SOME NUMERICAL SIMULATIONS OF OSCILLATIONS IN THE SOLAR ATMOSPHERE

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ABSTRACT

The new results, obtained from simulations of atmospheric oscillations are presented. The details of quasi-periodic shock waves, which are produced by photospheric and subphotospheric oscillations and spread up into the upper chromosphere and corona, as well as their interaction with the transition region between chromosphere and corona are considered. We present results of non-linear one-dimensional simulations of the process, and suggest cooperative studies of the phenomena using observations from MDI and SOHO coronal instruments.

Key words: solar atmosphere, chromosphere, corona, oscillations, excitation, acoustic events, shock waves, nonlinear wave-wake effect, SOHO

1. INTRODUCTION

In some situations, simple one-dimensional models may be more suitable for interpreting observational data than two or even three-dimensional models (Caltier & Porquet, 1998). In particular, one has such case considering the nonlinear response of the solar atmosphere to excitations of solar oscillations. The excitation source is located, accordingly Brown et al (1992) and Restaino et al (1993), just beneath the photosphere. Rimmeele et al (1995) have shown that such events take place in intergranular regions along dark lanes of the granulation pattern.

Earlier we presented results of simulations of atmospheric response on a single excitation (Andreev & Kosovichev, 1995). Now we perform what happens when atmospheric waves stimulated by subphotospheric oscillations. We also present results of the atmospheric reactions to a sudden cooling localized in the photosphere. This simulates the process described by Rimmeele et al (1995).

2. THE MODEL

2.1. Equations

The equations describing vertical motions in a magnetic flux tube in a 1.5D approximation are

\[ \frac{dz}{dt} = \nu, \quad \frac{\partial \nu}{\partial t} = -\frac{A}{s} \frac{\partial \rho}{\partial s} - g, \quad \frac{\partial}{\partial t} \left( \frac{1}{\rho} \right) = \frac{\partial v}{\partial s}, \]

\[ \frac{\partial c}{\partial t} = -p \frac{\partial}{\partial s} \left( \frac{1}{\rho} \right) + Q_{\text{rad}}, \quad p + \frac{B^2}{8\pi} = p_{\text{ext}}, \]

\[ BA = \Phi = \text{const}, \]

where \( s \) is the Lagrange mass variable (\( ds = \rho Adz \)), \( z \) is the height above the photosphere, \( A(t,z) \) is the area of a circular cross-section of the magnetic tube, \( \nu \) is the velocity, \( p \) and \( B \) are the gas pressure and the magnetic field strength inside the tube, respectively, \( \Phi \) is the magnetic flux, \( p_{\text{ext}} \) is the total gas and magnetic pressure outside of the tube, \( \rho \) is the density inside the tube, \( e \) is the internal energy density, \( g \) is the gravitational acceleration, \( Q_{\text{rad}} \) is the radiative cooling rate. Plasma ionization, which increases dissipation of the wave energy in the upper chromosphere due to bulk viscosity resulting from the relaxation of the state of the gas, is considered according to Hartman and MacGregor (1980). The radiative cooling is taken in the optically thin approximation, in the form suggested by Rosner et al (1978) and MacNeice et al. (1984).

2.2. Numerical method

The equations have been solved numerically using the finite-difference technique of second-order accuracy, adopted by Kosovichev and Popov (1980) in which the discrete analogies of the basic laws of conservation of mass, momentum and energy are satisfied precisely, as are additional relations expressing balances of internal and kinetic plus gravitational energy.

3. LINEAR AND NONLINEAR OSCILLATIONS IN THE SOLAR ATMOSPHERE

Any excitation in the solar photospheric region produces acoustic waves. The density stratification in

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a solar atmosphere is favorable for reinforcing of the upward component of the initial perturbation. This results in steepening of the acoustic wave into the shock one with a number of quasi-periodic oscillations behind it. Such generation of oscillations behind the shock wave, so-called “wave-wake” effect, was described by Lamb (1909). The nonlinear wave-wake effect in the solar atmosphere (see, for example, Figure 1), was investigated by Kosovichev & Popov (1978). The mechanism, described at the beginning of this section, leads to transformation of secondary waves into shock waves propagating in the corona. So we have a sequence of shocks which interact with the transition region between chromosphere and corona (Hollweg. 1982; Andreev & Kosovichev, 1994).

Figure 1. The non-linear wave-wake effect in the corona: formation of quasi-periodic shocks as a result of large-amplitude perturbation in the photosphere (piston moving upward with a constant speed 100 m/s).

Figure 2. Oscillations at the photospheric level: (a) Initial Lagrangian motions (black ribbon at the bottom) and motions of 9 mass elements which initially were at the heights of 300, 900, 1200, 1800, 2200, 2400, 2700, 2900, 3200, 3500, 3900 and 4200 km (solid curves - chromospheric elements; dashed curves - coronal elements). (b) The velocity at different heights as a function of time. (c) The temperature (continuous curves) and the density (dashed curves) as functions of height in different time moments.

Figure 2 demonstrates (a) time evolution of oscillations at different heights (solid curves - chromospheric elements; dashed curves - coronal elements); (b) velocities in chromosphere and corona and (c) changes of temperature (continuous curves) and density (dashed curves) due to periodical subphotospheric perturbations. The interesting result is that 5 min oscillations of photosphere and low chromosphere transforms in the upper chromosphere and corona into quasi-periodic oscillations with the period about 7 min (Fig. 2a). This result is in a good agreement with observations (Kariyappa, 1994). Such periods were obtained when we supposed that magnetic field decreases with height as $z^{-2}$. Considering $z^{-n}$ in a common case, we obtain increasing of period of oscillations and of transition region rising when $n < 2$ and decreasing of the period and transition region rising height when $n > 2$. (a) Initial Lagrangian motions (black ribbon at the bottom) and motions of 9 mass elements which initially were at the heights of 300, 900, 1200, 1800, 2200, 2400, 2700, 2900, 3200, 3500, 3900 and 4200 km (solid curves - chromospheric elements; dashed curves - coronal elements). (b) The velocity at different heights as a function of time. (c) The temperature (continuous curves) and the density (dashed curves) as functions of height in different time moments.

Figure 3 shows the dependence of reflection coefficient of the transition region between chromosphere and corona versus velocity of the moving upward wave ($v_m$). $v_d$ is an amplitude of the reflected wave. It is well seen, that the reflected part significantly decreases when the ascending wave becomes stronger.
Figure 3. The reflection coefficient of the transition region between chromosphere and corona as a function of amplitude of the ascending wave $v_a$, $v_d$ is the amplitude of descending after reflection wave.

Figure 4. The velocity as a function of time at 5 different heights, 50, 160, 270, 380 and 490 km, in the lower chromosphere after the initial perturbation resulted from the intergranular cooling.

In Figures 4 and 5 we show the results of simulation of the process of sudden intergranular cooling which according to Rimele et al (1995) plays substantial role in excitation of solar oscillations. The gasdynamic perturbation resulted from the intergranular cooling was modelled by decreasing the pressure by 10% in a small volume 100 km high at the photospheric level.

Figure 5. Shock waves in the upper chromosphere and transition region after the initial perturbation resulted from the intergranular cooling.

Figure 4 shows the velocity as a function of time at 5 different heights, 50, 160, 270, 380 and 490 km, in the lower chromosphere after the initial perturbation. The results show a string downward motion during the first 100 s, and then subsequent oscillations of lower amplitude. It is important that the initial wave of the negative velocity shows predominantly the upward phase propagation in accordance with the observations by Rimele et al. Figure 5 shows that this perturbation results in shock waves of substantial amplitude in the upper chromosphere and transition region. In the chromosphere the characteristic time between consequent shocks is about 150 s, and, in the chromosphere-corona transition region, this time increases to 400 s.

4. CONCLUSION

Perturbations near the surface of the sun, which are the probable source of the solar oscillations, also excite quasi-periodic transient oscillations in chromosphere and corona. Period of these oscillations depends on the distribution of magnetic field versus height. Their amplitude can be sufficient enough to supply spicule-like phenomena. New calculations confirms that efficiency of wave reflection from chromosphere-corona transition region is significantly reduced at higher wave amplitudes.

Studies of coronal manifestation of solar oscillations with SOHO instruments will help to understand the physics of the acoustic events in the upper convective layer, and the role of the oscillations in the dynamics of the solar atmosphere.
REFERENCES


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