the frequency increase associated with magnetic activity is proportional to the activity index defined here. (See Figure 4.) Examining the frequency differences as a function of the mode turning points (Figure 5), we see evidence that the effect extends at least to a depth of 15 Mm, increasing somewhat with depth. This is consistent with the sound speed increases beneath sunspots seen in time-distance analysis (Kosovichev et al., 2000).

There is an increase in mode width in the active areas, peaking at around 3.5 mHz, but the dependence of its amplitude (or frequency location) on activity index is not so clear (Figure 6). It is more pronounced at the lower latitude. Likewise, there is an increase in the absolute value of the mostly negative asymmetry parameters (Figure 7) in the active regions at low latitude, but at higher latitude the am-

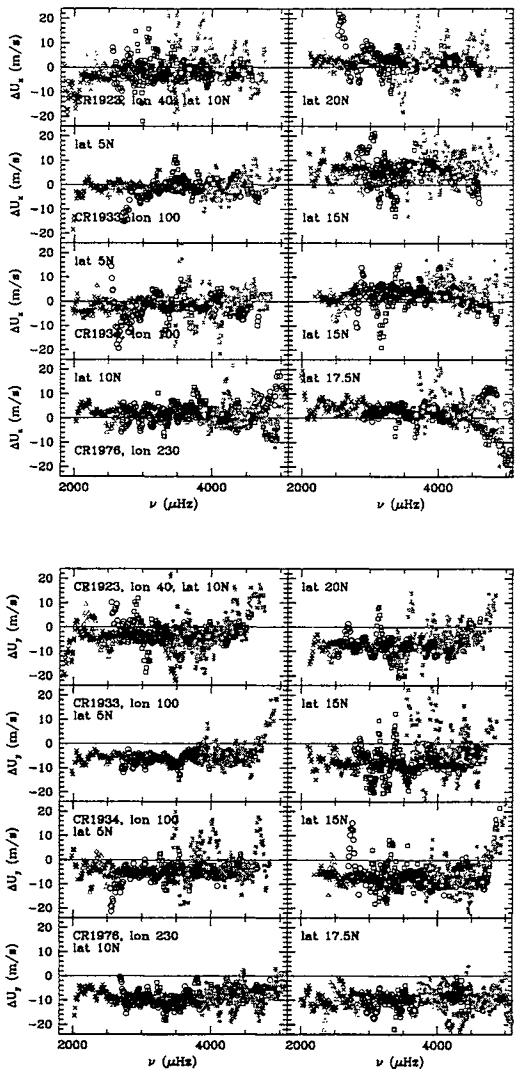

Figure 3. Horizontal velocity differences between full-disc and high-resolution observations for selected locations. The differences in the fit parameters U_x (above) and U_y (below), representing the depth-integrated response to flows in the zonal and meridional directions, are shown for individual modes as a function of frequency, with the same symbol codes. Differences are shown for quiet regions and two active areas.

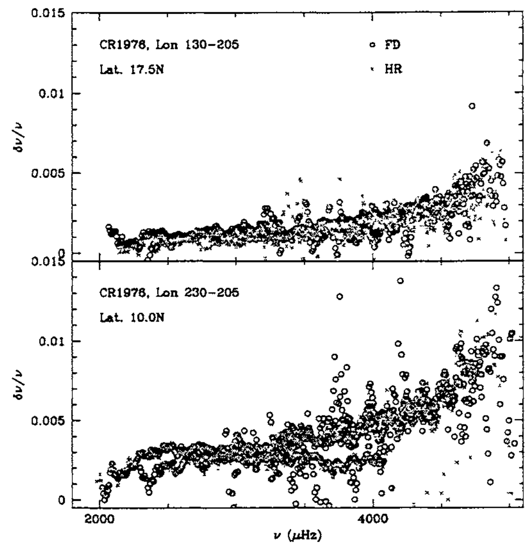

Figure 4. Frequency differences between sample active and quiet regions in CR 1976. For the same latitudes, the individual mode frequency differences between the quiet site (longitude 205°) and the active areas (longitudes 230° and 130°) are shown, plotted as a function of mode frequency. Open circles are for data derived from the full-disc observations, solid circles from the high-resolution data. Apart from greater scatter in the full-disc data, there are no systematic differences between the two sets evident.

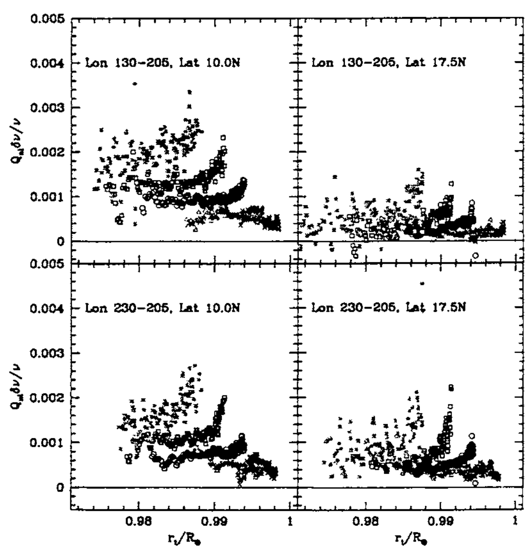

Figure 5. Weighted frequency differences between active and quiet regions. For the four sample comparison regions at the same latitudes and nearby longitudes, the individual mode frequency differences, scaleed by the inverse mode mass, are shown as a function of the classical mode turning point.

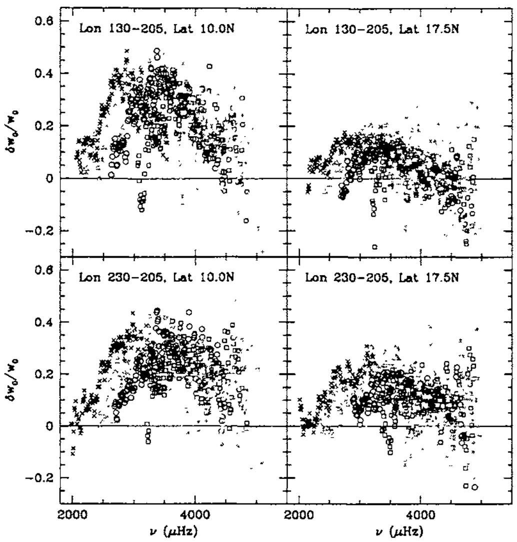

Figure 6. Differences in mode width between the active and quiet sites in CR 1976.

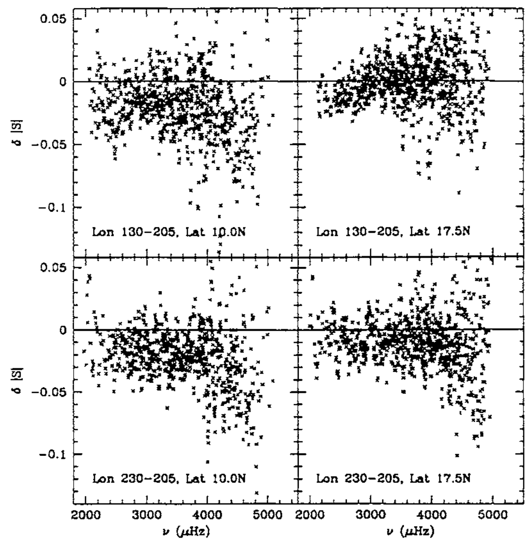

Figure 7. Differences in mode asymmetry between active and quiet sites. What is plotted is the difference between the absolute values of the asymmetry parameters; most of the asymmetries are of the same sign.

plitude of the effect is diminshed or even reversed. The magnetic activity is clearly influencing the excitation and damping of the oscillations; these effects deserve further investigation.

3. CONCLUSIONS

We cannot yet obtain sufficiently good mode-sets for analysis with a spatial resolution of less than about 15° heliographic (0.04 $R_\odot$); progress in improving the spatial resolution may involve hybrid sets of modes from different scales of analysis. At the present resolution there is, as expected, generally good agreement between mode-sets determined from coincident high-resolution and full-disc resolution MDI Dopplergrams. We attribute the consistent frequency differences seen farther from disc center to uncorrected variations in the plate scale and optical distortion. There is evidence that these effects increase with wavenumber and may vary with time, but apparently not with the magnetic activity level.

The mode frequencies are higher in regions of magnetic activity compared with quiet regions at the same latitude; this effect increases dramtically with mode degree. The sound-speed effects associated with magnetic activity are most pronounced near the surface. A significant increase in mode width in active regions, peaking at around 3.5 mHz, suggests enhanced mode damping in these regions. There is also evidence of increased asymmetry of the modes on active regions. This is also consistent with a significant role of magnetic activity in the mode excitation and damping processes. Magnetic activity does not noticeably affect the inferred near-surface flow velocities; if anything, the sub-surface velocity determinations may be somewhat less noisy in the active than the quiet regions.

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