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A theoretical study on the mechanism for spontaneous gravity wave generation using the renormalized perturbation method

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Gravity waves (GW) are categorized into orographic ones and non-orographic ones. The mechanisms for non-orographic GW generation are not clear, because the dynamics is quite nonlinear and complicated unlike orographic GW. Recently, it has been revealed that GW are spontaneously radiated from an approximately-balanced flow, especially in the jet/front systems (e.g. O'Sullivan & Dunkerton 1995). The balanced adjustment theory proposed by Plougonven & Zhang (2007) is considered to be the most likely to describe the spontaneous radiation. However, their theory has the following three flaws. [1] The physical interpretation for GW sources is not given. [2] The (singular) perturbation method is not used. [3] The reaction by GW radiation to the vortical flow is not considered. In this study, we propose a new theory, which is free from all these flaws. Validity of this new theory is carefully examined by using the result of numerical model simulation.

The essence of this new theory is that GW are radiated from the slaved components of the vortical flow through a quasi-resonance, when the ground-based frequencies of GW are significantly Doppler-shifted by the vortical flow and have timescales comparable to that of the slaved components.

So as to make the physics clear, linear potential vorticity (q), horizontal divergence (d), and ageostrophic vorticity (g) are used as dependent variables. The vortical flow is defined as the flow associated with q, and the slaved components are defined as d and g that are diagnostically determined from the distribution of q. In the linear theory, d and g contain high ground-based frequency components. As the nonlinear terms in these high frequency components contain slowly varying components with timescales comparable to that of q, it is necessary to include them in the theory. Thus, in order to consider both GW and these slowly varying components, five variables are used to construct the theory which describes the spontaneous radiation through the quasi-resonance (problem [1] is solved): q, two variables (d^{GW}, g^{GW}) for GW, and two variables (d^{diag}, g^{diag}) for slowly varying components.

For theoretical formulation, we use the renormalized perturbation method which is one of singular perturbation methods (problem [2] is solved). In addition, in order to take account of the Doppler shift, the eigenmode expansion in a given arbitrary vortical flow field is made for d^{GW} and g^{GW}. On the other hand, the ordinary renormalized perturbation method is applied to d^{diag} and g^{diag}. Diagnostic components, d^{diag} and g^{diag}, are separated into two parts: the GW radiation reaction and slaved component. The derived theoretical equations also contain the variation of q by the GW radiation reaction. This means that the problem [3] is solved.

In order to examine validity of the theory, the quasi-steady spontaneous radiation of GW in a vortex dipole is simulated using the Japan Meteorological Agency nonhydrostatic mesoscale model (NHM). The modon solution, that is an exact solution for three dimensional QG equations on the beta plane, is given as initial values to perform numerical integrations of the compressible nonhydrostatic equations. Similar to the previous studies, GW are radiated upward and downward from the jet exit region. GW phase structure is almost symmetric around the jet axis in the vertical cross section. The nearer to the dipole edge, the shorter the GW wavelength becomes. The GW are wrapped into the dipole vortices at its edge. Next, the renormalized group equations are integrated with GW sources obtained from the initial modon field that does not include GW. As a result, it turns out that these equations successfully reproduce spontaneously radiated GW in the jet exit region as is consistent with the result of NHM.

Keywords: spontaneous radiation, gravity wave, renormalized perturbation method