GRAVITY WAVE GENERATION BY LARGE SCALE BUBBLES

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ABSTRACT. The response of an isothermal atmosphere to small disturbances in entropy is studied taking compressible effects fully into account. The method of Green's functions is applied to solve the linearized hydrodynamic equations by Fourier transformation. A bubble may be created by perturbing the entropy within a finite volume. At first Lamb waves will be then emitted radially and the bubble undergoes a series of Brunt-Väisälä oscillations. We find that horizontally propagating waves are generated only by large bubbles exceeding a radius of about ten pressure scale heights, whereas smaller bubbles lead to motions propagating principally in the vertical direction.

1. INTRODUCTION

Lamb (1932) was the first, who studied modified acoustic waves in stratified atmospheres (Lamb waves). Meyer and Schmidt (1967) calculated their generation due to a single granulum supressing g-modes by assuming isothermal changes only. The different wave modes in isothermal atmospheres are extensively examined (e.g. Tolstoy 1963, Stein and Leibacher 1974). In the present paper the velocity, entropy and pressure field is explicitely calculated taking into account p- as well as g-modes. Using appropriate dimensionless quantities, the linear, adiabatic oscillations in an isothermal atmosphere are governed by a hermitian differential operator L_{ij} :-

$$L_{ij} q_j = Q_i \tag{1}$$

Here q_i denotes a five component vector associated with the three velocity components, entropy and pressure. Q_i represents a source term allowing for externally applied disturbances. We shall adopt here a Gaussian distribution (wave packet) as an entropy source. As a boundary condition we require all perturbations to vanish at infinity. Eq.(1) is solved by means of Fourier transformation in space and time. The differential operator L_{ij} then becomes an algebraic matrix, that may be inverted to give G_{ij} , which is a Green's function tensor. The solution

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for the quantities q_i may be given as a double integral, that can be evaluated by quadrature.

2. RESULTS

Some results may be seen from the following figures. In Fig.1-3 stream lines are presented showing oscillations created by small and large scale bubbles. The small bubbles case was already calculated by Gigas and Steffen (1984) in quantitative agreement with the results given below. The unit of length adopted in the following figures is $H_0 = \gamma H_p/(1-\gamma/2)$ and time is measured in $T_0 = H_0/c$, where γ is the ratio of specific heats, H_p pressure scale height and c the velocity of sound.

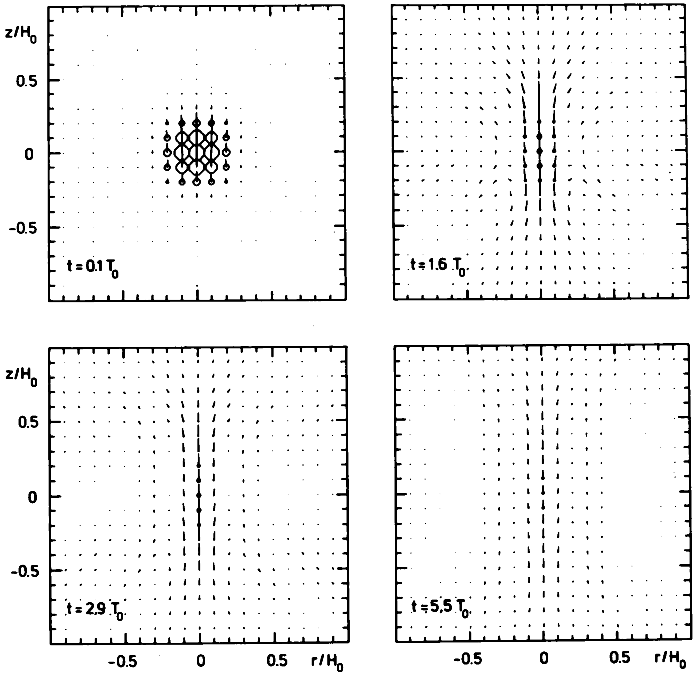

Figure 1. The time development of the velocity field after the atmosphere (γ = 5/3) is disturbed by a small scale bubble (radius = 0.2 H_0, which corresponds to 2 pressure scale heights). The number of Brunt-Väisälä oscillations being completed is 0, 1, 2 and 4 resp. By that time the velocity field has been stretched in the vertical direction and no sideway motion occur.

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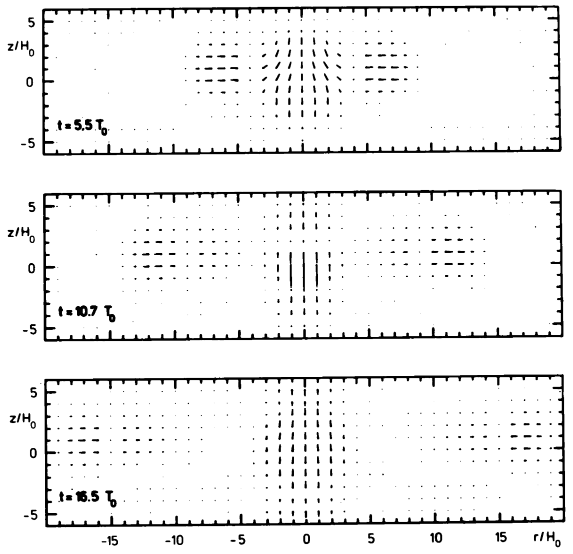

Figure 2. Same as Fig.1 , but starting with a large bubble (radius = 2 H_0 which corresponds to 20 pressure scale heights. The ratio of the specific heats is again γ = 5/3. g-modes are propagating sideways, whereas p-modes now keep oscillating at the center.

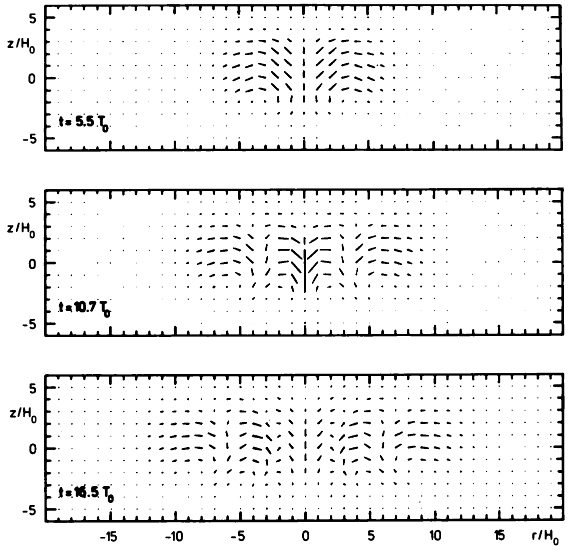

Figure 3. Same as Fig.2 , but γ = 1.1 . The radius of 2 H_0 corresponds in this case to 2.4 pressure scale heights. One can see now a real wave-like behavior of g-modes. p-modes are not present, because their amplitude is vanishingly small in this case.

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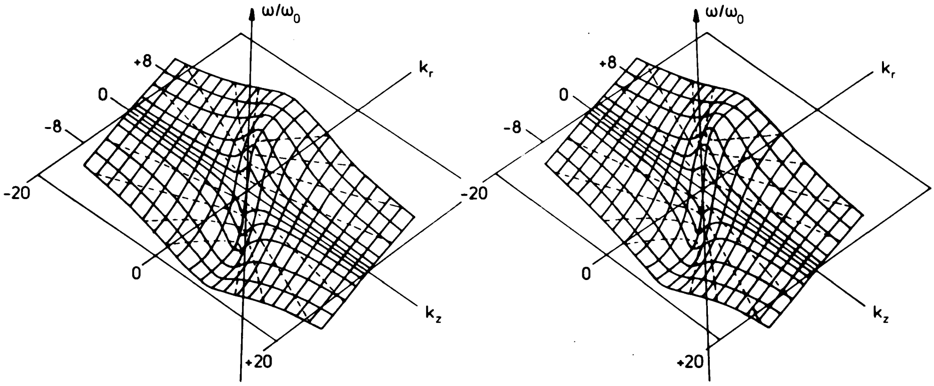

Figure 4. A stereo pair for the dispersion relation of the g-mode branch (prepared by R.C.Walker 1985). This can be seen three dimensional by free viewing or through two lenses.

3. DISCUSSION

It is found that large bubbles can create propagating g-modes. This may be explained in terms of dispersion relation (Fig.4): one can see a slope in k_r - direction (horizontal wave number). This slope leads to an effective group velocity in the horizontal direction in real space, if the interval of the Fourier integrals is restricted to small wave numbers k_r , which is the case for large bubbles (note that Fourier and real space are invers to each other). It is different with small bubbles, as also very large wave numbers contribute to the Fourier integrals. But for large wave numbers k_r no slope, i.e. no group velocity appears. Therefore small bubbles do not create gravity waves. Another feature appears from comparing Fig.2 and 3 . The latter case $\gamma = 1.1$ corresponds to a small coupling constant between p- and g-modes. In fact Fig.3 may also be reproduced when applying the anelastic approximation, in contrast to fig.2 , which is essentially non-anelastic.

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