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UNRAVELING MULTIMODAL NEARSHORE WIND-WAVE FIELDS ON THE DUTCH SHOREFACE

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INTRODUCTION

Changing (wind) climate might influence the magnitude, direction, and frequency of wave systems (Lobeto et al., 2021). However, in coastal engineering applications, generalized wave parameters are commonly used in climate change assessments with the risk of, for example, misrepresenting the nearshore transformation of wind-driven wave climates (Hegermiller et al., 2017). In consequence, these uncertainties in the nearshore (wind) climate will affect, amongst others, ship navigation, the implementation of marine renewable energy farms, the feasibility of coastal infrastructure and defences, or the efficiency of sandy coastal maintenance, and thus the decision-making of long-term, multidecadal coastal strategies (Rijksoverheid, 2013), especially when they are designed accounting for the Building with Nature concept (de Vriend et al., 2015).

THE GOAL AND THE APPROACH

This study analyses the importance and application of considering multiple coexisting wave trains on the Dutch shoreface. The wave trains at offshore and nearshore locations are analysed by spectral wave partitions (Portilla at el., 2009). Their temporal statistics are used to obtain wave families and get into wave systems (Portilla et al., 2015). In parallel, the spatio-temporal wave spectrum field in the North Sea and the Dutch shoreface is investigated using statistics and machine learning to spatially group wave families and to analyse the wave spectrum climate spatio-temporal variability. Finally, the wave families and characteristic wave spectrum are linked with atmospheric patterns, drivers of wind-waves in the North Sea.

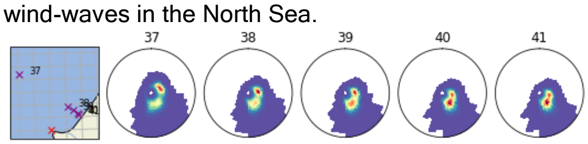

Figure 1 – Averaged nearshore wave spectrum from 2012 to 2016 for the Hoek van Holland, (representative for the Port of Rotterdam and the Sand Motor). Locations 37 to 41 are at 25, 20, 15, 10, and 5m depth respectively.

WAVE FREQUENCY-DIRECTIONAL SPECTRUM AVERAGED TEMPORAL AND SPATIAL ANALYSIS

For a first impression, the seasonality, multidecadal trends and the nearshore development of the wave energy within each frequency-directional bin of the wave spectrum averaged at all locations are investigated. The averaged spectrum shows energy peaks that are related to consistently occurring waves. When comparing adjacent locations, the nearshore processes on the wave propagation can be recognized, it results in a deflection of waves in cross-shore direction. The seasonally averaged spectrums and their anomaly to the long-term averaged wave spectrum show that, in general, winter (DJF) and spring (MAM) are the most and less energetic seasons, respectively; summer (JJA) shows an increase in southerly propagating waves with a period of 5 to 10 seconds and long perioded (15 sec) offshore directed waves; autumn (SON) shows an increase in short period waves in all directions, related to an increase in stormy local conditions. Finally, no multidecadal significant trends can be recognized.

OCCURRENCE OF MULTIMODAL SPECTRUMS

The wave partitions show that a unimodal wave spectrum occurs 35% of the time at the coast of North Holland, The Netherlands. Hence, an error might be introduced 65% of the time. Only 39% of the time is the angle between a wave train and the most energetic wave train smaller than 60 degrees. 43% of the time between 60 and 120 degrees. And 17% of the time in opposite directions. The difference in wave angle is half of the time larger than 50° when a threshold of one meter of deepwater significant wave height is used, as defined by Holthuijsen (2007).

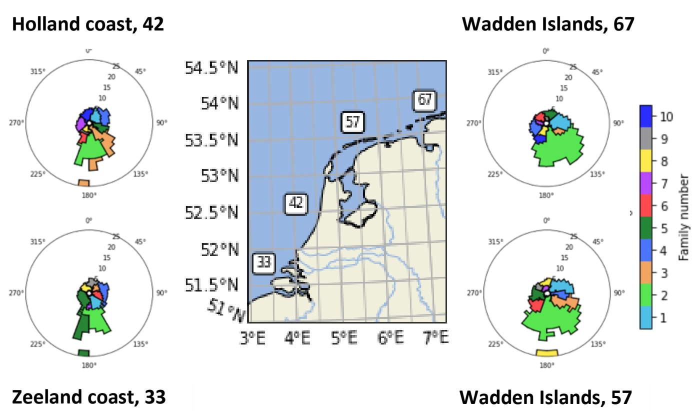

Figure 2. Wave families at Zeeland coast (33), Holland coast (42), and Wadden Islands (57 and 67).

NEARSHORE WAVE FAMILIES

Consistently occurring wave trains are analysed with wave families. The wave families give more detailed information about the nearshore wave transformation compared to an averaged frequency-directional spectrum. The cross-shore variation of the wave families shows that waves directed towards the coast, slightly decrease the relative angle between waves and shore.

Also, offshore wave development can be recognized in these wave families.

A challenge is that wave families are defined at each location independently. Relating wave families at different locations can give insight into the spatial extent and development of wave systems, for example shown in Figure 1. Manual relating wave families is possible but time-consuming. Here, we grouped the wave families through machine-learning techniques, showing that the results are most consistent in small spatial domains (Hoogervorst, 2022). Seemingly inconsistent labelling of wave families might occur when the spatial domain is increased in this automated process.

CHARACTERISTIC WAVE SPECTRUMS

An additional method is used for a more detailed temporal-spatial analysis of the wave spectral data, where the wave spectral data is classified and analysed through a sequence of machine learning techniques. The formed so-called Sea States describe the spatial and temporal variability of various wave conditions, both calm weather and stormy conditions. Spatial variability can give insight into the wave propagation, spatial extent, and influences of forcing conditions; and temporal statistics can be used for extreme value analysis. Wave partitions and wave families give additional insight into the number of coexisting waves and their propagation direction, which is usually narrowly distributed for each Sea State. A Sea State therefore describes a specific direction of following, crossing, and opposing waves, or a combination of them. For example, the representative spectrum at each offshore location of Sea State 59 is depicted in figure 3.

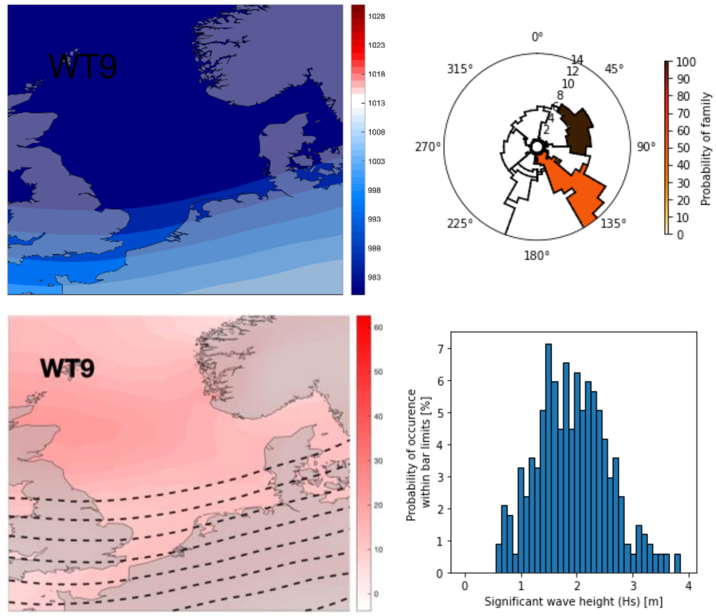

Figure 4: The sea level pressure and its gradient of Weather type 9 on the top left and bottom left, respectively. The top right shows the probability that a wave family at location 42 has energy when Weather Type 9 is occurring. A histogram of the Significant wave height, related to all the energy within the spectrum, during the occurrence of Weather Type 9 is depicted in the bottom right.

RELATIONSHIP BETWEEN WIND AND WAVES

The wave propagation direction has a strong correlation with the weather conditions. The statistics show that larger sea level pressure gradients lead to a more energetic wave field and that one high or low-pressure system can generate multimodal wave conditions with crossing waves. These multimodal wave fields do therefore also occur during high energetic wave conditions. One exemplary condition shown in figure 4 is Weather Type 9, which describes a low-pressure system with its pivot point at the northeastern tip of Great Brittain. During this weather condition at location 42, waves with a period of around 6 seconds, propagate in a north-easterly direction. About 70% of the time, there are additional waves propagating from the center of the low-pressure system in a south-easterly direction, resulting in a bimodal wave spectrum. The energy within the spectrum is expressed as one significant wave height at the bottom right corner, showing waves traditionally would vary from 0.5 to 4 meters.

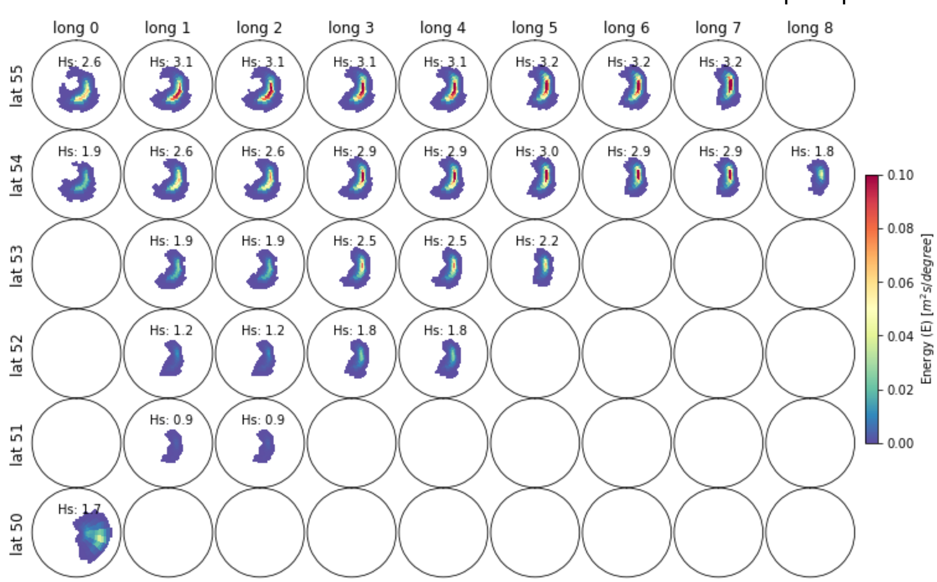

Figure 3: The representative frequency-directional spectrum at the offshore locations of Sea State 59, indicated by the latitudinal and coordinal coordinates. The radial axis describes the wave period from 0 to 22 seconds. The wave propagation direction is the bin position compared to the center.

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