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Isolated turbidity maxima in shelf seas

D.G. Bowers*, K.M. Ellis, S.E. Jones

School of Ocean Sciences, University of Wales (Bangor), Menai Bridge, Anglesey, LL595AB, UK

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Abstract

Visible-band satellite pictures of the Irish Sea reveal the presence of isolated areas of enhanced turbidity which are geographically fixed and present all year, although they are more strongly marked in winter. The positions of these maxima coincide with areas of fast tidal currents: some of the dissipated tidal energy is used to raise fine sediments into suspension, producing the turbidity. However, there is no obvious source of fine sediment at the maxima, and without a source they would be expected to diffuse away, down the turbidity gradient. Their continued presence is therefore a puzzle, and it has proved difficult to reproduce these features in numerical models. Recent observations, presented here, suggest a possible mechanism by which isolated turbidity maxima may be maintained. These measurements show that the gradients of concentration on the sides of the turbidity maximum are in opposite senses for different particle sizes, and that there is a flux of fine particles out of the maximum and one of larger particles into it. A mechanism which can explain this observation, and which can also explain the continued presence of turbidity maxima isolated from a local source is as follows: the high turbulent energy levels at the centre of the patch tear flocculated particles apart. These fine particles then diffuse away down the gradient of fine particles and to areas of lower energy. Here they aggregate to form larger particles which diffuse back down the gradient of large particles towards the centre of the turbidity maximum, where they are torn up and the cycle continues. The source of material for the turbidity maxima is therefore larger flocculated particles in the surrounding water. This idea is tested quantitatively with an analytical solution to the steady-state diffusion equation incorporating aggregation and dis-aggregation of particles as simple functions of turbulent energy. The solution shows that isolated maxima of fine suspended particles can be maintained at regions of high turbulence without the necessity to invoke a local (non-sustainable) source. Within the maximum, strong vertical mixing lifts the slow settling fine particles to the surface to produce an isolated surface turbidity maximum as observed. We conclude that for models to successfully produce turbidity maxima in the presence of diffusion they should incorporate at least two particle size classes and aggregation and dis-aggregation of particles according to the local level of turbulence.

Keywords: Turbidity maxima; Turbulence; Aggregation; Break-up

*Corresponding author

E-mail address: oss063@bangor.ac.uk (D.G. Bowers).

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1. Introduction

The geographical distribution of turbidity in the surface waters of the Irish Sea has been established with the aid of visible band satellite imagery (Simpson and Brown, 1987; Bowers et al., 1998; Binding et al., 2003). A striking feature of these images is the presence of isolated areas of high turbidity. These are the size of large cities, are geographically fixed (they are located in regions of fast tidal streams) and are present all year, although they are larger and more marked in winter.

An example image is shown in Fig. 1. Three turbidity maxima have been labelled on this figure.

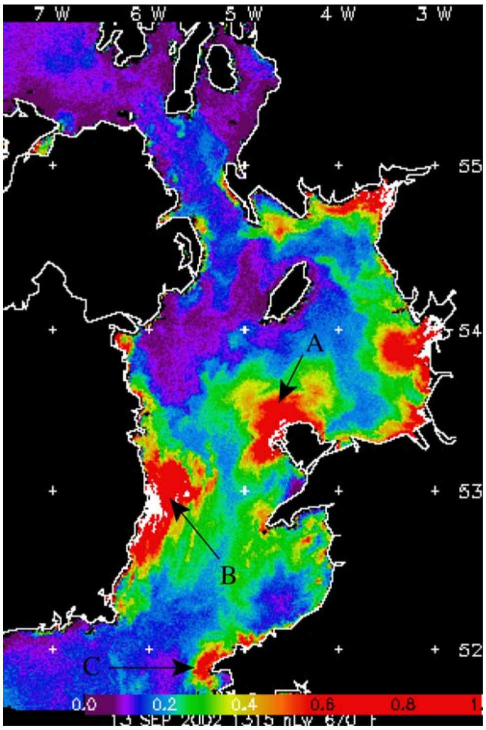

Fig. 1. SeaWiFS image of the Irish Sea showing remote sensing reflectance at 665 nm. The image has been colour coded so that areas of high reflectance (corresponding to turbid surface water) are shown in red and those of low reflectance (clear water) in violet. The features marked A, B and C are surface turbidity maxima isolated from any obvious source of fine sediment. Their continued existence in the presence of strong horizontal diffusion is an anomaly which is explored in this paper. (The date of this image is 13th September 2002; image courtesy of University of Dundee and RSDAS, Plymouth).

The one labelled A is about 30 km across. Ship surveys (Weeks, 1990; Gaffney, 2001; Bowers et al., 2002) have confirmed that these features contain enhanced concentrations of suspended sediments, and that the sediments are vertically mixed (the maxima are not just surface phenomena). Particle concentrations in these maxima reach about 10–15 mg l^{-1} in winter and about 5 mg l^{-1} in the summer, and in each case are 2–3 times greater than the ambient concentration in the Irish Sea at that time (see Fig. 2).

The observations of turbidity in the Irish Sea appear to be consistent with the supply of energy. Bowers (2003) postulated that the energy supply alone could account for the observed variation: the spatial variation of tidal energy explains the geographical pattern (the turbidity maxima coincide with fast currents), and the yearly variation in the input of wind energy accounts for the higher concentrations in winter. This idea was tested with a simple model in which a fixed fraction (about 10^{-4}) of the available energy was used to maintain sediment in suspension. The model gave excellent agreement with the observations provided there

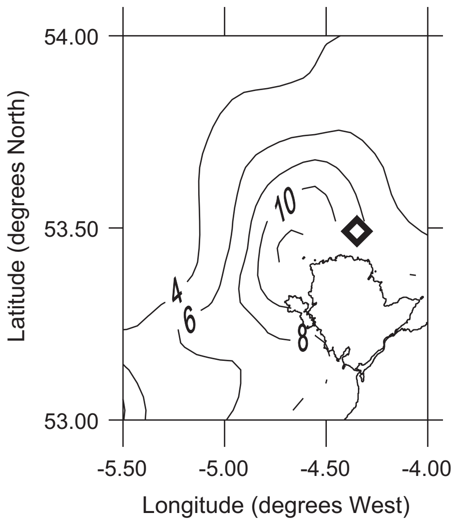

Fig. 2. Location of the study site (diamond symbol) on the eastern side of the turbidity maximum A in Fig. 1. Measurements were made of the gradients and fluxes of different particle sizes over a tidal cycle in July 2002. The contours represent maximum (winter) concentrations of surface suspended sediments in mg l^{-1}, based on satellite observations.