Geophysical Research Abstracts, Vol. 9, 03047, 2007
SRef-ID: 1607-7962/gra/EGU2007-A-03047

Semi-transparent waveguides in GFD: resonant excitation of waveguide modes and their nonlinear evolution

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The waveguide modes with strong dispersion appear in a number of situations in GFD. The examples are equatorial waves, topographic waves and edge waves in the ocean. In all of these cases the non-trapped modes are also present in the spectrum of the respective models. We show that in wide ranges of parameters the weakly nonlinear interactions between a pair of trapped waves, or a trapped wave and a mean current in the waveguide, and an incoming non-trapped wave lead to resonant excitation of the former (a parametric-resonance type subharmonic excitation). Thus, this process is generic, although it has been studied previously only for edge waves in the works of Whitham and collaborators in 1970s. We show how this mechanism works for equatorial and topographic waves. We demonstrate that the resonant growth of the amplitudes of the waveguide modes is arrested by nonlinearity at a significant level, largely exceeding the amplitude of the incoming non-trapped wave. An important role in this process is played by a secondary non-trapped mode, which is generated by nonlinear interaction between the growing trapped modes. The whole process, thus, may be considered as a resonant scattering of the non-trapped mode on the semi-transparent waveguide or, alternatively, as a specific subharmonic instability of the non-trapped wave. Generally, the Landau equation for the nonlinear evolution of the amplitude of the waveguide mode has multiple attracting solutions. If slow spatial modulation of the waves is allowed, which leads to Ginzburg - Landau type equation, these multiple equilibria lead to spatio-temporal organization and appearance of typical domain-wall coherent structures in the modulated amplitude of waveguide modes. While the solutions of the synchronism conditions for the three-wave interactions of this kind are dense in the phase-space, those for wave-wave-mean are not and provide a resonance response of the waveguide only for particular incoming waves (a resonator effect).