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# Spatial wave structure created by wind input

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## ABSTRACT

Waves on the open sea grow under the influence of strong winds. However, most wave models used in offshore engineering neglect any energy input or dissipation. This paper explores the possible effects of energy transferred from the wind on the nonlinear dynamics of steep wave groups. Whilst for uni-directional propagation, all that occurs is the preferential amplification of solitons, in directional spread wave groups, energy input can trigger the formation of complex geometric structures in the wave field.

KEY WORDS: Waves; wave growth; wind input; nonlinear Schrodinger equation.

## INTRODUCTION

Most models of individual steep waves used for engineering design are based on solutions to the Laplace equation and the kinematic and dynamic free-surface boundary conditions. These models conserve mass, energy, momentum and so on. Thus, they are conservative.

However, extreme waves on the open ocean are most likely to occur in severe locally wind-driven sea-states where there will be considerable energy and momentum input transferred from the wind to the water motion. There will also be transfers out of the wave motion into mean motion of parts of the water column and smaller-scale turbulent motion. This paper neglects dissipation of the wave motion, concentrating instead on whether local energy input from the wind may affect the local dynamics of steep wave groups.

Rather than start with the full field equations, we choose to take a narrow-banded weakly nonlinear model for the wave motion, the nonlinear Schrodinger equation, and add a single negative damping term to make the system weakly unstable – thus, we consider a simple version of the Ginzberg-Landau equation used by physicists. This nonlinear evolution equation is intended to replicate in the simplest possible way some of the dynamic effects of energy input into the wave field. Whilst a physical interpretation of our energy input model could be the greater exposure of tall waves to increased wind speeds further up through the atmospheric boundary layer, this work is intended to make no claims about the appropriateness of the precise form of energy input term in an NLS-type approximation. Instead we aim to explore whether local energy input might play a role in the dynamics of large wave groups.

For a uni-directional solitary wave group, weak instability simply causes the wave group height to increase and the width to decrease such that the slowly evolving and growing group always resembles a solitary wave group (a soliton). This result is well known in nonlinear optics, where it is of considerable importance in that preferential energy input into the coherent solitons rather than the optical noise in an optical fiber can help restore the structure of the pulse after many kilometers of propagation, Mollenauer and Smith (1988). Then, amplification can help overcome the combined effects of dispersion and losses. See also Wabnitz (1995) and Leibovich and Randall (1979).

More interesting in an oceanographic context is the behaviour for a directionally spread focussed wave group in 2-D. We find that a NewWave type group converging to focus is little affected by the nonlinearity until focus is approached. Thereafter the nonlinear dynamics associated with focussing with no energy input are amplified by energy input. The extension of the wave crests and the contraction of the group along its direction of advance are both exacerbated – even to the extent that the group splits along the crest direction. Thereafter rather complicated spatial structure can arise – the wave envelope in space can resemble a hexagonal ring before this splits and additional patterns result, giving rise to a ‘three sisters’ effect.