Performance of algorithms for rapid first guess prediction of surf heights

Andrew Saulter[1] , Tim Poate[2] and Nigel Tozer[3]
[1] Met Office, FitzRoy Road, Exeter, UK
[2] University of Plymouth, Drake Circus, Plymouth, UK
[3] HR Wallingford, Howbery Park, Wallingford, UK

Feasibility of beach-by-beach surf forecasting on a national scale?

Whilst accurate prediction of surf conditions is possible using state of the art models and survey methods, maintaining bathymetry data and running such models to cover large stretches of coastline presents a major challenge and computational expense for forecasting agencies.

However, if some degree of accuracy or detail can be sacrificed, physically based yet computationally efficient generation of 'first guess' surf forecasts may be possible, by using schemes that focus on the key processes affecting transition of waves from offshore to coast.

Developing such systems, with the aim of being relatively simple to deploy and fast to run, can enable a national agency such as the Met Office to generate practically useful forecasts of surf conditions on beaches nationwide; assisting decision making for lifeguards, beach-goers and other coastal users.

The Scheme

A set of algorithms, which draw from a mix of shallow water wave physics parameterizations in spectral wave modelling and empirical formulae for breaker height prediction, are combined for surf prediction.

Step 1 - Coastal refraction and dissipation

Raw model spectra or spectra reconstructed from model integrated parameters (Bunney et al., 2013) are propagated shoreward, subject to modification based on a beach's *swell window* and *slope of the seabed* over the *approach distance* from model cell location to the beach (Figure 1).

Simulated processes modify the wave energy via:

1. Offshore wave direction – not all wave energy will be directed shoreward
2. Bottom friction – wave orbital motions are constrained at the sea bed (Hasselmann et al., 1973) over the beach approach
3. Refraction and shoaling – energy density changes as the waves slow down in shallow water

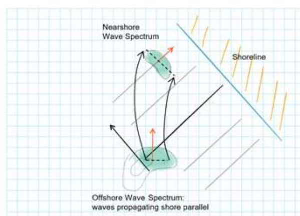

Figure 1. Schematic of key filtering and refraction processes underpinning change in wave energy from offshore to outer surf zone. Only the shoreward propagating components of wave energy contribute to the nearshore wave spectrum; the effect of refraction in shallow water leads to an increase in along-crest distance between wave rays, resulting in a reduction in wave energy density.

Process 1 is affected by wave direction and spreading in the offshore. All processes are sensitive to wave period; and particularly to long periods.

Testing of two downscaling options, using raw model spectra (QRefrac) and partially reconstructed spectra (IRefrac), against two-dimensional SWAN models (Booij et al., 1999) has demonstrated that comparable accuracy can be achieved with an order of magnitude time saving for simple to moderately complex cases (e.g. Figure 2; Saulter, 2016).

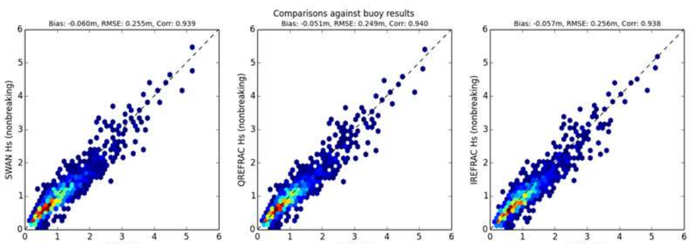

Figure 2. Comparison of SWAN (raw model spectra at boundary), QRefrac (raw model spectra at boundary) and IRefrac (partially reconstructed model spectra at boundary) algorithm estimation of significant wave heights against Channel Coastal Observatory buoy at Saunton Sands; 1 year data sample (2012).

Step 2 - Empirical formulae for surf height estimation

Surf height estimates use the breaking wave formulae of Goda (2000), with surf height identified as the height of waves at onset of breaking in the outer surf zone (non-saturated breaking). This occurs for a specific condition in the Goda formulae (Figure 3) where:

$$H_b = H_{off}\max[0.92, \beta_{max}],\text{ for } \beta_{max} = 0.32\left(H_{off}/L_{off}\right)^{-0.29} e^{2.4\tan\theta}$$

In common with other breaker formulae, the key dependencies are on *offshore wave steepness* defined in deep water (H_{off} / L_{off}) and *local beach slope* ($\tan\theta$). To calculate the offshore values, the refracted waves from Step 1 are 'reverse-shoaled' into deep water along a theoretical wave ray with direct incidence to the beach and using linear theory. Primary factors affecting wave breaking are then:

- Wave period; affects shoaling and refraction characteristics
- Beach slope; affects speed of transition to breaking – breaker type
- 3D variation in morphology; localised breaking effects – not included in the present system

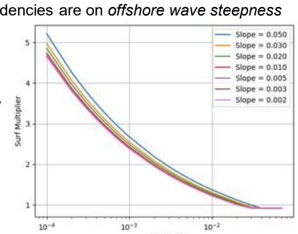

Figure 3. Variation of Goda (2000) wave breaking factor (surf multiplier) for outer surf zone versus offshore wave steepness

Verification – acquisition of surf height data

The University of Plymouth Coastal Marine Applied Research group (CMAR) analysed and provided outer surf zone breaker height data from archives of beach studies undertaken by university's Coastal Processes Research Group (CPRG, Figure 4).

The studies consist of single or multiple pressure sensor deployments. Tidal excursion and the vertical position of the sensors restricts the period of time in which the outer surf zone is measured. Data were mined for surf height measurements based on the deployment type:

1- Where an array of wave sensors were deployed, time-synchronous wave heights were extracted and used to identify the cross-shore break-point from which breaker height was defined.

2- Where a single sensor was deployed, time-series of wave heights were analysed to identify the (Hs/h) point at which peak waves occurred (Figure 5). There is some potential for non-stationarity in conditions to affect the quality of these data.

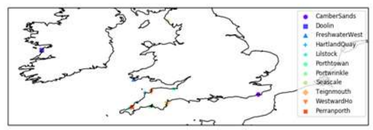

Figure 4. Locations of CPRG study sites used for surf height data mining

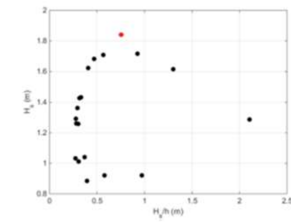

Figure 5. Relative wave height (Hs/h) distribution from Westward Ho! against wave height (Hs). Red symbol indicates the extracted breaker height.

Verification – comparison against offshore predictions

Outer surf zone breaker heights derived from the CPRG data were compared against predictions using a) the IRefrac downscaler and Goda breaker prediction; b) a model estimate of wave height at the nearest cell in the Met Office European region 8km wave model (i.e. boundary condition to a).

The comparison (Figure 5) demonstrates that the forecasts are skilful (error standard deviation less than observed) and show a significant improvement in surf prediction versus the simple proxy of using offshore waves as predictors (reduction in forecast bias and error standard deviation). Outliers generally occur in more complex cases where physical processes that are either not accounted for in the algorithms, or prevent a proper observation of the surf heights, can be identified.

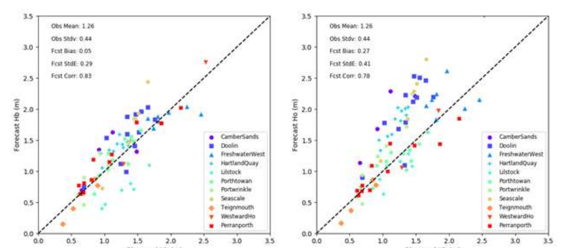

Figure 6. Comparison of observed breaking wave height (Hb, x-axis) versus: (left) predicted wave height based on downscaling and surf height prediction; (right) a naïve prediction using modelled wave height at closest grid cell (Ho). Surf prediction outliers occur at Lilstock (LST), where strong tidal variations affect incident energy and are not represented in the driving model, and Doolin, where beach profile is relatively steep and has a stepped morphology (Poate et al. 2017)

Practical Applications

A python library has been developed and has enabled the Met Office and University of Plymouth to set-up a beach weather, surf and rip current risk forecast service at 245 beaches manned by RNLI Lifeguards. Configuration requires a knowledge of beach location, swell window, and estimates of slope both for the beach and its approaches. Surf forecast data for 5 days ahead can be generated within a few minutes on a single processor desktop PC. The forecasts are used as a management decision making and education tool.

Further development

The key challenges for these routines are to reduce uncertainties in more complex coastal settings and further localise forecasts by identifying schemes to parameterise effects of beach/reef bathymetry in focusing surf waves and better represent surf variability that is inherent in meso-/macro-tidal environments.

References

Booij, N., R.C. Ris, and L.H. Holthuijsen, 1999: A third-generation wave model for coastal regions, Part I, model description and validation. J. Geophys. Res., 104, 7,649–7,666.

Bunney, C., A. Saulter, and T. Palmer, 2013: Reconstruction of Complex 2D Wave Spectra for Rapid Deployment of Nearshore Wave Models. In: Coasts, Marine Structures and Breakwaters 2013: ICE Conference Proceedings. Sep 2013, Edinburgh.

Goda, Y., 2000: Random Seas and Design of Maritime Structures. Singapore, World Scientific Publishing Co. Pte. Ltd.

Hasselmann, K., T.P. Barnett, E. Bouws, H. Carlson, D.E. Cartwright, K. Enke, J.A. Ewing, H. Gienapp, D.E. Hasselmann, P. Kruseman, A. Meerburg, P. Muller, D.J. Olbers, K. Richter, W. Sell, and H. Walden, 1973: Measurements of wind-wave growth and swell decay during the Joint North Sea Wave Project (JONSWAP). Deutsch. Hydrogr. Z., Suppl., A8, 12, 95pp.

Poate, T., G. Masselink, M.J. Austin, M. Dickson and R. McCall, 2017: The role of bed roughness in wave transformation across sloping rock shore platforms. J. Geophys. Res: Earth Surface, 123, https://doi.org/10.1002/2017JF004277

Saulter, A., 2016: Testing the performance of simple methods for nearshore wave downscaling. Met Office, Forecasting Research Technical Report No. 613. https://digital.nmla.metoffice.gov.uk/IO_0fe72ac4-852b-4965-a0c8-098e3f140b7e/

Met Office FitzRoy Road, Exeter, Devon, EX1 3PB United Kingdom
Tel: +44 1392 885680 Fax: +44 1392 885681
Email: andrew.saulter@metoffice.gov.uk