RESPONSE OF A BOUNDED ATMOSPHERE TO A NON-RESONANT EXCITATION

I: Isothermal Case

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Abstract. The response of a bounded atmosphere to a non-resonant excitation applied at its basis is studied. It is shown that the essential feature related to this kind of excitation is that the distribution of the energy of the velocity field relatively to the frequency and horizontal wavelength is a function of height and merely depends on the structure of the atmosphere above the level at which it is considered. The preliminary results concerning an isothermal atmosphere are presented and their relevance to the solar case is discussed.

1. Introduction

Many attempts to interpret the five-minute solar oscillation discovered by Leighton (1960) have been proposed in the literature: the theoretical studies have been reviewed by Schatzman and Souffrin (1967) and by Stein and Leibacher (1974). Essentially there exist two different approaches: either the involved mechanism is an instability of the subphotospheric layers occurring for some frequencies, or the oscillation corresponds to the response of the photospheric and chromospheric layers to an underlying excitation which is supposed related to the convective instability. In this paper some aspects of this latter approach will be developed.

In some works (Souffrin, 1966, 1970; Zhugzhda, 1973; Moore, 1974; Chen, 1974) the model considered is a semi-infinite isothermal atmosphere with a radiation condition at infinity, so that reflection of the waves does not take place. However, as far as the Sun is concerned, the reflections cannot be reasonably neglected: Bahng and Schwarzschild (1963) have shown that for the propagation of vertical waves in an isothermal atmosphere the presence of a very hot corona can be taken into account by using a free surface upper boundary condition. This result can be extended to oblique waves in a more general atmosphere (Provost, 1974). The model considered here will take into account this reflection property due to the steep increase of the temperature in the transition zone chromosphere–corona.

The structural properties of the atmosphere play the predominant role in various theoretical models in the following way: it is considered that if the atmosphere has undamped eigenmodes, these modes will be resonant for any excitation of this atmosphere. Following this conception many resonant models have been constructed (Aure et al., 1971) but the failure of these models is that the results are very dependent of the choice of the parameters of the models and of the boundary conditions: the number of parameters is such that arbitrary resonant frequencies can be obtained. In
other models the observed motions are considered as forced motions induced by convection and the excitation is represented in different explicit ways. As the process of generation of the motions is not well known, the assumption is made, that the convective zone acts as an 'oscillating lower boundary', i.e. the dependence of a physical quantity on space and time \((X(x, t))\) is given at the basis of the atmosphere. In the literature there exist different choices for the assumed quantity \(X\): vertical velocity (Whitney, 1958; Meyer and Schmidt, 1967; Stix, 1970; Zhugzhda, 1973); Eulerian pressure perturbation (Worral, 1972; Moore, 1974). This choice is not discussed in most of these works. Nevertheless it is fundamental because it determines the modes in which the energy of the response is distributed: in an atmosphere where the value of a quantity \(X(x, t)\) is imposed at the basis, most of the energy is contained in the eigenmodes of the atmosphere corresponding to the lower boundary condition \(X=0\). We note that if the excitation is stationary in time the amplitude of such eigenmodes is infinite. The above argument is valid as long as a non trivial motion may exist with a zero value of \(X\).

The aim of the present paper is to study the response of an atmosphere, bounded above by a hot corona, to a statistically stationary excitation specified in such a way as to avoid resonances: the quantity imposed at the oscillating lower boundary is the energy, quadratic quantity which cannot be zero. It is understood that this is the best we can do as long as the power spectra of the oscillatory modes relevant to the external solar layers remain unknown. This form of the excitation will permit us to determine the evolution with the altitude of the motions in a model of atmosphere, which satisfies two important properties of the solar atmosphere: the existence of reflections due to the hot corona and the statistically stationary character of the motions suggested by the observations.

In a first part the model is presented and the calculations of the spatio-temporal power spectra of the velocity field are given when the energy of the motions is imposed at the basis of the atmosphere. In a second part the general characteristics of these spectra are discussed and illustrated by the results corresponding to an isothermal atmosphere. In the conclusion the solar case is considered and we try to determine if the specific properties of the response to a non-resonant excitation are supported by the observational data about the photospheric and chromospheric oscillation.

2. Definition and Formal Solution of the Problem

We consider the following simplified model of the solar atmosphere, an isothermal atmosphere 1 of perfect gas horizontally stratified by an uniform gravity field directed along the vertical axis \(Oz\), is bounded above by a very hot atmosphere 2 representing the corona. This hot corona behaves like a perfectly reflecting layer, for the perturbations of the atmosphere 1, at the limit of infinite temperature and will be replaced by a free surface upper boundary condition situated at the level \(z=L\). This approximation is discussed by Bahng and Schwarzschild (1963) in the case of waves with vertical propagation in an isothermal atmosphere; many authors used this condition a priori