



Internal waves impact on the sea surface

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We theoretically analyse the impact of subsurface currents induced by internal waves on nonlinear Stokes surface waves. A uniformly valid steady model, including the deep surface wave's amplitude–frequency modulation, is considered under conditions that approach the group resonance point. Such a model is constructed by making allowance for the surface waves nonlinear dispersive properties that inevitably are linked with the impact of amplitude variations on the surface wave's frequency in an inhomogeneous medium. We present analytical and numerical solutions of the modulation equations under conditions that are close to group velocity resonance.

We note the key results of our near-resonant SW modulation model:

- (i) Interaction with large-scale solitary IWs leads to strong modulations of the SW envelope. The surface countercurrent causes a growth in SW steepness and results in an envelope shape that follows the current profile. The steepness of modulation grows with the intensity of IW-induced current and is symmetric relative to the current profile axis. A moderate high-frequency oscillation is imposed on the algebraic part of the solution.
- (ii) Modulation by a large-scale positive solitary IW-induced current leads to surface smoothing accompanied by the formation of several zero-level amplitude minima, the number of which grows with the intensity of the IW-induced current. As the interaction length grows, the smoothing strengthens accordingly.
- (iii) An IW forerunner can arise ahead of the IW train for a long SW, manifesting itself as a modulated SW train with a period that is comparable to the IW spatial scale.
- (iv) Leaving the internal wave field, the surface waves preserve the resulting modulation.
- (v) A trace of IW in the case of negative subsurface current can also arise for a relatively short SW scenario in the form of a modulated SW train of comparable intensity.
- (vi) The modulation period of surface waves can be shorter than the IW period (for short periodic and following IW trains) and the modulation depth may be non-uniform along the IW train.
- (vii) Excitation of resonantly coupled surface wave packets whose group velocity corresponds to the IW phase velocity is effective on the counter subsurface flow produced by IW. It has a dynamic threshold that is defined by the space scale and intensity of the internal waves.