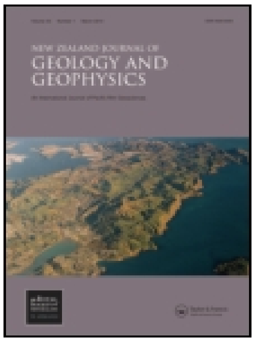

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Significance of storm surges on the New Zealand coast

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Letters to the Editor

Significance of storm surges on the New Zealand coast

Comment

There is little doubt that large storm systems combine wave attack and super-elevated water levels to cause coastal erosion and flooding, and to create powerful alongshore currents important in the dispersal of coastal sediments. While the role of storm wave attack has been intensively studied over the last decade, water level effects are less well-known. Thus Heath's analysis of the surge effects associated with three of the most damaging storms in the last decade is an important contribution to understanding coastal erosion.

However, in view of the widespread and frequent incidence of storm surge damage at such diverse locations as Omaha Beach, Northland; Raumati; southern Pegasus Bay; and on the North Otago coast, the conclusions are somewhat puzzling. In the last named area coastal erosion is intense and there is frequent salt-water flooding of crop and pasture land which is 5–8 m above mean sealevel. Specifically, the conclusions that "the magnitude of the surges analysed are each less than 0·6 m and by themselves would not cause significant flooding . . . (though) they would however affect the inland extent of shoreline erosion . . ." (p. 265), require clarification. It is implied that the erosive effect will be minimal since on a sandy shore, "a 0·6 m surge would give rise to an additional 6–18 m of beach being covered by water" (p. 265). A major effect would be that surges of this magnitude have a pronounced influence on alongshore current flow and hence on sediment dispersal initiated by tides and waves seaward of the surf zone.

It is suggested here that the analysis is incomplete insofar as at least three additional factors would have acted to varying degrees to increase water levels, beach inundation, and inshore current flows beyond the levels determined by Heath.

Wave Set-up

In addition to the isostatic adjustment ("inverted barometer effect") and the direct wind set-up components studied by Heath, there is also an appreciable component rise in mean water level against the shore which is caused by shoaling and breaking of the wind waves accompanying the storm surge—hence a "wave set-up" component. Much basic research has been devoted to this phenomenon since it is believed to be the driving mechanism for longshore currents and rip currents in the surf zone of beaches and because it is an important element in designing structures to resist storm surge overtopping. This research is sufficiently advanced that the Coastal Engineering Research Centre of the U.S. Army Corps of Engineers (C.E.R.C.) has published an operational procedure for its estimation in storm surge design problems.

The magnitude of wave set-up is a function of wave height, wave period, depth of breaking, and beach slope. It is larger for sandy shores with gently sloping offshore profiles. The wave set-up contribution to water level at the shore can either be calculated directly from formulae or read from nomographs presented in C.E.R.C. (1977 pp. 3-93–3-101).

Typically, occurring wave conditions in storm systems along the east coast, South Island, and elsewhere, have breaker heights, H_b = 3–4 m; and periods in the range T = 10–12 seconds. Depending upon the nearshore bed slope, the C.E.R.C. procedures indicate a wave set-up of 0·4–0·5 m which will occur at the beach in addition to the 0·4–0·6 m (isostatic plus wind) components identified by Heath. It can therefore be seen that the wave set-up component by itself may have been as large as the sum of the other two components. I conclude that surge water levels at the shore were more probably of the order of 1 m for at least two of the storms analysed by Heath (April 1968; September 1976), and may have been higher.

The C.E.R.C. procedure assumes zero wave refraction such that a maximum of the shoaling effect of the waves is apparent as a rise in mean water level over the inshore zone. Should there be significant wave refraction then a portion of the effect appears as an elevated water level, while the remainder is directed alongshore to reinforce the "coastal jet" flow identified by Heath and to drive powerfully erosive rip currents.

Interaction with the Tide

The absolute elevations reached by the runup of waves in storm surges also depends upon interaction of the storm system and the normal astronomical tide. This is readily understood in relation to peak water levels since a surge coinciding with spring high water will obviously produce a higher peak than a coincidence with a neap, and the damage will peak at times of high water.

However, the temporal pattern and duration of a surge system at a given site are more complex matters. Variation from place to place and from storm to storm in these aspects may contribute as much to erosion and flooding as does the elevation of water levels.

Rossiter (1971, p. 160) has demonstrated considerable interdependence between the tide and surges for parts of the U.K. coast, and argued that the coupling arises during their propagation together in shallow or restricted water. For negative surges (depressions of sea level) the time of high water can be retarded, while in the case of one positive surge, Rossiter noted an advance of 90 minutes in the time of high water.

Though conditions on the U.K. coast may be different than those around New Zealand it is probable that non-linear surge/tide interactions occur, particularly on broad shallow sections of the shelf (as off Canterbury) and in restricted water bodies such as Lyttelton Harbour. It is relevant here that in each of the last two years surge water levels up to 0·8 m above the tide have been recorded at Lyttelton.

While the modifying effects of restricted water body geometries are specifically acknowledged by Heath, and have been investigated by him in previous studies, the debate here concerns the "significance of storm surges on the New Zealand coast".

Wave Run-up versus Water Level

It is important not to confuse the uprush limit of broken waves on the shore with the elevations reached by surge water levels, particularly where wave set-up is not considered. Heath argued that, "on sandy New Zealand beaches having typical slopes of 2–6°, a 0·6 m surge would give rise to an additional 6–18 m of beach being covered by water" (p. 265).

Uprush characteristics such as length, volume, velocity, and turbulence are not only functions of beach slope and water level, but are also strongly conditioned by breaker type, height, period, and the degree of variability in these properties. Uprush effects are compounded by the powerful erosive effects of the backwash. In storm wave conditions the latter is the primary agent of beach erosion (Kirk 1975).

Breaker characteristics and hence flow conditions on the beach are markedly affected by depth of water in the inshore zone, and so are sensitive to the increased water levels of storm surges. For this reason the erosive power of the storm surge runup and backwash system is greatly enhanced. It is therefore necessary to add wave set-up and runup enhancement to the two components specified by Heath to fully account for the inland extent and overtopping risk. It is rather facile and results in serious underestimates to convert a given rise in water level via a beach slope angle to a beach width, "covered by water", as if no effects deriving from wave action existed. Nor are runup and set-up effects such as those described confined to gently sloping sandy beaches. On the more steeply sloping mixed sand and gravel beaches of the Waitaki and Timaru coasts, persistent coastal erosion and saltwater inundation are costly facts of life presently exercising a number of organisations.

To conclude, the significance of storm surges in coastal erosion and flooding problems has, in my opinion, been underestimated by Heath, since both water levels at the shore and runup behaviour are intensified by factors not included in his analysis. It is suggested that a full evaluation requires study of both the wave and the water level contributions to the total effect of particular storms as they occur on given shoreline geometries and sea-bed topographies.

25 September 1979

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Reply

My paper was originally prompted by frequently hearing comments such as Dr Kirk's, of storm surge damage at such diverse locations as Omaha Beach, Northland; Raumati; southern Pegasus Bay; and on the North Otago coast. The aim was to investigate, from tide gauge records of sea surface elevation, the magnitude of surges during three of the larger recent storms on the New Zealand coast.

Wind and Wave Set-up

The spectrum of sea surface elevation contains motions on a variety of time and space scales ranging from capillary waves to longest periods of the tide. In making any study of variations of sea surface elevation it is therefore important to define what part of the spectrum one is studying. Storm surges as defined by Groen & Groves (1962) 'may be characterised as being sea surface disturbances with dominant periods ranging roughly from 10^3 to 10^5 s. In terms of the dynamics of the process they are described by the long wave equations of motion, and therefore within the range of periods include only large scale spatial variability. The shorter period wind waves are therefore excluded.

The radiation stress associated with the wind waves, however, gives rise to a rise in sea level on the coast inshore from where the waves break. Small scale aspects of this wind wave set-up are generally regarded as separate from the motions encompassed by the term storm surge (see e.g., C.E.R.C. 1977).

My paper is based on observed sea surface elevations from harbour sites removed from the open coast, and these records will reflect the broad scale influence of the wind wave set-up. The wind wave set-up will exhibit temporal variability with the frequency of the wind wave groups and a spatial variability depending both on the temporal variability and the spatial dependence imposed on the wind waves by the sea-floor morphology. This variable wind wave set-up is likely to generate edge waves which will travel along the coast (see e.g., Gallagher (1971) who discusses measurements from Cape Palliser). An overall edge wave spectrum will develop which does not depend strongly on any one coastal feature, and it is this part of the spectrum that will be exhibited in the tide gauge records. In brief, the tide gauge observations reflect the presence of the broad scale effect of the wind wave set-up in addition to other signals; study of the local variability of the wind wave set-up which depends on the detailed local sea-floor morphology and wind wave climate was outside the scope of my paper, although, as pointed out by Dr Kirk, is likely to be important at specific locations, mostly on the open coast.

The Interaction with the Tide

Again I feel it difficult to reply to this comment unless Dr Kirk gives observational evidence of non-linear surge tide interaction on the New Zealand coast. His comments rely strongly on the United Kingdom experience of observed surge tide interaction.

The interaction on the New Zealand coast is probably not as great as that observed in the U.K. and it is not just a matter of extrapolating from the U.K. experience to imply that the same situation will exist on the New Zealand coast. In general it would appear that the storm surge elevations are larger on the U.K. coast than on the N.Z. coast. The tidal elevations are also larger on the U.K. coast. Therefore with both signals, the storm surge and the tides, being smaller on the N.Z. coast, the non-linear interaction is also likely to be correspondingly smaller. Some measure of the relative influence of non-linear processes can be gained by comparing the relative size of the over-tides on the U.K. and N.Z. coast; these over-tides result from non-linear interaction within the tides themselves. The first harmonic of the principal lunar semi-diurnal tidal constituent (M_4) in the eastern Irish Sea has amplitudes up to 0·25 m, whereas at Lyttelton the M_4 amplitude is 0·004 m and has a maximum observed value on the N.Z. coast at Dunedin of 0·08 m (tidal constants lodged at the Bidston Observatory of the Institute of Oceanographic Sciences). Dr Kirk specifically mentions Lyttelton Harbour—analysis of tide gauge records from Lyttelton indicates the presence of an edge wave on the east coast of N.Z. with a period of 2·4–2·7 h. This edge wave appears to be generally excited by the wind and can be excited by tsunamis (Heath 1979).

Wave Run-up versus Water Level

Dr Kirk's final comment concerns my converting a vertical surge elevation to additional width of the beach covered due to the surge, with the inference that this will be the only effect of the surge. As I mention, the additional width of beach covered will affect the inland extent of the storm erosion as discussed in the cited reference.

26 October 1979.

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New Zealand Theses in Earth Sciences

ROBINSON, P. H.

"An investigation into the processes of entrainment, transportation and deposition of debris in polar ice, with special reference to Taylor Glacier, Antarctica" (Ph.D., 1979. Victoria University of Wellington, New Zealand) 195 p.

In the present study two separate, but interdependent lines of evidence contribute to an understanding of debris behaviour within Taylor Glacier. The evidence comes from: (1) the thermal regime of the glacier; and (2) features of the debris within the glacier.

The main purpose of studying the thermal regime in the basal ice of Taylor Glacier was to provide information about the likely entrainment and transportation of debris occurring at the glacier sole. Assuming steady-state conditions, the distribution of basal temperatures for Taylor Glacier was determined from the rate of geothermal heat influx at the base of the ice, the temperature near the ice surface, the vertical components of velocity within the glacier, and the ice thickness. The calculated temperature distributions indicate that in over 50% of the lower ablation area, the basal ice is at pressure melting.

An investigation of englacial and basal debris features led to the conclusion that this material was incorporated by two separate processes operating at the glacier sole. The englacial debris was incorporated by pressure melting and regelation (involving particles), and incorporation of the basal debris was by freezing model regelation (involving blocks). These processes probably occur close to the glacier margin, where the inner warm basal ice is in contact with the marginal cold ice. Here the debris is frozen to the sole and remains relatively unmodified during transport to the margin — the site of deposition.

Both lines of evidence indicate that Taylor Glacier is, and has been, capable of erosion and entrainment of debris at the glacier sole, and that this debris has similar features to the already deposited drift in upper Taylor Valley. This implies that recent past climatic changes have had little effect on the entrainment, transportation and deposition of debris from Taylor Glacier.

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