# Modelled influence of bathymetry and tidal currents on wave conditions in the Faroese area.

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## Abstract

A high resolution third generation wave model SWAN is implemented for the area surrounding the Faroe Islands. Idealized runs are conducted in order to quantify effects caused by the bathymetry and nonstationary tidal currents. Some preliminary results are presented and discussed.

Model results indicate that the main influence occurs in specific coastal areas where the tidal currents are strongest. At these locations the model gives considerable changes in the local sea state, an increase of up to 15-25% in wave height and correspondingly large alterations in wave steepness and energy dissipation are observed. The model has not yet been validated for real weather situations, but the tidal influence on the model results are similar to those seen in local wave measurements, and the potentially dangerous areas predicted by the model seem to be in accordance with the experience of local sailors.

## Introduction

In offshore areas it is primarily the quality and resolution of the wind model driving the wave model that lead to improved wave forecasts. Improving the resolution of a wave model beyond the resolution of the forcing wind model will not improve the wave forecasts for deep sea offshore conditions (Kommen *et al.*, 1994). However in regions where finite depth and tidal processes affect the wave field, or in coastal regions, where sheltering and limiting fetch effects play an important role, increasing the resolution may improve the wave forecast.

Currently pre-operational wave model testing is done for the Faroese area. The aim is to clarify to what extent a local high resolution wave model can give better information compared to coarser wave models covering the area. Implementation of a local high resolution wind model is beyond the scope of the present study, so the only improvements gained from a local model will be caused by better bottom topography and inclusion of the tidal influence.

In this paper some preliminary results will be outlined, giving a first impression of the influence of depth refraction and tidal currents on local sea conditions. To isolate the effect of the bottom topography and tidal currents, the situations inspected correspond to fully developed sea conditions.

### The Area

A local wave monitoring programme was started twenty five years ago based on four wave rider buoys placed offshore as shown in Figure 1. The purpose of the programme was to give better wave information to local fishermen, and in time to obtain a better understanding of the local wave climate (Davidsen and Hansen, 1981). The measuring programme has been in operation since, with only minor technical adaptations (Heinesen, 2001).

In the coastal zone the tidal currents can be quite strong, with a speed of up to 4 m/s, but the tidal impact on water depth, are on the other hand small, with an amplitude for the semidiurnal tide of 0.2 m east of the central Faroes and around 1 m on the westernmost coast (Simonsen, 1999).

Reports from fishermen as well as visual observations in coastal waters show pronounced interaction between tidal current and the wave field. Some of the local sailors experiences, with the tidal current and its effect on wave conditions, have been summarized and published in a booklet (Heinesen, 1985). One example from the booklet is given in Figure 2, where the red areas indicate potentially dangerous sailing conditions if the wind goes in opposite direction of the current.

The model domain used in these simulations is too coarse to resolve all potential dangerous areas in the inner coastal areas. The main aim of these simulations is to look at the larger picture, and to identify when and where the bathymetry and/or tidal currents become important. Finer scale simulations, for different areas and situations, can be done later based on some general information gained here.

## The model

SWAN (Simulating WAves Nearshore) is a phase averaged wind wave model (Booij *et al.*, 2004). This means that it is not the individual waves that are resolved in the model, but it is instead the mean spatial distribution of all local waves (e.g. the wave spectrum) that is propagated and transformed by different physical processes.

SWAN is a third generation wave model which means that wave-wave interactions are taken into account without any presumptions on the shape of the wave spectrum.

The wave-wave interaction requires a lot of extra computational power for each computational time step, limiting the applicability of third generation wave models for coastal investigations. This computational demand can be reduced in SWAN by selecting an implicit propagation scheme that can run with a coarser time resolution, and thereby allowing higher spatial resolution. When this is said it is important to recognise that in the limit where the spatial variations of bathymetry or currents become large compared to the wavelengths being modelled, the linear and statistical foundation of the phase averaged models breaks down.

The following propagation, wave generation and dissipation processes are represented in SWAN:

- refraction and shoaling due to spatial variations in bottom and current
- blocking and reflections by opposing currents
- transmission trough, blockage by or reflection from obstacles
- diffraction is also included, although in a restricted sense
- generation by wind, including the variations in relative wind speed caused by the currents
- dissipation by whitecapping, depth induced breaking and bottom friction
- wave-wave interactions (quadruplets and triads)

(Booij *et al.*, 1999;Booij *et al.*, 2004), (Holthuijsen *et al.*, 2003).

## Model setup

The model is run for fully developed sea conditions with and without unstationary tidal currents. In this manner the influence from the bathymetry and currents can be isolated. All basic setup parameters of the model were set at their default options, and WAM4 source terms are used (Booij *et al.*, 2004). The model domain is given in Figure 1. Bathymetry generation and details concerning the tidal model, used for the SWAN computations, are described in (Simonsen, 1999). The tidal currents used for the tests shown here are composed of the two main tidal components M2 and S2, and correspond to spring tide conditions. The model grid resolution is 926 meters in space and incorporates 36 directions and 36 frequencies.

## Results

The stationary runs without currents showed no bathymetry generated influence in sea states forced by moderate winds. The only effects detectable were caused by sheltering or slanting fetch. The stationary runs with strong winds (20 m/s) indicate that the wave field starts to feel the bottom at depths around 200 meters. Under these conditions the wave height decreases at the offshore banks and at the upwind edge of the shelf. Closer inspection reveals that this decrease in wave height is merely an effect of negative shoaling and geometrical defocusing. No increased dissipation, bottom breaking or alterations in wave steepness occur for these areas.

The stationary runs with strong winds give a slight increase in the wave height at the downwind side of the offshore banks. This suggest that bottom steered caustics might occur in this area. The runs including the non-stationary tidal current show on the other hand, that the currents do generally not lead to accumulated effects, such as caustics etc., in wave parameters in the offshore areas. The bottom steered concentration of wave energy on the lee side of the banks is thus smeared out by the tidal currents.

At the offshore banks the tidally forced parameter changes are largest in moderate wind situations. Model results from one such situation, are displayed in Figures 3-5, where the wind speed is 10 m/s coming from the West. Figure 3 displays the changes in wave height if the effect of the opposing currents is accounted for, Figure 4 displays in an equivalent manner the changes in wave steepness, and Figure 5 gives the total wave dissipation. For orientation the parameter values at the upwind boundary and at the buoy positions are given in Table 1.

At the banks the tidal influence on wave conditions is noteworthy in moderate winds, but become insignificant under stormy situations.

The tidal currents do significant impact on the sea states on some of the coastal areas (see Figures 3-5). The wave height increases in some locations with up to 15-20%, regardless of the wind speed, and a similar impact is also seen in steepness and wave dissipation. In the coastal zone the current influence the wave field is not only dependant on the wave and current directions, but also on the incoming wave height.

In the upwind regions the changes triggered by the tidal current appear in accordance with the local current (higher steeper waves in opposing current etc.), but in the coastal regions where sheltering also plays a role, the picture becomes more complex. As can be seen in Figures 3-4 the locations with large increase in steepness, due to the current, are not always identical with the locations where the wave height is amplified. The amount of wave dissipation (see Figure 5) can therefore aid in the detection of potentially dangerous locations.

Comparing the model results (Figures 3-5) to the plots based on local sailor experience concerning troublesome areas in the coastal zone (see Figure 2) there seem to be several similarities.

Some of the parameter values, for two idealised cases with and without currents, are given in Table 1 for the buoy locations. The results in Table 1 indicate quite clearly that the tidal currents only have a minor importance at these offshore sites.

The model results from idealised weather situations can't be used to validate the model, but some general trends of the tidal impact on the wave measurements (phase lag between tidal modulations in wave height an period at WVD-4 under westerly winds etc.), seem to be reproduced in the model results.

## Discussion

The model results suggest that the bathymetry and current influences in the offshore region, including the banks, do generally not have a large impact on the sea state. It is therefore not essential to include these areas in a future high resolution local model. Close to land the impact from the tidal currents is seen to be quite substantial at some locations.

The idealized model results seem to be in accordance with local experience regarding the currents influence on potential dangerous wave conditions. The accumulated sailor experience is based on a multitude of different wave and weather conditions, where wind- and pressure-driven currents might play a significant role. The idealized modelling presented here does not take into account other currents than the tidally driven, and might therefore miss some of the current effects under specific conditions. When this is said, the model results have the advantage that they can pinpoint areas more precisely that are potentially dangerous as well as give information on the current induced parameter changes at these locations.

The model results presented here must be interpreted with some care, as the grid resolution used here is too coarse to properly reconstruct the physical circumstances in many coastal areas. It must also be remembered that the model is based on linear theory assuming that gradients in bathymetry and currents are much smaller than the modelled wavelengths, which strictly speaking is not accurate for all locations close to the shore.

With respect to future wave modelling of the Faroe area, it is clear that the main focus aught to be in the near shore regions. The preliminary results suggest that influence by bottom and current effects mainly become significant inside the 200 meter depth contour. It is also apparent that the inner areas aught to be modelled using better resolution.

Further improvement of bottom topography, which is necessary for a higher resolution coastal model, are available from an ongoing measuring project (Simonsen *et al.*, 2002).

Idealised model runs can be used, as here, to inspect the influence of bathymetry or currents on sea conditions, or to transport offshore design storms into near shore regions etc.

One alternative future use would be to utilize the idealized model runs to fill gaps in some of the recorded measurement series. The idea is to construct a database with multiple wave parameters for all buoy locations, as in Table 1 but without the tidal influence, covering many different wind speeds and directions. Then if one buoy is not operating, the approximate wave parameter values at this location could, in real time, be estimated from the database using the knowledge of the heights, periods, directions, etc. of the waves recorded at the other sites at that time.

## Conclusion

Idealized test runs have been performed in order to better understand the influence from bathymetry and tidal currents, on the sea conditions in the area around the Faroe Islands. A small part of these tests have been displayed here, and some preliminary results are discussed.

The combined effect of bathymetry and tidal currents do not seem to have an important impact on the sea state, or the ability to create caustics in the offshore region. There is therefore not important to include the offshore areas (depth > 200m) in a local high resolution wave model.

Model investigations of the buoy positions reveal that the tidal influence is relatively weak at these locations. Some of the general features, concerning the tidal impact in wave measurements, are also exhibited by the idealized model runs.

In the coastal zone, the tidal currents can significantly alter the sea states. The largest variations occur in areas with strong following or opposing currents. The variations are generally in opposite phase compared to the local current, i.e. higher and steeper waves in opposing currents and lower and less steep waves in following currents.

The idealized model runs do indicate that some coastal areas might be potentially dangerous due to the effect of the current on the local sea state. The problematic areas seem, in spite of relatively coarse resolution in the coastal zone, to bee in accordance with local experience. It therefore seems plausible that further modelling will aid the recognition and classification of potentially dangerous coastal areas.

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**Table 1**

Parameter values at the upwind boundary and buoy locations, generated from idealised runs, when the wind comes from the West. The values given in brackets correspond to max- and minimum values obtained when the effect of unstationary currents is accounted for.

| Wind speed | Parameter | Deep water | WV-1 (East) | WV-2 (West) | WV-3 (North) | WVD-4 (South) |
|---|---|---|---|---|---|---|
| | *Depth* | >500 m | 140 m | 110 m | 120 m | 285 m |
| | $H_{m0}$ *[m]* | 2.5 | 1.7 (1.5-1.7) | 2.4 (2.3-2.4) | 2.4 (2.2-2.5) | 2.4 (2.2-2.4) |
| | *Mean dir. [ ˚]* | 0 | 5.6 (0.4-9.9) | 3.1 (0.0-6.4) | 356.5 (353.0-359.0) | 6.0 (3.3-8.4) |
| | $T_{m01}$ *[s]* | 5.9 | 4.3 (4.1-4.3) | 5.6 (5.6-6.0) | 5.6 (5.4-6.1) | 5.5 (5.3-5.5) |
| 10 m/s | $T_{m02}$ *[s]* | 5.3 | 3.9 (3.7-3.9) | 5.0 (4.9-5.4) | 5.0 (4.7-5.5) | 4.8 (4.7-5.0) |
| | $T_p$ *[s]* | 8.4 | 5.3 (4.8-5.3) | 8.4 (8.4) | 8.4 (7.7-8.4) | 8.4 (7.7-8.4) |
| | *Steepness* | 0.058 | 0.071 (0.064-0.073) | 0.063 (0.054-0.061) | 0.064 (0.050-0.064) | 0.065 (0.057-0.067) |
| | $H_{m0}$ *[m]* | 10.6 | 6.5 (6.2-6.5) | 9.7 (9.7-9.9) | 9.5 (9.0-10.0) | 9.5 (9.2-9.9) |
| | *Mean dir. [ ˚]* | 0 | 8.2 (3.3-11.7) | 8.3 (6.1-9.9) | 351.4 (349.2-353.0) | 10.1 (8.4-11.6) |
| 20 m/s | $T_{m01}$ *[s]* | 12.7 | 7.9 (7.6-8.0) | 12.3 (12.1-12.5) | 11.9 (11.5-12.4) | 11.5 (11.3-11.9) |
| | $T_{m02}$ *[s]* | 11.5 | 7.0 (6.7-7.2) | 11.0 (10.7-11.4) | 10.6 (10.1-11.3) | 10.2 (10.0-10.6) |
| | $T_p$ *[s]* | 17.7 | 8.4 (8.4) | 17.7 (17.7) | 17.7 (17.7) | 17.7 (17.7) |
| | *Steepness* | 0.051 | 0.085 (0.083-0.085) | 0.053 (0.051-0.052) | 0.055 (0.051-0.054) | 0.058 (0.055-0.056) |

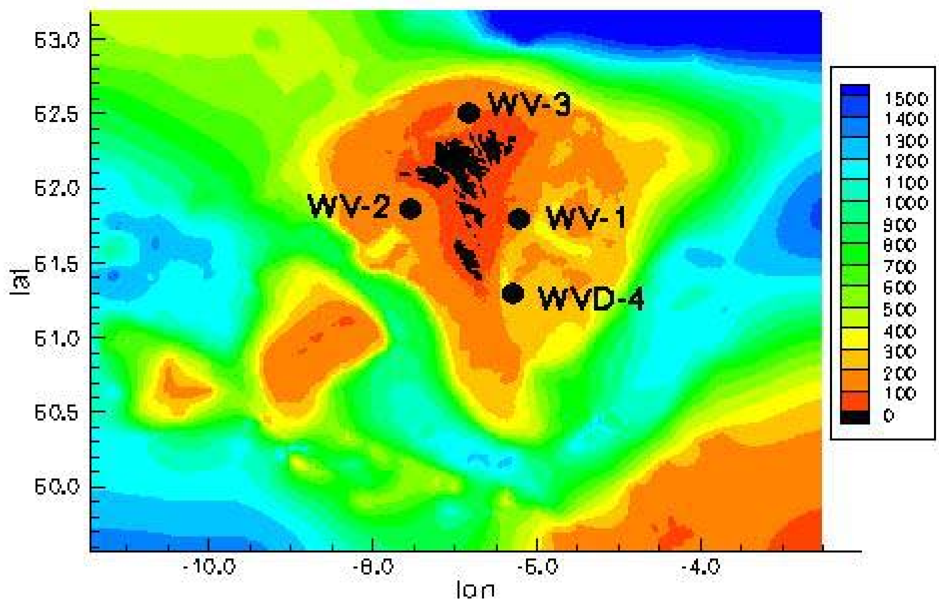


**Figure 1**

The model domain is given with depth contours in meters. The marked points represent the locations of the waverider buoys.

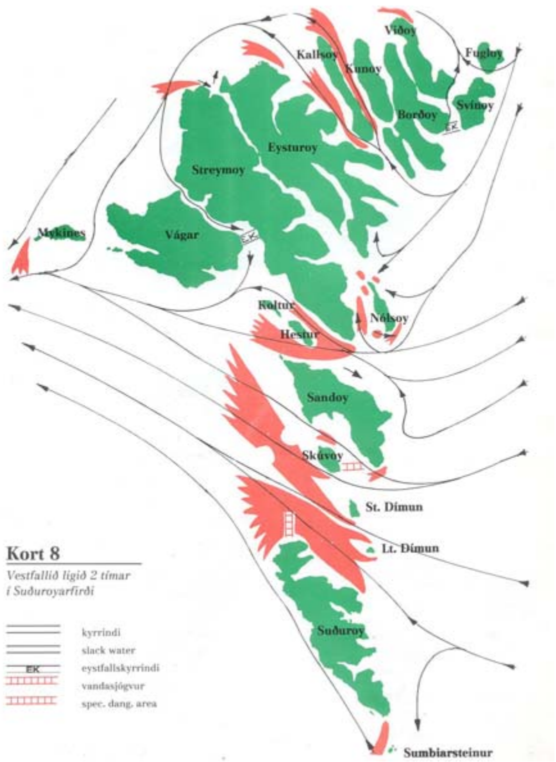


**Figure 2**

The arrows give the direction of the current. The red areas indicate regions that are potential dangerous for smaller vessels, if the wind/wave direction is in opposite directions as the currents. This figure is taken from (Heinesen, 1985) and is based accumulated knowledge of several local sailors.

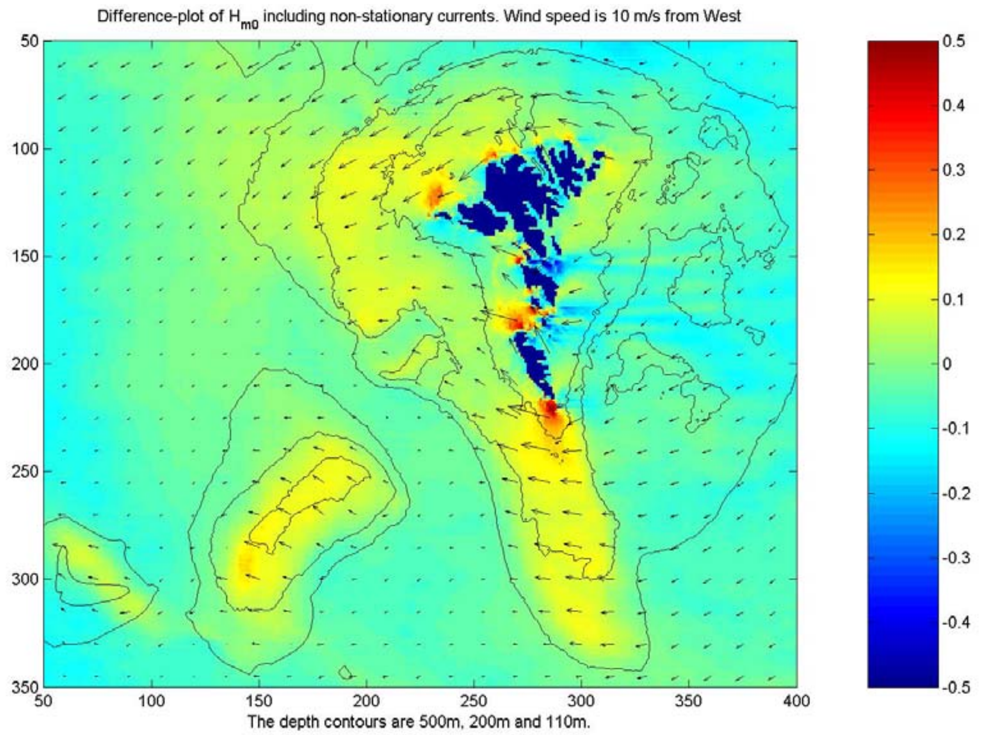


**Figure 3**

This figure gives the change in the wave height between a run including the effect of the tidal current and an equivalent run without currents. The wind speed is 10 m/s coming from the West. The colourbar gives variation in wave height in meters. For comparison the wave height at the upwind boundary is 2.5 m.

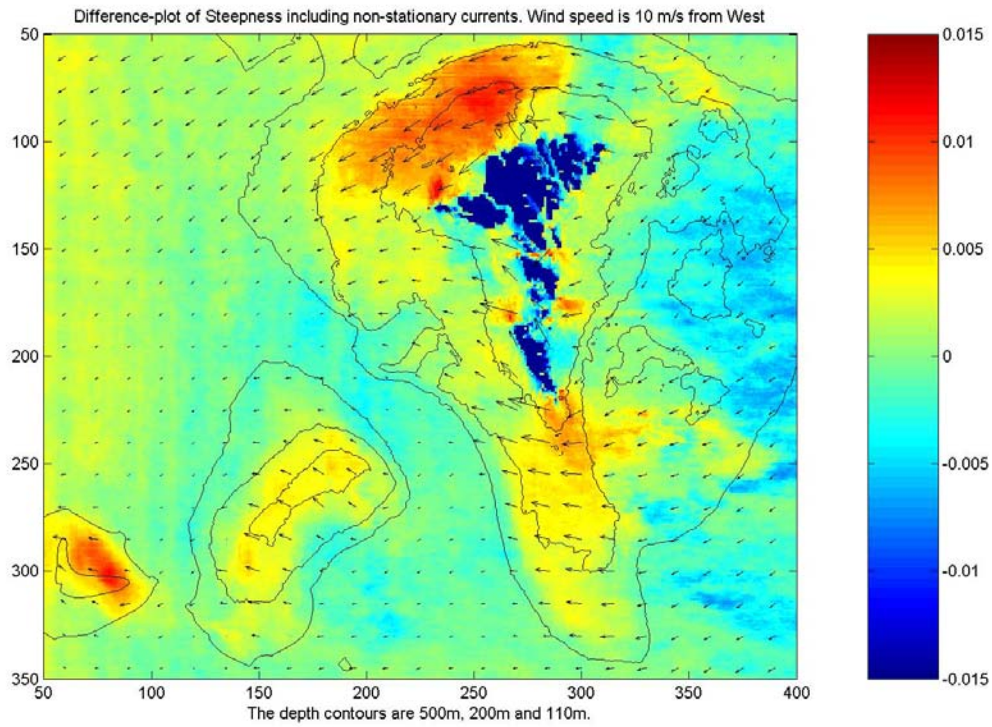


**Figure 4**

This figure gives the change in the wave steepness between a run including the effect of the tidal current and an equivalent run without currents. The wind speed is 10 m/s coming from the West. For comparison the wave steepness at the upwind boundary is 0.058.

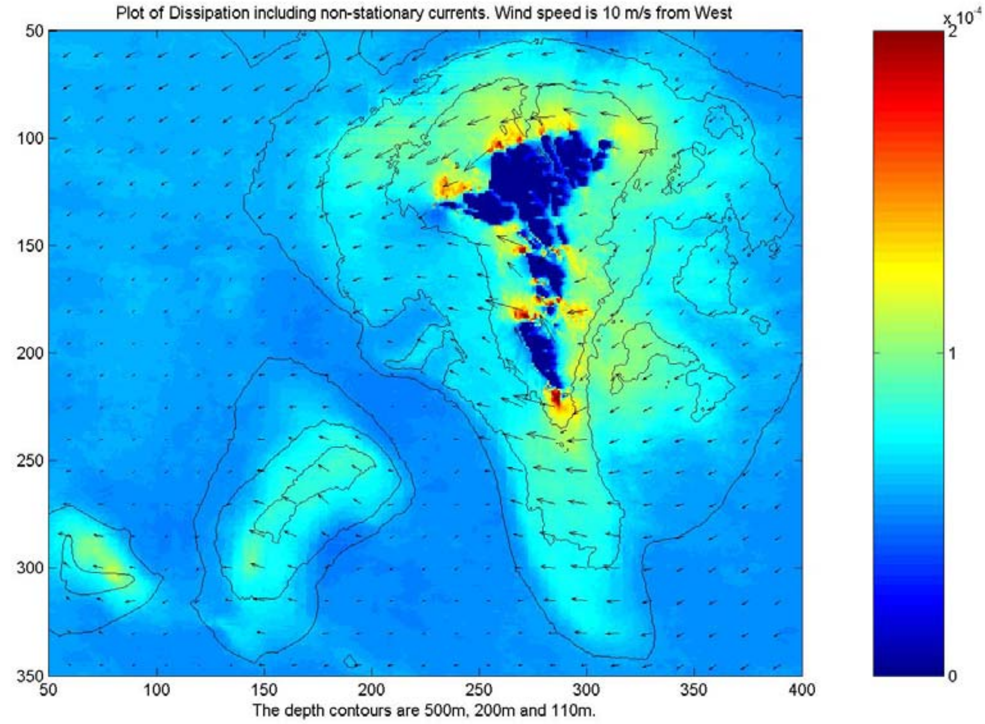


**Figure 5**

This figure gives the wave dissipation from the same run as Figure 3-4. The wind speed is 10 m/s coming from the West.