Acoustic Gravity Vortices in the Atmosphere

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It is pointed out that the theory for acoustic-gravity vortices is applicable to recent observations of very large amplitude solitary waves in the atmosphere.

Key words: Nonlinear dynamics, Acoustic, Vortices, Atmosphere

The nonlinear terms in the equations that govern the motion of liquids, gases and plasmas can sometimes be responsible for the appearance of ordered solutions which do not have to evolve into a disordered state. Recent observations [1] of atmospheric disturbances propagating with no appreciable change in structure support this view. Here it will be suggested that a vortex theory for acoustic-gravity waves can account for such solitary structures.

It is tempting to describe the solitary waves [1] observed in the atmosphere by means of the archetypal nonlinear equation, namely the wellknown Korteweg-de Vries equation, e.g. [2, 3], that has soliton solutions and which, for example, successfully has explained how long-wavelength water waves can appear in solitary wave forms due to a close balance between nonlinearity and dispersion. However, a detailed analysis [4] shows that such solitary wave solutions of the Korteweg-de Vries equation do not exist in the atmosphere unless attention is focused on its upper part where charged particle effects are important [5]. Thus, we have to look for an alternative theoretical description of the observed structures.

Considering the nonlinear behaviour of acoustic-gravity waves, one has to start from the usual fluid equations [6] that govern the motion of the atmosphere. One then finds that the low-frequency, short-wavelength disturbances can be described by a pair of coupled equations [7] which for structures moving with a constant velocity in the horizontal direction reduce to the Hasegawa-Mima equation [8] if the squared Brunt-Väisälä frequency ω_g^2 is negative, and to the Shukla-Yu equation [9] if ω_g^2 is positive. These equations have no localized one-dimensional solutions and are thus in all respects significantly different from the Korteweg-de Vries equation. However, it can be shown that they have vortex solutions [7–10], termed acoustic-gravity modons, which are two- or three-dimensional localized perturbations moving in the horizontal direction with no change in structure. These solitary disturbances are generated in regions where, using typical parameters [6], $\omega_g^2 \approx -7\,(0.4\,\varrho_0'/\varrho_0 - T_0'/T_0)$ is negative, i.e. where the equilibrium temperature T_0 changes more rapidly than the equilibrium density ϱ_0, and they move with a velocity of the order of $|\omega_g\,\varrho_0/\varrho_0'|$. The prime represents here the derivative with respect to the vertical coordinate. The solutions are trapped in the waveguide where temperature inversion occurs [6] and the Richardson number is of order unity. Thus there are qualitative similarities between the recent observations [1] and the vortex theory [7] for acoustic-gravity waves. To the authors knowledge, it has not been possible to connect other previous observations with such a theory.

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