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Analysis of intense internal wave evolution in the Seas of Japan and Okhotsk using satellite data from synthetic aperture radar and radiometers

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The paper is concerned with investigation of the internal wave (IW) dynamics in the areas of the Sea of Okhotsk and the Sea of Japan by their surface manifestations recorded by MODIS radiometer (MODerate resolution Imaging Spectro-radiometer) of the Terra and Aqua satellites and synthetic aperture radar ASAR of the Envisat satellite. Principal attention is focused on complex study of the dynamics of intense internal waves propagating in a shelf zone of the ocean. The analysis is based on the investigation of kinematic characteristics of surface manifestations of internal wave trains (wave fronts) and amplitude characteristics of the obtained SAR images. It is intended to find the basic mechanism of IW manifestations on the oceanic surface under given hydrometeorologic conditions, determine the character of internal wave trains (Korteweg-de Vries solitons, Gardner solitons, or Benjamin-Ono solitons), and compute dynamics of IW solitons with allowance for changes in the shelf depth by a definite approximate model (Korteweg-de Vries equation, Gardner equation, CC-mode, and so on). At the current stage of the research we have assessed different mechanisms of surface IW events, and calculated their linear kinematic characteristics under assumption of a quasi-plane IW wave front for a horizontally inhomogeneous ocean. The kinematic characteristics of surface IW events (propagation velocity and shape of phase front) calculated in experiments are compared with the theoretical estimates. Kinematic characteristics of internal waves were calculated in processing a sequence of two satellite snapshots taken with a time interval of 1 hour and 40 minutes for the Terra and Aqua satellites (September 15, 2003, the Sea of Japan) and with a time interval of 12 hours for the Envisat satellite (June 14, 2007, the Sea of Okhotsk). Analysis of the obtained data leads to the conclusion that in the area of interest internal waves are primarily nonlinear. Consequently, the Gardner equation is chosen for analysis of their dynamics taking into consideration variations of the shelf zone depth. The dynamics of intense IW in the shelf zone will be calculated using a modified approximate approach developed by the authors' research team earlier. The approach is based on representing the group of intense IWs near the shelf by a population of solitons whose amplitude is close to the amplitude of limiting solitons of the Gardner equation (Korteweg-de Vries equation with cubic nonlinearity) with variable parameters. The quasi-stationary soliton evolution in media with slowly varying (compared to the IW scale) parameters has been well studied by now. The quasi-stationary behavior of the wave process allows the solution to be regarded to be close to a stationary solitary wave – a soliton with slowly varying parameters, thus, reducing description of solitary wave field transformation to a much simpler problem, namely, to description of the dynamics of a finite number of independent soliton parameters. For soliton parameters comparable with (or exceeding) the scale of medium changes, soliton field transformation becomes nonstationary and more diverse. This concerns, in particular, solitons with maximum amplitude that arise in the course of IW evolution on the shelf. The keystone in the construction of the proposed approximate solution for description of dynamics of such intense IW solitons is their compound structure. These solitons have a form of a plateau of arbitrary length, bounded by relatively narrow field kinks of different polarity that are, together with the solitons, stationary solutions of Gardner equation with constant parameters. We will consider in our paper the situations when, at variable cubic nonlinearity, the quasi-stationary conditions are not fulfilled for a rather extended soliton upon the whole, but are met for kinks forming the front and rear of the evolving quasi-soliton.