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Short-term and long-term evolution of modulational wave train under influence of current

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The modulational instability or the quasi-resonance is considered to play a pivotal role in the generation of freak waves in the ocean. The steepness and the frequency bandwidth, which are known to govern the initial stability of both regular and irregular wave train, are now used to predict the long-term evolution. In this study we extend the pioneering works of Toffoli et al. (2011) and Onorato et al. (2011) demonstrating the influence of current on the wave train evolution via modification of these basic parameters. We have conducted a laboratory experiment at the Ocean Engineering Tank of the Univ. of Tokyo (Kinoshita Lab) investigating the evolution of the marginally stable modulational wave train under influence of opposing current. The experimental results were compared against the numerical solution of the NLSC (Current modified NonLinear Schrodinger) derived by Hjelmervik and Trulsen (2009). For the cases that transitioned into unstable condition, the spatial scale of the evolution was well reproduced by the NLSC. The maximum wave amplitudes reached the level of experimental observation at a realistic spatial scale. On the other hand, there was a case that evolved much faster in the wave tank than the NLSC solution. However, even in this case, the maximum amplitudes observed in the experiment well agreed with the maximum amplitude estimated by Onorato et al. (2011); this was reported earlier by Toffoli et al. (2011) at WISE. Finally, the evolution of the cases that remained stable largely varied between the experiment and NLSC solution. The straightforward interpretation of the successful comparison of the NLSC solution and the tank experiment is that the evolution after encounter with the opposing current is governed by the enhanced nonlinearity. We have compared the amplification of the wave amplitude estimated by action balance and by the NLSC. It turns out that the two estimates do not match. This is because the first term of the r.h.s. of the NLSC is inconsistent with the action conservation principle. If this term alone should account for the action balance, the term should be increased by two-fold. We have also taken into consideration the wave number change corresponding to the second term of the r.h.s., but that did not correct the action conservation based on NLSC. Nevertheless, the work by Onorato et al. (2011) and our experimental result reported by Toffoli et al. (2011, WISE) indicate that the key to understand the impact of the evolution of the wave train encountering an opposing current, is the enhancement of the nonlinearity.

In the comparisons above, we assumed that the current speed changes from one value to the other and remains the same afterwards.Now how does the structure of f(x) influence the wave train evolution? If all can be explained by enhanced nonlinearity after the current speed reached the value Uo, the structure of f(x) is irrelevant. We have numerically compared the difference of f(x)=Uo*sinx^2 and f(x)=0.5Uo(1+tanh(x)). The result is that the estimated maximum modulation amplitude compares well between the two cases. What was most significantly influenced was the recurrence period. The recurrence period did not change with current speed for the sinusoidal cases, but for the hyperbolic tangent cases, the recurrence period largely varied with current speed. Stiassini and Kroszynski (1982) theoretically derived that the recurrence period depends on three parameters, ratio of steepness to frequency bandwidth (i.e. inverse of BFI), side-band wave amplitude and phase. Inspired by this theory, we have numerically experimented the long-term evolution of unstable wave train with various opposing current speeds. With the hyperbolic tangent case, the recurrence period changed with current speed and seemed to depend on the modified inverse BFI under current influence, in qualitative agreement with the S&K theory.