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MHD WAVES IN A STRATIFIED VISCOUS SOLAR ATMOSPHERE

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ABSTRACT

We study MHD wave propagation in a gravitationally stratified isothermal viscous atmosphere of the Sun, permeated by a uniform magentic field. We perform numerical simulations by launching a slow wave on the upper boundary. The driven slow wave propagates down from low-β to high-β plasma across the region where the plasma β is unity. It is found that mode conversion takes place at $z \approx -1.8$ in the layer $\beta \approx 1$. The amplitudes of horizontal and vertical velocites are smaller than those obtained in the absence of viscosity.

Key words: Sun: atmosphere - Sun: oscillations

1. INTRODUCTION

In recent years it has become apparent that the solar atmosphere is permeated by magnetic structures. These structures support a number of wave modes. The actual wave depends upon the local sound speed, Alfvén speed, temperature, pressure, magnetic flux density and field inclination. In high-β plasma regions, the fast mode is a longitudinal acoustic wave while in low-β plasma regions, the slow mode is a longitudinal acoustic wave propagating along the magnetic field lines (Rosenthal et al. 2002; Bogdan et al. 2002, 2003; Cally 2005, 2007).

Numerical simulations of MHD waves have been carried out by Rosenthal et al. (2002), Bogdan et al. (2003) and Carlsson & Bogdan (2006). McLaughlin & Hood (2006) studied wave propagation near magnetic null points and pointed out that fast waves partially convert into slow waves as the disturbance passes the $\beta \approx 1$ layer from a low-β to high-β plasma. McDougall & Hood (2007) investigated mode conversion in a stratified and isothermal atmosphere with a uniform vertical magnetic field, from a low-β to high-β environment analytically and numerically. In this paper, we extend the study of McDougall & Hood (2007) to a stratified viscous environment of the solar atmosphere using the same one dimensional setup.

2. BASIC EQUATIONS AND BOUNDARY CONDITIONS

We consider a simple one dimensional model composed of a gravitationally stratified viscous solar atmosphere permeated by a uniform magnetic field. We assume a constant gravitational force and a uniform vertical magnetic field along the z-axis of $\mathbf{B_0} = B_0\hat{z}$. If we consider the momentum equation and ideal gas law under equilibrium conditions of uniform temperature T_0, we obtain a z-dependence of the equilibrium pressure and density of $p_0(z) = p_0(0)e^{-z/H}$ and $\rho_0(z) = \rho_0(0)e^{-z/H}$, where $H = RT_0/\tilde{\mu}g$ is the coronal scale height (≈ 60 Mm). The plasma β will depend on z due to the gravitational stratification. This ensures that our waves propagate across the $\beta \approx 1$ layer. We consider small perturbations from equilibrium and linearize the basic MHD equations governing the motions of the stratified isothermal viscous atmosphere of the Sun.

As we are studying the propagation of waves from the upper boundary, we impose the boundary conditions: $v_z = \sin\omega t, v_x = 0, \frac{\partial B_z}{\partial t} = 0, B_x = -\frac{1}{k}\frac{\partial B_z}{\partial z}, \frac{\partial p}{\partial z} = 0, \frac{\partial \rho}{\partial z} = 0$. We drive a slow wave from the upper boundry by imposing v_z because in low-β plasmas slow waves propagate parallel to direction of magnetic field.

3. NUMERICAL RESULTS AND DISCUSSION

We use the MacCormack method to solve the non-dimensional linearized MHD equations of our 1D model. This scheme is second order accurate in both time and space. We run the simulation for $-10 \leq z \leq 5$ with 5001 grid points by choosing β=0.2 and L equals to the coronal scale height H so that in our simulation z=1 corresponds to one coronal scale height. We consider a driving frequency of 2π and choose k arbitrarily.

Behavior in the absence of viscous wave propagation across the $\beta \approx 1$ layer has been discussed by McDougall & Hood (2007). We compare our results, obtained in the presence of viscosity, with the results of McDougall

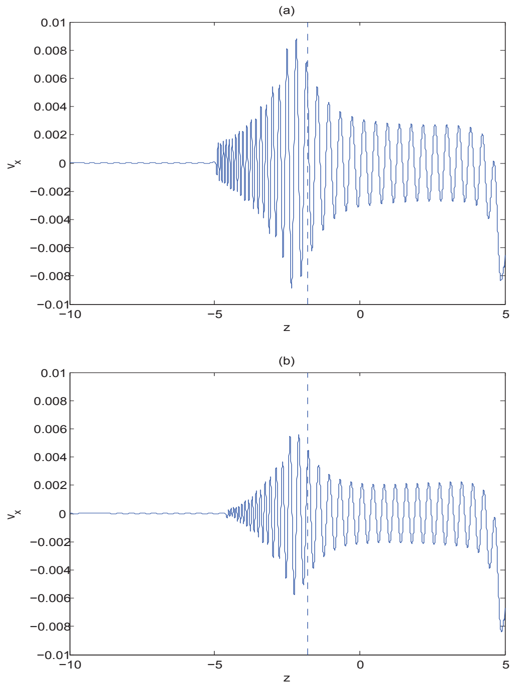

Figure 1. Horizontal velocity v_x as a function of z for t=35 and $\omega = 2\pi$ in the (a) absence of viscosity and (b) presence of viscosity. The dashed line denotes the layer $c_s = v_A$.

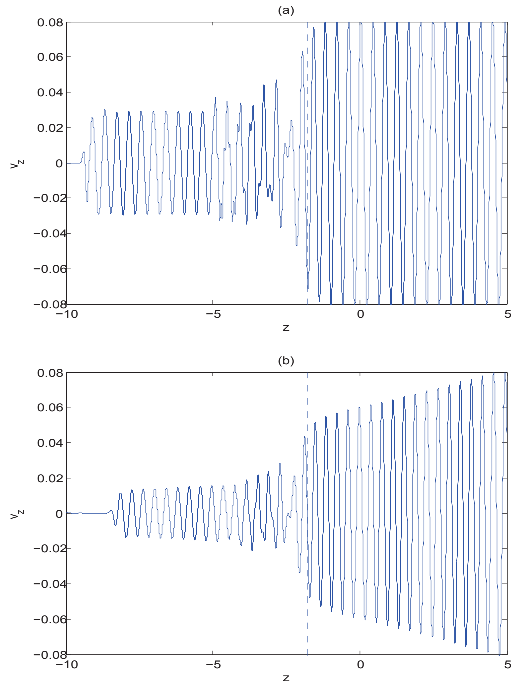

Figure 2. (a) Vertical velocity v_z as a function of z for t=35 and $\omega = 2\pi$ in the (a) absence of viscosity and (b) presence of viscosity. The dashed line denotes the layer $c_s = v_A$.

& Hood (2007), by plotting the figures for transformed variables at t=35 and $\omega = 2\pi$ as a function of z. From Figures 1 and 2 it can be seen that the slow wave driven from the upper boundary in the low-β plasma reaches the $\beta = 1$ layer as a slow wave. Mode conversion occurs in this layer and after that the converted part of the wave propagates as a slow wave and the transmitted part as a fast wave in the high-β plasma even when compressive viscosity is taken into account in a stratified isothemal atmosphere. Figure 2b shows that these slow and fast waves interact and cause interference in the region $-4.5 \leq z \leq -1.8$ in the high-β plasma. This interference region is slightly smaller than the interference region $-4.9 \leq z \leq -1.8$ observed in Figure 2a in the absence of viscosity. In the presence of viscosity the fast wave fades out in front at $z \approx -8.5$ (Fig. 2b) and the slow wave propagates up to $z \approx -4.5$ (Fig. 1b), whereas in the absence of viscosity the fast wave fades out in front at $z \approx -9.3$ (Fig. 2a) and the slow wave propagates up to $z \approx -4.9$ (Fig. 1a). Figure 2b depicts that the amplitude of vertical velocity decreases gradually due to viscosity. If we compare the results shown in Figure 1b with the results shown in Figure 1a, we observe that the amplitude of the horizontal velocity is smaller in the low-β plasma region, but it is interesting to note that as the wave crosses the $\beta \approx 1$ layer, the decay of the amplitudes of velocities is faster than the decay of amplitudes in the case of the absence of viscosity. Thus, in the presence of viscosity, the above observed changes in the behaviour of wave propagation are due to the damping effect of viscosity.

4. CONCLUSIONS

Our simulation shows that when a wave passes from low-β to high-β plasma through the layer $\beta \approx 1$ the mode conversion occurs at the point $z \approx -1.8$ in this layer. Interference due to the interaction of the converted part (slow wave) and the transmitted part (fast wave) of the wave is observed but the size of the interference region reduces to a slightly smaller region than that obtained in the absence of viscosity. The fast wave fades out slightly earlier in the presence of viscosity. The amplitude of the vertical velocity decreases gradually with z. The amplitude of the horizontal velocity is smaller but the trend of variation of amplitudes with z is similar to that obtained in the absence of viscosity. Thus we conclude that viscosity influences the amplitudes of horizontal and vertical velocites, the length of the interference region and the propagation of fast and slow waves.

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