Predicting jellyfish outbreaks around Shetland using MIKE 3

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Abstract

Usually, jellyfish are considered harmful to coastal human activities. The long-distance travel of jellyfish is controlled by drifting current. Hence, it is necessary to investigate hydrodynamic characters to be able to have an early warning system against jellyfish attacks. In this paper, MIKE 3 is used to investigate circulation around Shetland and its effect on jellyfish outbreaks. It was found that wind driven currents entraining oceanic waters brought in by pressure-driven currents are the main reason for jellyfish outbreaks. Also, it was found that stratification and bathymetry should be further investigated in order to obtain a more complete picture of the hydrographical effect on jellyfish transport.

Keywords: MIKE 3, shelf zone, circulation, Shetland, jellyfish.

1 Introduction

Some gelatinous zooplankton and particularly jellyfish have adverse effect on human activities in coastal waters. Many researchers in the field of marine ecosystem are investigating that effect, e.g. Hay, et al. [1]. Although most gelatinous plankton are capable of some type of locomotion, their long-distance travel is generally under the control of currents and other patterns of water movement (the jellieszone [2]). From the point of view of transport, jellyfish, like fish larva, are different from sediment and pollutant in that the former is able to maintain a certain position within the water column and drifted horizontally by water currents while the later is completely controlled by both water movement and density of both water and particles (falling velocity).
Many researchers studied the effect of climatic and hydrodynamic factors on plankton transport. Graham, et al [3] reviewed the role of physical processes and phenomena that promote aggregations of gelatinous zooplankton.

On the Northeast Atlantic, the following research was done. Lynam et al [4] studied the effect of climatic changes represented by the North Atlantic Oscillation Index on jellyfish abundance in the North Sea. Harms et al [5] used a hydrodynamic model to investigate the effect of the North Atlantic current system and its branched cross-shelf currents on transporting copepods to the North Sea waters. Speirs et al [6], [7] used the 3-D baroclinic model HAMSOM to produce flow field necessary to investigate copepod demography in the Norwegian Sea and North East Atlantic. Heath and Gallego [8] used the same model to study transport of haddock larva in the North Sea. Proctor et al [9] used a 2-D sea circulation model to investigate interannual variability in the advection of sandeel larvae on the northwest European shelf.

In the USA waters, the following research was done. Johnson et al [10] studied the effect of current on jellyfish life cycle on the continental shelf in the northern Gulf of Mexico between the Mississippi River Delta in Louisiana and Apalachicola, Florida. They used POM and a Lagrangian particle-tracking model. As part of SABRE (South Atlantic Bight Recruitment Experiment) Werner et al [11], and Hare et al. [12] used a 3-D circulation model to investigate the effect of oceanographic parameters on the transport of larval menhaden.

Many researchers investigated circulation in shallow waters and exchange with deep waters. Cochrane and Kelly [13] investigated circulation on the Texas-Louisiana continental shelf using available observations. Lentz et al. [14], [15], [16] has thoroughly investigated the issue of along- and cross shelf currents in the areas of mid shelf, inner shelf and surf zone. Recently, he and Chapman [17] have published a new theory on effect of stratification and along-shore currents on cross-shelf currents. While Lentz applied his studies to the coastal waters of North Carolina, the USA, Turrell [18] investigated circulation in the North Sea and exchange with deep North Atlantic.

As a part of the EUROGEL (EURopean GELatinous zooplankton), this paper uses the 3-D hydrodynamic model MIKE 3 to investigate circulation around Shetland, the UK, and derive possible mechanisms that drive jellyfish onshore causing considerable harm to coastal activities around Shetland.

The model set up and driving forces will be discussed in Section 2. Depiction of the general circulation pattern as derived from the hydrodynamic simulations will be discussed in Section 3. The paper will be concluded in Section 4.

2 Model setup

The hydrodynamic module of MIKE 3 is a three-dimensional model that solves the following equations using the finite differences method [19].

1. Mass conservation equation.
2. Reynolds-averaged Navier-Stokes primitive-variables equations in three dimensions, including the effect of turbulence and variable density.
3. Conservation equations for salinity and temperature.
The turbulence term is determined using Smagorinsky approach for horizontal terms and $k-\varepsilon$ equations for vertical term.

The model domain is a $138 \times 375$ km rectangle covering the shallow waters around Shetland and bounded on the west side by the shelf break (Fig. 1). It has four open boundaries. It is covered by a 3-km finite difference grid. The water column is divided into 7-m thick layers. The bathymetry is obtained from the repository of UCAR (University Corporation for Atmospheric Research) datasets [20].

Bed friction is determined with a quadratic law where the roughness height is constant with a value of 0.05 m. Temperature and salinity are assumed spatially and temporally uniform, in other words, the flow is assumed homogeneous.

It is found that variation of wind field over the computational domain is small; therefore, a daily-averaged spatially constant wind field is applied. Wind field is obtained from the NCEP/NCAR reanalysis project [21] at 1.875W, 59.9986N.

Water level at the open boundary is obtained from the program SNAC [22], [23]. The model takes into consideration both atmospheric pressure forcing and tidal residual current. The original model uses 100-day moving average atmospheric pressure forcing. Therefore, the output does not represent daily water level variation. The model is modified to make calculations depending on daily-average atmospheric pressure. The study presented in this paper concentrates on monthly averaged circulation. It is found that daily average and
100-day moving average atmospheric pressures produce monthly-averaged current fields with small differences (Fig. 2).

Figure 2: Simulation results for velocity to the south of Shetland using (1) SNAC, (2) SNAC monthly average, (3) modified SNAC, (4) Modified SNAC monthly average.

Figure 3: Monthly averaged surface current with (1) shelf-edge current, (2) north current, (3) south current.
The study is done for the years 1999 to 2001 with a time step of 180 seconds. For each year, three runs are done; one with only wind forcing, another with forcing from only water level at the open boundaries, and the third is forced by both water level and wind. Water level forcing at the open boundaries reflects the atmospheric pressure effect on circulation. The current field was stored every six hours. After simulation, the monthly arithmetic mean of the current is determined.

3 Results and discussion

When the water level forcing is applied separately, it produces a persistent current field characterized by the following (Fig. 3). A main northward current is running along the shelf slope with two branching southeast currents; one is running to the north of Shetland (called hereafter north current) and the other is running to the south of Shetland (between Shetland and Orkney, and called hereafter south current). The atmospheric pressure effect is stronger in deep water than in shallow water. This flow pattern is in good agreement with the findings of Turrell [18]. Isobath 50 is considered a threshold between shallow and deep waters. This is in good agreement with Lentz [16] estimation that depths equal to Ekman depth, which is about 40 m, divide the shelf zone into two separate regions in terms of parameters affecting flow.

In deep water, wind-driven surface current veers on average 52 degrees to the right of the forcing wind. Wind-driven current in deep water is less significant than pressure-driven current. This is in agreement with Lentz et al. [15] conclusion that momentum balance in mid-shelf zone (deep water) is geostrophic while on inner-shelf wind stress influence is stronger. Shallow water area around Shetland is divided into three separate regions with different response to wind. The first region is to the west of the southern part of Shetland (called hereafter west area), the second is to the east of the southern part of Shetland (called hereafter east area), and the third is St. Magnus Bay (Fig. 4).

In the west area, the wind drives alongshore surface current. The current flows northward unless the wind is westerly, due to which the current turns
southward flushing the area (Fig. 5). The combined effect of both wind and pressure (westerly wind excluded) is characterized by a counter-clockwise eddy in the west area entraining oceanic water from the south current. This eddy is expected to be the main driving source that carries jellyfish to the coasts of Shetland. This is justified by reports on jellyfish attacks in September of 1999 and 2001 when prevailing wind is southerly. However, in September of 2000 there was also strong southerly wind but there is no jellyfish reports. Hence, although the depicted circulation is one of the parameters controlling jellyfish outbreak, it is not the only one. Lentz [16] suggested that stratification enhances mass exchange between deep and shallow waters while that exchange is “shutdown” abruptly when stratification is broken. Hence, it is necessary to include stratification as one of the parameters controlling jellyfish outbreak.

Figure 5: Surface current in west area due to (a) 8.62 m/s westerly wind (b) 3.96 m/s southerly wind (c) westerly wind and atmospheric pressure (d) southerly wind and atmospheric pressure.

Figure 6: Surface current in east area due to pressure and (a) 8.19 m/s westerly wind (b) 3.77 m/s northerly wind.
In the east area, there is always wind-driven alongshore current. The current is always northward but when the wind is northerly the current direction is reversed to become southerly (Fig. 6). The north current forms an eddy with the wind-driven northerly current. The eddy is formed far from the shore because the east area has extended area of shallow water (less than 5 m). Cochrane and Kelly [13] depicted a gyre in their investigation. They explained it as interaction between shallow water current and shelf-edge current. It is expected that bathymetry is one of the factors that determine the formation of eddies/gyres in shallow waters.

In St. Magnus Bay, usually, wind creates counter-clockwise eddy entraining oceanic water from the south current. However, there is no report on jellyfish attacks. Stratification should be considered for that bay.

It should be noted that during the investigation period, there was no easterly wind.

4 Conclusion

Circulation around Shetland is investigated using MIKE 3 driven by wind and atmospheric pressure in an effort to find a hydrodynamic mechanism that controls jellyfish drifting and hence be able to provide a sort of early warning system against jellyfish attacks to aquaculture. The area around Shetland is divided into three regions: 1) the west area is characterised by oceanic water entraining eddy that carries jellyfish to Shetland coasts. It is needed to investigate stratification effect on enabling cross-shelf transport of jellyfish in this area. 2) The east area is characterised by along-shore current that produces a sort of local circulation. It is needed to investigate the reasons that an eddy is produced in the west area while there is no eddy in the east area. 3) St. Magnus Bay is characterised by counter-clockwise eddy that entrains oceanic water but there is no report on jellyfish attacks.

Acknowledgements

This work was conducted under the project EUROGEL, supported by the European Commission through Contract No. EVK3-CT-2002-00074. The first author is very grateful to the University of Aberdeen, the UK for offering him a fellowship as a part of EUROGEL project. He is also grateful to DHI who offered free license and training on MIKE 3 for this research.

References


