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Horizontal dispersion in shelf seas: High resolution modelling as an aid to sparse sampling

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ABSTRACT

The ability of a hydrodynamic model to reproduce the results of a dye release experiment conducted in a wide shelf sea environment was investigated with the help of the Massachusetts Institute of Technology general circulation model (MITgcm). In the field experiment a fluorescent tracer, Rhodamine WT, was injected into the seasonal pycnocline, and its evolution was tracked for two days using a towed undulating vehicle equipped with a fluorometer and a CTD. With a 50 m horizontal resolution grid, and with three different forcings initialized in the model (viz: tides, stationary current, and wind stress on the free surface), it was possible to replicate the dye patch evolution quite accurately. The mechanisms responsible for the enhancement of horizontal dispersion were investigated on the basis of the model results. It was found that enhancement of the dye dispersion was controlled by vertically sheared currents that, in combination with vertical diapycnal mixing, led to a substantial increase in the "effective" horizontal mixing. The values of "effective" horizontal mixing found from the model runs were in good agreement with those obtained from in-situ data, and the probable degree to which the observational techniques undersampled the dye patch was revealed.

Introduction

Isolated underwater topographies are known as potential sources for mesoscale and finescale oceanic variability and are therefore of great importance to the local and regional ecology through enhanced mixing in the vertical and horizontal. Strong tidal currents and wind driven flows can enhance vertical mixing in the areas of underwater banks (Nash and Moum, 2001; Vlasenko et al., 2013). The Celtic Sea, with its wide shelf (~ 250 km), contains a number of such underwater features. One of them, Jones Bank (Fig. 1), located in the central part of the Celtic Sea shelf, was the study area for the 25-th cruise of the R/V *"James Cook"* (hereafter JC25). One of the goals of the field campaign was an investigation of the mixing processes that control horizontal dispersion and vertical eddy diffusion of a passive tracer released during JC25. Rhodamine WT, a fluorescent dye tracer, was injected into the seasonal pycnocline at the depth of the buoyancy frequency maximum (approximately 35 m). The methodological details of the experiment are reported in the paper by Inall et al. (2013).

Two dominant dynamical processes acting in the area of Jones Bank are the tides and wind driven motions. Both processes generate vertical shears in the background currents that can affect horizontal dispersion. Inall et al. (2013) performed an analysis of the spectrum of oceanic currents recorded at the mooring MS1 located at the top of the bank (see Fig. 1) and found that the temporal variability of the vertical shear of the horizontal currents within the thermocline was dominated by inertial oscillations at the time of observation. As a result, the main conclusion derived by Inall et al. (2013) was a recognition that the horizontal dispersion in the dye release experiment was remarkably enhanced by the vertical shear related to inertial oscillations (wind driven shear dispersion). The possibility of such a mechanism of intensification of horizontal mixing by vertical diapycnal exchange in low frequency ocsillating vertically sheared currents was pointed out by Young et al. (1982), but had not been witnessed in situ until the work of Inall et al. (2013).

It should be noted here, and borne in mind throughout this paper, that it is a challenging task to keep track of a sub-surface dye patch over many days using just ship-mounted equipment. Continuous, synoptic tracking can be done only by an aircraft that flies around the dye patch during several days conducting measurements remotely, which is an expensive procedure. An alternative and more commonly used methodology (Sundermeyer and

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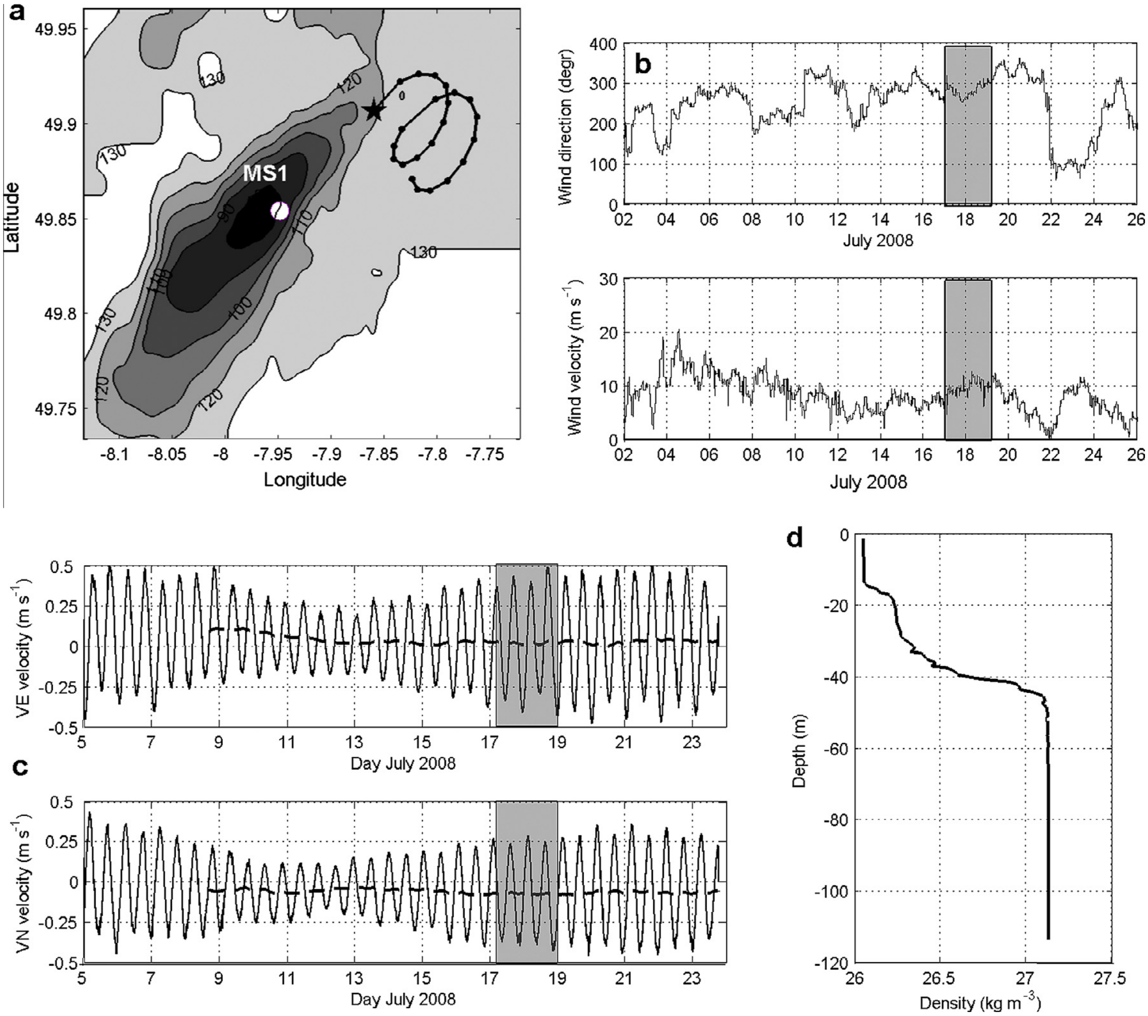

Fig. 1. (a) Bathymetry of Jones Bank, drifter track for the first 24 h after dye release (black dots and lines). Pentagram shows the position at the bank where dye and drifter were released. Position of the moorings MS1 is shown by closed white circle. (b) Wind direction and velocity during JC25. Rectangles correspond to dye release time interval. (c) Zonal and meridional vertically averaged velocities recorded at mooring MS1. Dashed lines show stationary currents. Rectangles correspond to dye release time interval. (d) CTD profile of density on the 17th of July 2008.

Ledwell, 2001) is to deploy an undulating device towed behind a moving vessel that can record the dye concentration in real time. Such an approach allows for the dye to be mapped along the ship's track over several days for relatively low cost, but it is still not good enough to give a complete picture of the tracer dispersion, in the sense that objective maps of the dye concentration have to be reconstructed from often sparse sampling of the real dye distribution. The absence of dye data beyond the tracks produces the gaps in observational data that is entirely expected in any real observational campaign. In many of these cases it is some kind of art to evaluate the characteristics of the mixing processes correctly using sparse data because of some unavoidable level of uncertainty. Such are the known limitations of dye release experiments.

The main goal of the present study was to simulate numerically the dye release experiment conducted near Jones Bank during JC25 and to compare the model-predicted dye fields with the in-situ data to answer the questions whether numerical modelling can firstly corroborate observational analyses and secondly provide a deeper insight into an understanding of the dye evolution. The paper is organized as follows. Section "JC25 experiment" discusses the details of the field experiment. Section "Numerical model" briefly outlines the model details. Section "Modelling of the dynamical processes" presents modelling results of the dynamical processes operating in the area under investigation and Section "Replication of the dye release experiment" describes modelling of the dye release. The paper ends with a discussion and some conclusions.

JC25 experiment

Moorings with thermistor chains and Acoustic Doppler Current Profilers (ADCP) were deployed at the beginning of the JC25 (Inall et al., 2013). For the dye release Rhodamine WT was chosen as a passive tracer due to its ability to be detectable for several days after release at a level sufficient for detection by a fluorometer (details can be found in Ledwell et al. (2004)). The fluorometer was mounted in a towed Scanfish vehicle which scanned the whole water column undulating from 5 m below the surface to a depth of 10 m above the bed. Scanfish cycled every 2 min giving an effective horizontal resolution of approximately 250 m.

Strong north-westerly winds were recorded at the beginning of July with wind speed over 15 m s^{-1} on 5-th July, Fig. 1b. After quite stormy conditions the wind speed dropped steadily by July 13-th, but the wind-induced circulation remained in the area and affected all dynamical processes including the dye dispersion. The ADCP signal recorded at the mooring MS1 revealed a background