Modulational interactions of broad-band gravity waves observed during N-Sea storms.

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The conjecture explored in this note is that the interference of "latent" wave groups evolving in different directions at differing group celerities might provide a (partial) explanation for 'freak' waves and correlated large "riding" waves, with associated phase loops, observed in extreme seas.

A series of papers describing experimental measurements of the evolution of wave groups by Stansberg (e.g. Stansberg, 2000) were undertaken to demonstrate the hypothesis that freak waves result from the natural process of evolution of wave groups in accordance with the predictions of the nonlinear Schrödinger equation (NLS). Similar experiments were undertaken by Clauss and Kühnlein (1997) in order to determine the response characteristics of scale model offshore structures. Their experiments give a valuable insight into possible mechanisms of freak wave causation in the laboratory which can be studied by numerical simulations based on the NLS equation.

Papers by Mollo-Christenson and coworkers (M-C and Ramamonjiarisoa, 1982, Chereskin and M-C., 1983) argued that similar evolutionary behaviour of the envelope modulations also occurs in deep water storm waves. Recently Magnusson *et al.* (1999) have provided further observational support using measurements in the North Sea. They have used both the linear and nonlinear evolution equations to obtain estimates of the effect of local wave packet evolution on wave height statistics.

Storm waves observed by Linfoot *et al.* (2000) at the North Alwyn platform in the North Sea exhibit the familiar modulational characteristics and wave group statistics expected from narrow band theory (Longuet-Higgins, 1952) However, close inspection of group profiles, sampled at high-rate (5Hz), shows instances of carrier frequencies which are noticeably different from their neighbours while others show locally correlated "riding" waves (Figure 1a) which appear as secondary loops in the instantaneous phase-time plot . These features are not explained by narrow-band processes.

It is our contention that these features provide observational support for arguments originally made by Mollo-Christensen and cited recently by Donelan *et al.*(1996) that the sea surface during broad-banded storms may be represented by the interaction of independent evolving wave packets which may be travelling in different directions at different wave group celerities- even in circumstances when the directional spectrum is unimodal.

The prime analysis method used in this study was the S-transform (Stockwell *et al.* 1996) which provides a time-frequency matrix directly related to the time evolution of the conventional water surface power spectral density. We show how this matrix is interpreted by applying the S-transform to the evolution and interaction of simulated wave packets. This method has been applied to the North Alwyn storm data to derive time-frequency plots of typical wave packets which we interpret as representing both evolution and interaction as shown in Figure 1(b).

A number of time-series decomposition algorithms published recently have been tested to provide representations of the "latent" wave groups represented in the original times series from the wave altimeters. These include the time-varying autocorrelation method of Prado and West (1997) and the Empirical Mode Decomposition of Huang *et al.* (1998), and a time-varying filter technique based on the inversion of the S-transform matrix as shown in Figure 1(c).

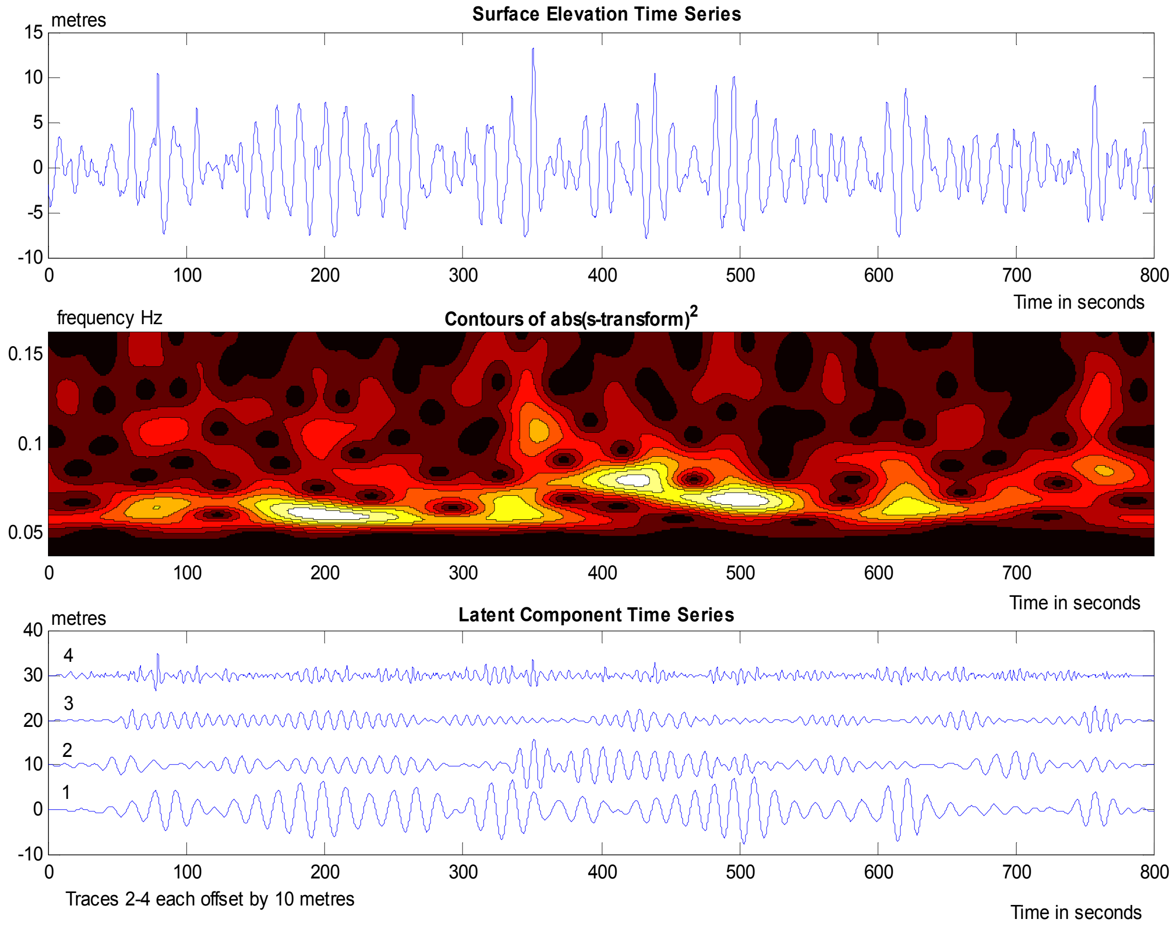

Figure 1: 800 seconds of wave data from North Sea storm (1 Jan 1995): (a) water surface elevation time series (b) Time –frequency contour plot derived from S-Transform matrix:light patches indicate high energy concentrations (c) Component time series produced by adaptive inversion of S-Transform matrix. A 5% Hanning taper applied to the ends of time series in plots (b) and (c) .

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