SWAN ([1]) is a state-of-the-art numerical model to predict the generation and subsequent evolution of wind-generated waves in the coastal environment. The model is based on a stochastic description of the wave field represented by the frequency-directional spectrum of the wave energy subject to changes in the propagation as well as non-linear interactions, wind forcing and dissipation. Engineers, consultants and academics use the model to predict the wave transformation over complex bathymetry and flow fields yielding insight into the nearshore conditions that are relevant for the computation of for instance harbour access, sediment transport and design storm conditions for coastal safety. The stochastic description assumes that the wave field is 1) quasi-homogeneous and 2) Gaussian, which implies that the wave field is completely defined by the variance only. As a result, a fundamental limitation of the model is that it does not predict constructive and destructive interference that comes with waves that are phase coupled. These interference patterns come about when waves interact with rapidly varying bathymetry and flow fields or in the presence of quay walls as well as harbour access channels. In these cases both refraction and diffraction are important physical processes that determine the locally varying wave height. Furthermore, the presence of these kinds of features may not only affect the near field but also the far field due to wave focusing and defocusing, resulting in alongshore varying wave conditions along the coast and subsequent design conditions.

Figure 1: Wave rays over tidal jet. The rays are indicated by solid curves, and arrows mark the ambient current.
To account for interference effects the standard transport equation for spectral wave energy that is used in SWAN is modified, taking into account the evolution of the correlation of different wave components when interacting with bathymetric variability ([2], [3]) as well as current variability ([4]). Inclusion of both bathymetric and flow variability is of key importance in the prediction of wave transformation in for instance tidal basins where ebb and flood channels intersect shallow shoals. To test the performance of the new model, which is referred to as the QCM (quasi-coherent model), the wave transformation of a narrow banded wave field over a narrow tidal jet is examined. The example is formulated over a spatial domain of 4000 [m] × 4000 [m] and a constant depth of 10 [m]. Waves enter the domain along the left boundary, at x1= 0. In this example a symmetric Gaussian shape is selected to describe the initial wave spectrum over the wavenumber space. The parameters governing the initial spectrum are the peak wavenumber (or the corresponding peak wave period, T0, and direction, θ0), the standard-deviation, Sd, and the significant wave height, Hs0. These parameters are given as follows: T0 = 20 [s], θ0 = 15 [deg], Sd = 0.001 [1/m] and Hs0 = 1 [m], respectively.

The evolution of the wave field in this wave-current interaction problem is described in Figure 1. Arrows indicate the tidal jet, and the evolution pattern of the wave field is represented by the wave-rays at the peak wave number represented by the solid lines. Over areas where rays converge and form focal zones, higher wave heights are expected. It is clearly shown how the waves refract and form a focusing zone close to x1 = 2000 [m]. Beyond zones of ray crossing (x1 > 2000 [m]), interference structures emerge.

The evolution of the wave field shown in Figure 1 will assist in interpreting the main results of the example shown in Figure 2. These results present a comparison between three different models in terms of the spatial distribution of the significant wave height, Hs. The left panel shows the results of the new model (the QCM). These results are verified through a comparison to the results due to REF/DIF1 model ([5]), which provides a numerical solution of the parabolic approximation of the well-known mild-slope equation (e.g., [6]). Since REF/DIF1 provides the results due to an initial monochromatic wave condition, the final results due to the complete initial spectrum is constructed through a superposition of the individual ones as detailed in [7]. Ultimately, in order to demonstrate the statistical contribution of the interference terms, the results due to QCM are also compared to the results of the present SWAN model ([1]).

The physical pattern described by the rays in Figure 1 is also reflected statistically in the results of Figure 2. While the results of QCM and REF/DIF1 agree quite well and share a similar evolution pattern, the results due to SWAN increasingly deviate beyond the crossing zone. As explained earlier, the transport equation employed by SWAN disregards the generation of cross-correlations (correlations of different wave components), which transport the information about wave interference. The QCM, on the other hand, does account for this information, and therefore, in regions where the statistical contribution of wave interference is significant, the discrepancies between the results of QCM and SWAN will be pronounced.
The effect of wave interferences can contribute significantly for cases where the variation scale of the medium is at the same order or smaller than the scale of the correlation length ([2], [3]). Specifically, as demonstrated in [4], in order to obtain a statistical signature of wave interferences, correlation should emerge between the incoming field and the interference structure it forms, with the dominance of the interference effect determined by the correlation value itself.

In the example considered here, the value assigned to Sd corresponds to a correlation length of a few kilometers. As a result, a strong correlation emerges between the incoming wave field and the interference pattern it forms. This leads to the generation of cross-correlation terms which are transported together with the variance terms, and eventually, altering dramatically the statistics of the scattered field, as appeared through the comparison of QCM and SWAN in Figure 2 in terms of Hs.

As can be seen in Figure 2, the contribution of the interference terms to the distribution of Hs is not confined to the focusing areas, but spreads over the whole domain and beyond. It is therefore concluded that for regions involving rapid variability in the medium (e.g., coastal regions or oceanic regions which tend to contain submesoscale currents), consideration of the statistical information of wave interference might be crucial for many applications, such as, wave-induced circulation and transport process in coastal regions or for prediction of extreme elevations in the open ocean. To account for this, SWAN will be extended with the QCM method, thus allowing for the description of the evolution of a quasi-coherent wave field subject to wind forcing, non-linear interaction and wave dissipation.

REFERENCES