Focused waves onto a plane beach

Physical modelling in the U.K. Coastal Research Facility

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Focused wave groups and the UKCRF

Introduction

This poster demonstrates some preliminary results from a collaborative project between Oxford University and UMIST carried out in the UK Coastal Research Facility (UKCRF). The aim of the research was to investigate the interaction of steep focused wave groups with a plane beach and a sea wall.

Background

Waves change significantly as they propagate inshore. The most extreme event in a random sea is atypical of the waves in that sea. Thus, the modifications to a large but localised wave group as it advances inshore, particularly on the set-up and crest elevation is more relevant for the prediction of sea defence overtopping and lee shore flooding than the behaviour of regular waves. It is likely that small changes to the incident wave group affect the surface set-up and wave height and have a significant effect on coastal flooding.

Major advances have been made in the past decade regarding the temporal and spatial profiles of the most extreme waves in unidirectional and spread deepwater seas. One contribution has been the so-called NewWave concept of a focused wave group (Tromans *et al.* (1991), Jonathan and Taylor (1997), and Taylor and Haagsma (1994)). In the region of the largest wave crest, the focused wave group has a profile proportional to the auto-correlation function (Lindgren (1970)). By a similar methodology, the shape of the group about the deepest trough is the inverted auto-correlation function.

Experimental Set-up

The UKCRF is a 27 m cross-shore by 36 m alongshore multi-element wave basin. The mean water level at paddles is 0.5 m. Instrumentation includes an array of up to 32 wave gauges, a 2D laser Doppler anemometer (LDA), several acoustic Doppler velocimeters, and two video cameras.

Tromans, P.S., Anaturk, A.R., and Hagemeijer, P. (1991) A new model for the kinematics of large ocean waves – application as a design wave. Proc. *1st Int. Offshore and Polar Eng. Conf.*, Edinburgh, U.K., 11-16 August, 64-71.

Jonathan, P. and Taylor, P.H. (1997) On Irregular, Nonlinear Waves in a Spread Sea. *J. Offshore Mechanics and Arctic Engineering,* 119, 37-41.

Taylor, P.H., and Haagsma, I.J. (1994) Focussing of steep wave groups on deep water. *Proc. Int. Symposium: Waves – physical and numerical modelling*, Vancouver, Canada, 21-24 August, 862-870.

Baldock, T.E, Swan, C., and Taylor, P.H. (1996) A laboratory study of nonlinear surface waves on water. *Phil. Trans. R. Soc. Lond.* A 354: 649-676.

Lindgren, G. (1970) Some properties of a normal process near a local maximum. *Ann. Math. Stat.* 41, 1870-1883.

UKCRF with sea wall in place

Development of spread sea focused wave

Focused wave groups and the UKCRF

NewWave

A focused wave group has individual wave components that come into phase at a particular time and place. NewWave theory can be used to generate an extreme wave group that is representative of a real event in a random sea state by the use of a realistic energy spectrum, such as Pierson-Moskowitz, as follows:

$$NewWave = A_N \times \frac{\int S(\omega)\cos(\omega t)d\omega}{\int S(\omega)d\omega}$$

where *S(ω)* is the desired sea spectrum, ω is the frequency and A_N is the linear crest amplitude:

$$A_N = \left(2m_0\left(\ln N\right)\right)^{1/2}$$

where m_o is the first moment of the underlying spectrum and *N* is the number of waves.

Experimental results and analysis

Surface elevation results for a single extreme wave group are shown in this poster. The wave group was the largest event generated in the UKCRF - a Pierson Moskowitz spectrum with an ω_p of 2.91 rad/s and a NewWave crest amplitude of 114mm.

Two sets of results are shown – those where the crests of the individual wave components coincided – crest focused – and those where the troughs coincided – trough focused. The surface elevation of a crest focused group is given the symbol η and the trough focus the symbol η^* (after Baldock et al 1996).

The crest focus is composed of free and bound waves:

$$\eta = \eta_f + \eta_b$$

The *free* wave is described:

$$\eta_f = \sum_{n=1}^{\infty} a_n \cos\left(k_n x - \omega_n t + \phi_n\right)$$

Where a_n is the wave component amplitude, *k* is the wave number, ω is the frequency and ϕ is the phase angle.

Assuming a Stokes-like expansion, the *bound* wave can be represented as:

$$\eta_b = \sum_{n=1}^{\infty}\sum_{m=1}^{\infty} a_n a_m F_{nm}^{(2)} + \sum_{n=1}^{\infty}\sum_{m=1}^{\infty}\sum_{l=1}^{\infty} a_n a_m a_l F_{nml}^{(3)} + \ldots$$

where *F* are the expansion coefficients.

By the addition and subtraction of the crest and trough focused waves it is possible to separate the free and bound wave components of the experimental data:

$$\eta_{diff} = \frac{1}{2}(\eta - \eta^*) = \eta_f + \sum_{n=1}^{\infty}\sum_{m=1}^{\infty}\sum_{l=1}^{\infty} a_n a_m a_l F_{nml}^{(3)} + \ldots$$

$$\eta_{sum} = \frac{1}{2}(\eta + \eta^*) = \sum_{n=1}^{\infty}\sum_{m=1}^{\infty} a_n a_m F_{nm}^{(2)} + \ldots$$

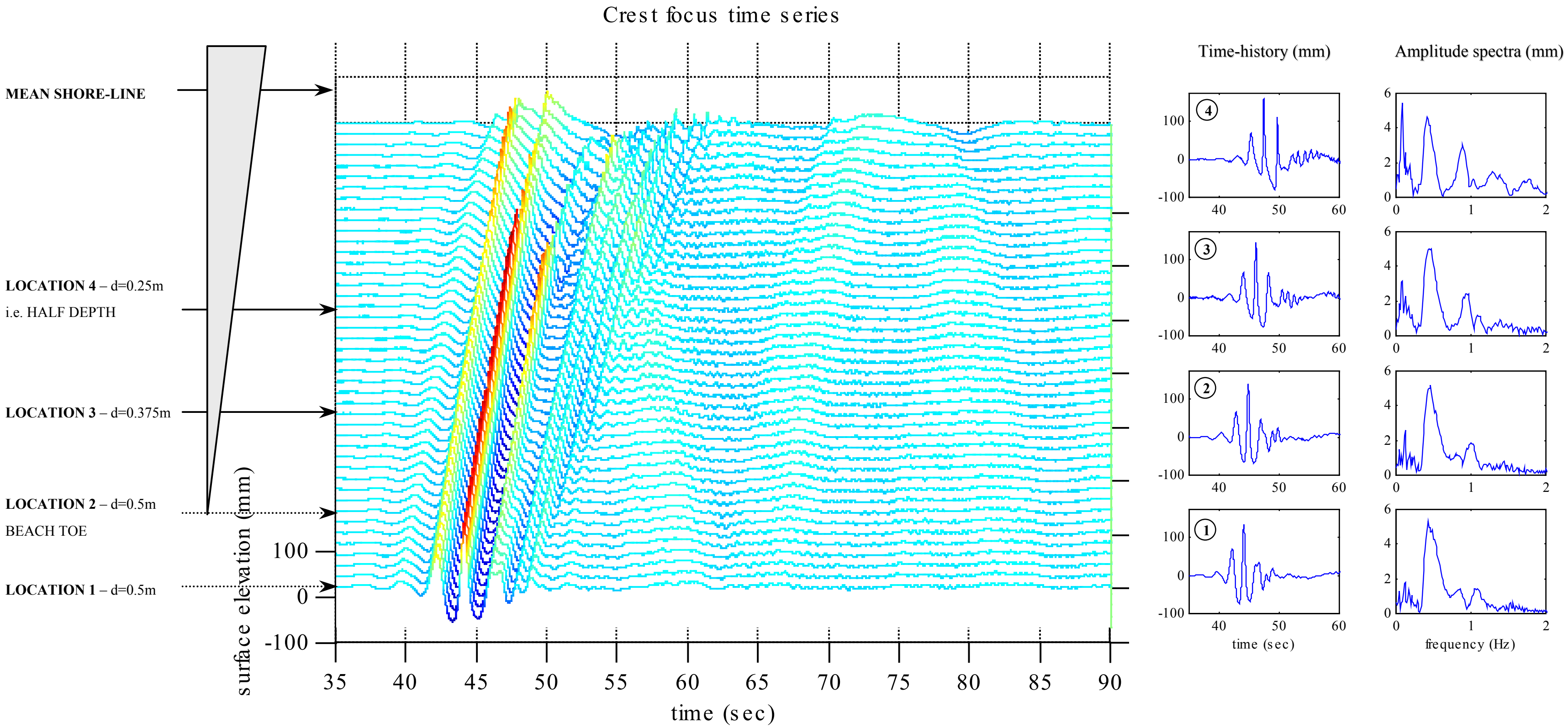
Furthermore, if the data is bandpass filtered, the underlying locally linear structure of the group can be separated from the various bound harmonics.

Conclusions

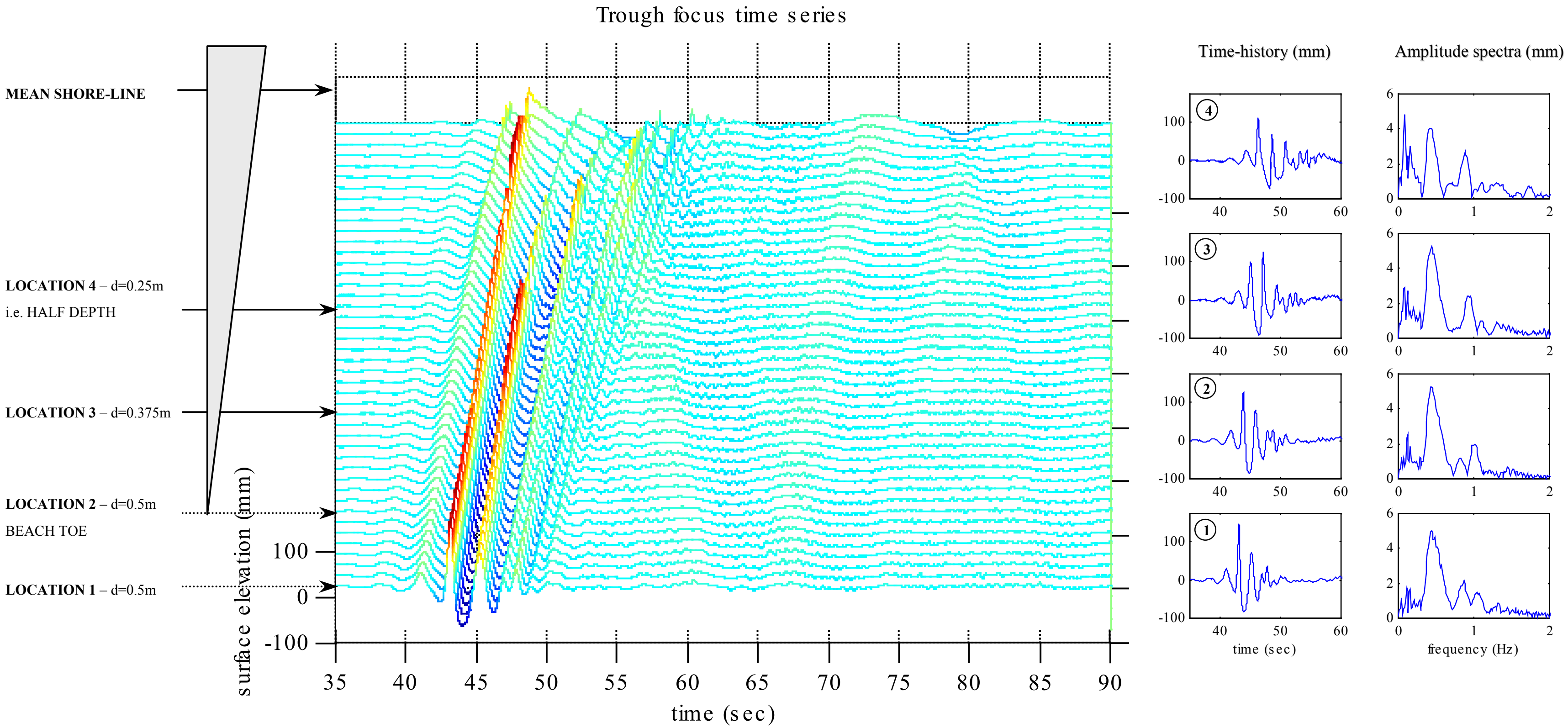
Preliminary investigations of sequential wave gauge data shows:

- the evolution of different terms of the Stokes expansion
- the reflection of the ingoing low frequency *bound* wave as a long *free* wave which reverberates across the tank
- the long free wave is dependent on the wave group envelope *only* i.e. both crest and trough focused wave groups produce the *same* free wave.

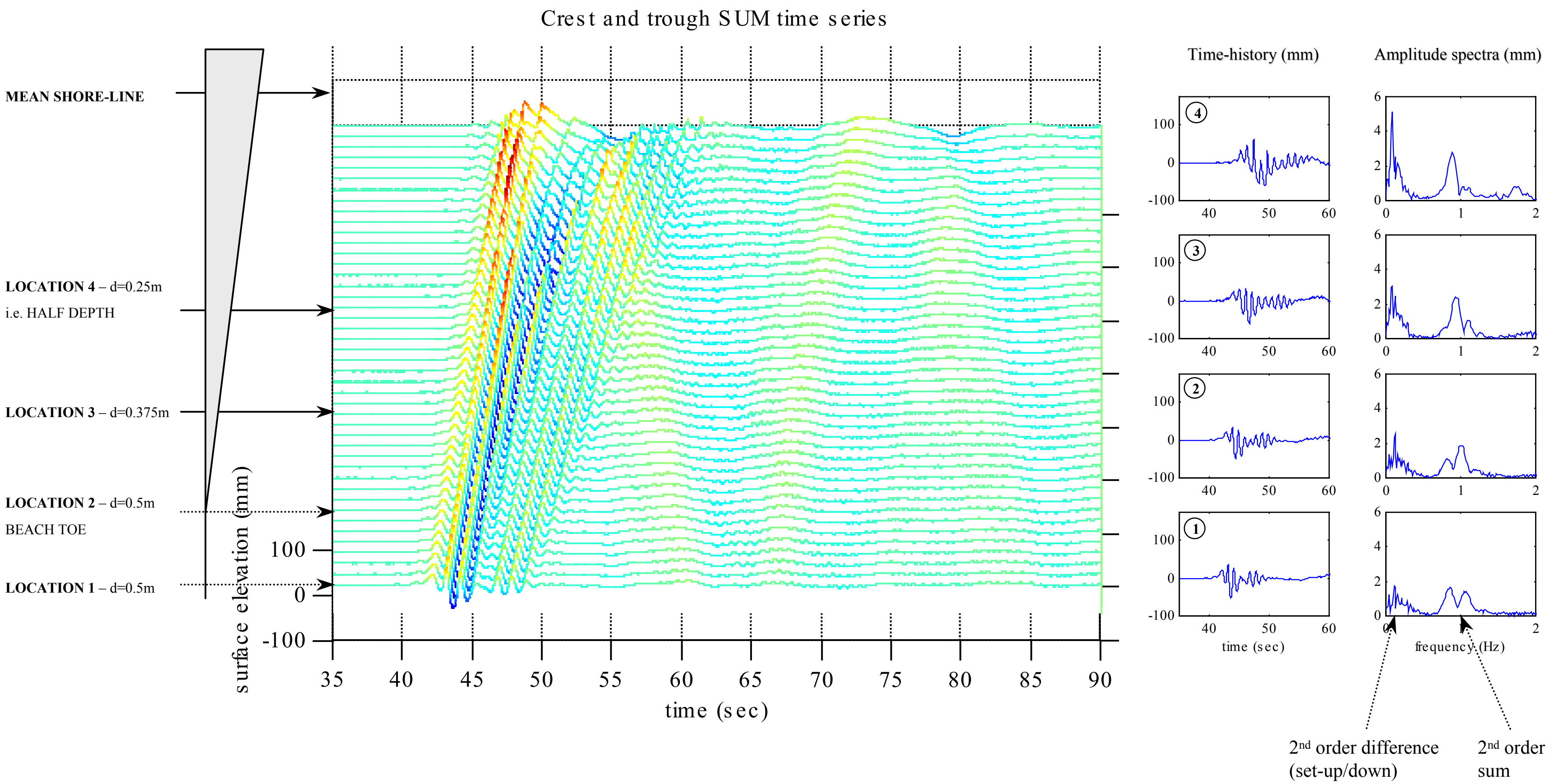
Crest focus wave groups



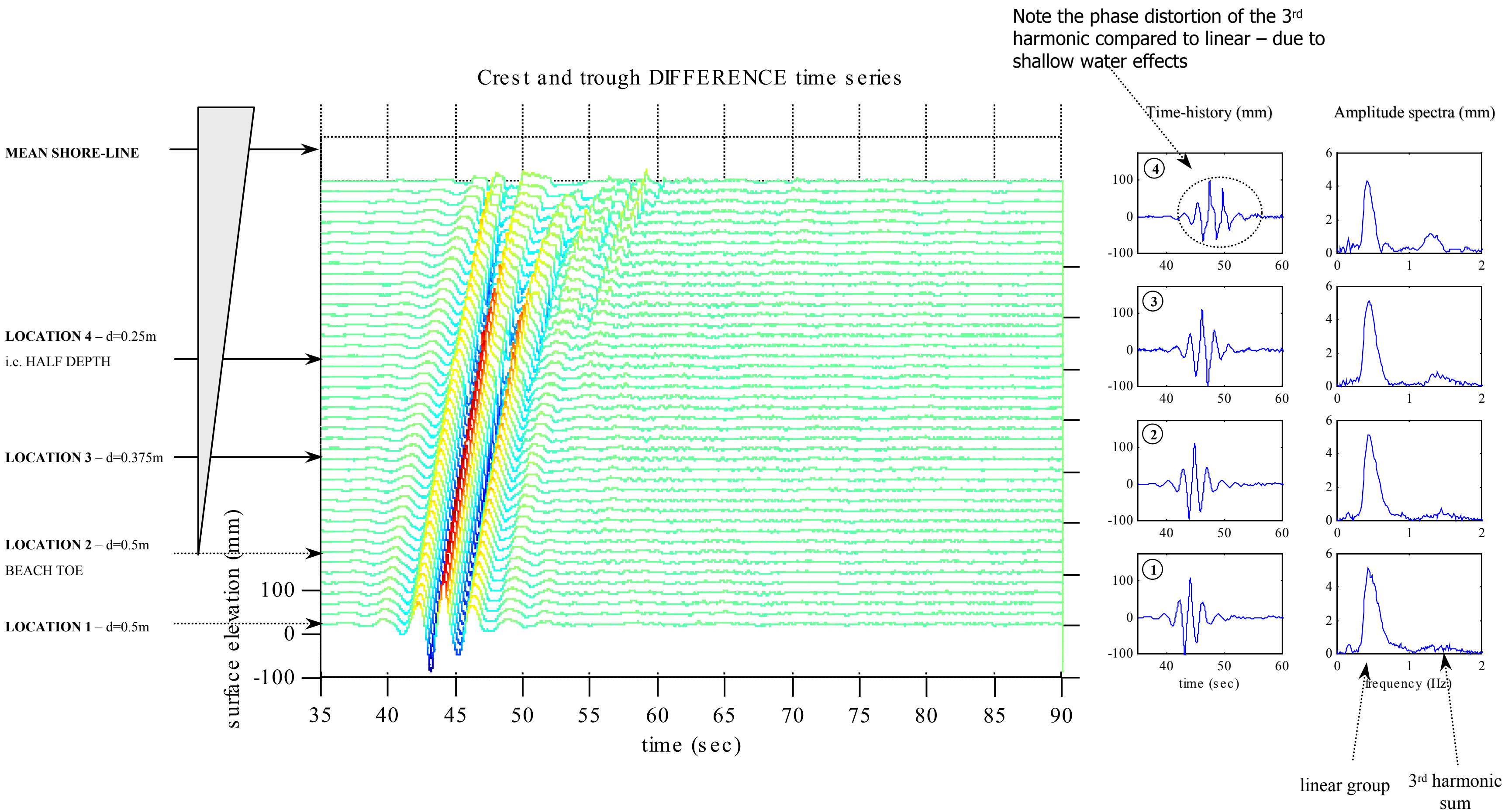
Trough focus wave groups



‘Sum’ series – *even* harmonics

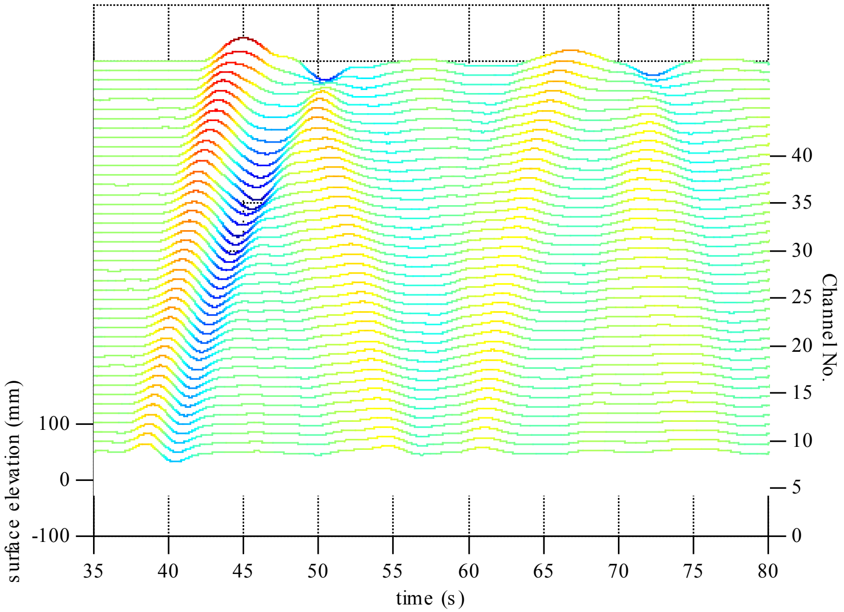


‘Difference’ series – *odd* harmonics

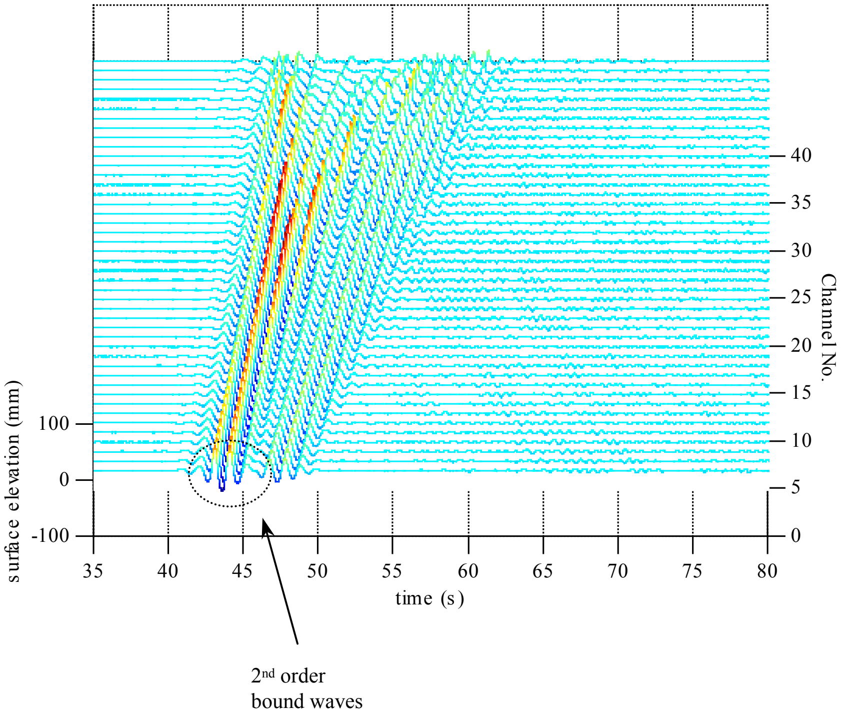


‘Sum’ series – filtered at 0.5Hz

Low pass filtered

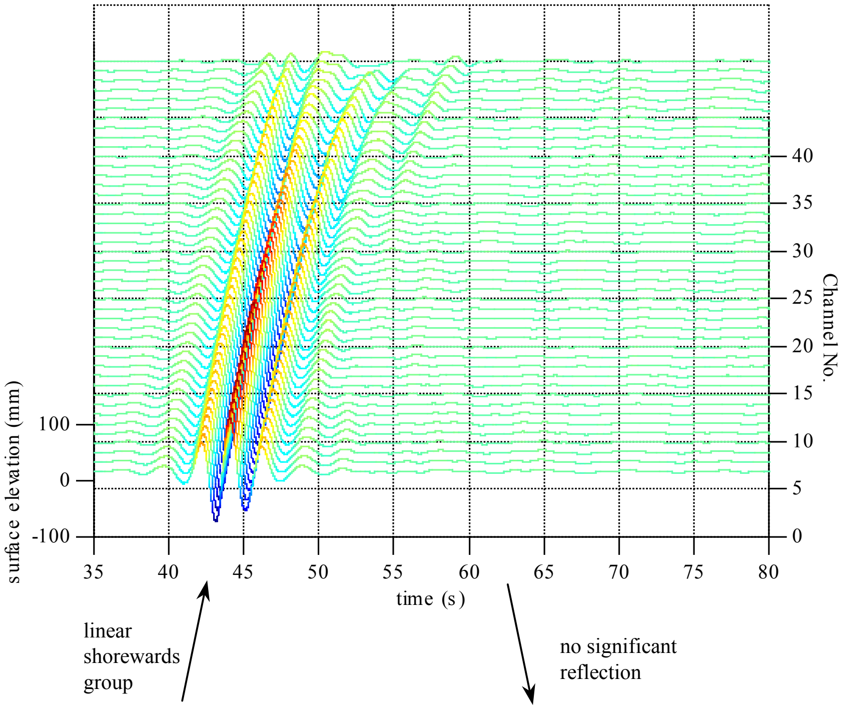


High pass filtered



‘Difference’ series – filtered at 1Hz

Low pass filtered



High pass filtered