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Effects of seasonal variations on sediment-plume streaks from dredging operations

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ABSTRACT

When mixtures of aggregates and water dredged from the seabed are discharged at the surface into the adjacent water from a barge, coarse sediments sink immediately and fine sediments are suspended forming a plume. Recently, elongated plumes of fine sediment were observed by satellites near a dredging location on the continental shelf. Such plume streaks were longer in certain conditions with seasonality than expected or reported previously. Therefore, the present work studied the appearance of sediment plume with field measurements and numerical simulations and explains the seasonally varying restoring force and thicknesses of the surface mixed layer resulting from the vertical density distribution near the surface, along with mixing by hydrodynamic process. The resulting mixtures, after vertical restoring and mixing with the surroundings, determine the horizontal transport of suspended sediments. A numerical model successfully reproduced and explained the results from field measurements and satellite images along with the seasonal variations.

1. Introduction

During mining operations of marine aggregates from the ocean bottom, significant amounts of seawater and sediments are released back to the sea from the barge. The mixture of aggregates and seawater is dredged from the seabed with hydraulic pumps, brought through pipes to the sea surface and then poured through chutes from the side of the barge. Coarser and denser sands in the mixture sink almost immediately to the seabed and are deposited near the mining site. On the other hand, fine sediments in the mixture have densities which are not enough to cause them to sink fast, resulting in suspension for a long time. Hence depending on the surrounding surface conditions, suspended sediments are expected to be able to travel several kilometers away from the dredging location (Wit et al., 2014). Such suspended sediments have potential impacts on water quality in the water column; for instance the increase in turbidity, which inhibits sunlight from penetrating deeper waters. The limited availability of light reduces primary production and vegetation on the seabed is smothered, ultimately affecting the local benthic community and habitat (Erftemeijer and Lewis III, 2006; Kim and Lim, 2007; Capello et al., 2013; Wit et al., 2014).

Therefore, the physical behaviors and concentrations of suspended sediments, with resulting turbidity, have been widely studied in relation to environmental and ecological issues, and there have been many attempts to estimate how long fine sediments can be suspended at the surface and how far they can travel away from the source. Hitherto, Lagrangian observations, such as tracing sediment clouds using a ship, have been used to study suspended sediment transport. Such Lagrangian observations, however, are limited in capturing only a narrow picture of the transport of a suspended sediment cloud in a small area for a short time period; moreover it's easy to lose track of the cloud when there is a sudden change of current direction. Hence in conventional in-situ observations, plume lengths of dredged and suspended sediments are reported to have a maximum of 11 km (Hitchcock and Drucker, 1996) and are usually no more than several kilometers (e.g., Goodwin and Michaelis, 1984; Newell et al., 1998; Battisto and Friedrichs, 2003; Kutser et al., 2007). Only in numerical simulations are plume lengths seen to develop to a maximum of 20 km from a long continuous source after one month with long-period removal of significant background disturbances (Kim and Lim, 2009).

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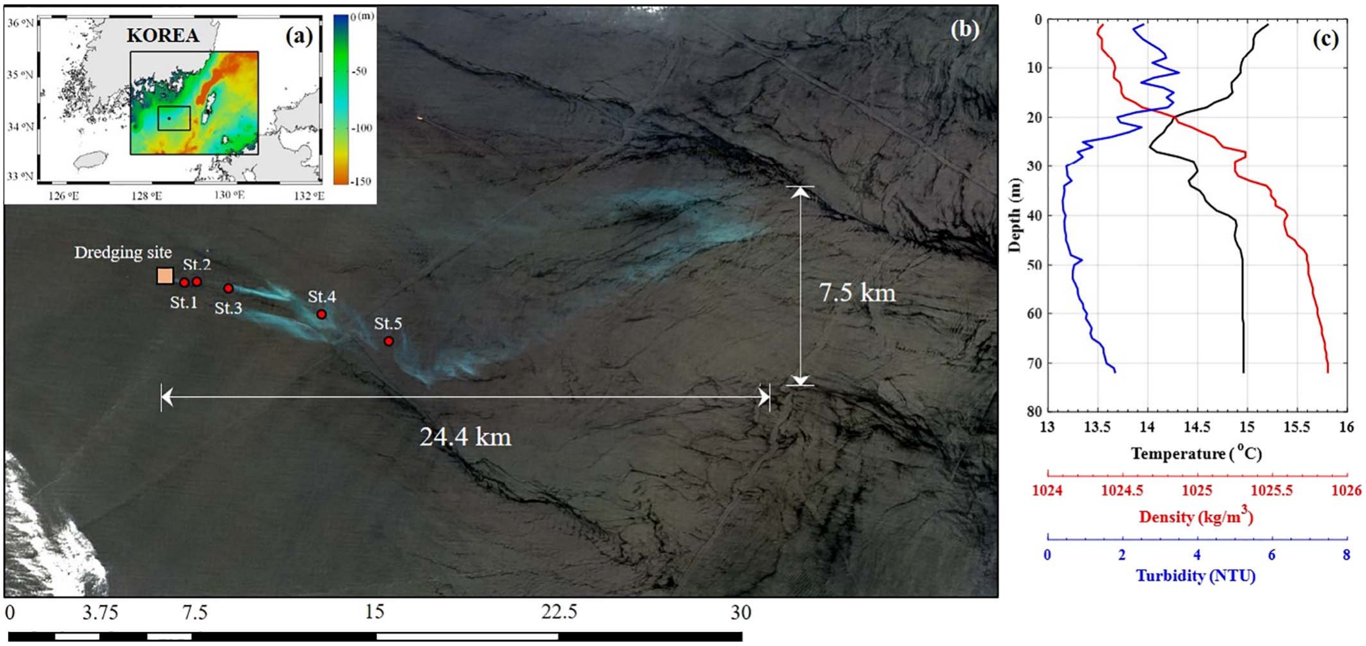

Fig. 1. (a) Geographical layout of the study area, (b) satellite image (Landsat 8) of suspended sediment plume (May 19th, 2015, 10:30 am), (c) example of field observed profiles of temperature, density and turbidity.

Table 1
Characteristics of suspended sediment plumes observed from GOCI satellite images.

	Spring (March–May)		Summer (June–August)		Autumn (September–November)		Winter (December–February)	
Longitudinal distance of suspended sediment plume	< 10 km	> 10 km	< 10 km	> 10 km	< 10 km	> 10 km	< 10 km	> 10 km
Number of suspended sediment plume	2	4	1	5	1	3		1
Total number of suspended sediment plume	6/8		6/9		4/12		1/12	
Probability for presence of the suspended sediment plume	75%		66.67%		33.33%		8.33%	

Remote observations have recently expanded suspended-sediment cloud tracking capabilities in conditions of clear visibility, and facilitated finding traces of those clouds which hitherto have not been observed well (Ali et al., 2016; Kim et al., 2014; Son et al., 2014). As an example, Landsat 8 recently captured an image of a plume streak with length over 20 km within 8–10 h of release (Fig. 1). And we found more examples of longer streaks from images taken by the Geostationary Ocean Color Imager (GOCI) during three years from 2012 to 2015 and summarized on Table 1. In this area off southern Korea, dredging has been carried out one or twice a week, and during operations, images obtained in a total of 41 different days were available to be analyzed; among them, streak images of plumes appeared 17 times. Interestingly, those plumes appeared with seasonal variability: elongated plume streaks appeared 12 times in 17 images from spring and summer, 4 times in 12 images from autumn and only once in 12 images during winter (Table 1). So, the development of such elongated plume streaks may be seasonally variable, a phenomenon which was previously unknown.

Without any discontinuities such as abrupt changes of current, fronts between the different water bodies, strong lateral velocity gradients by the rivers, a source can produce a continuous streak by the uninterrupted release of a scalar substance. Over a long time and in a large space, discontinuations of the streamlines or water bodies can produce many streaks with various lengths, sizes, and locations. Once such discontinuities occur and those disconnected streaks occupy a whole domain, we can determine macroscopic transport based on this area of occupation of multiple scalar streaks. Transport related with streaks has been intensively studied through theory, as well as numerical and field experiments (e.g., Garret, 2006; Sundermeyer and Price, 1998; Sundermeyer et al., 2005). In the macro-scale view, understanding development of streaks must be the first step to study rather macro-scale dispersion and transport of scalars. Such macro-scale transport has not yet been observed nor studied well, except for field experiments in which dye was released and investigated (Sundermeyer and Price, 1998). Fortunately, the release of fine sediments during the dredging of marine aggregates provided an opportunity to study the initial stage of macro-streak development, despite being a special case. During 8–12 h of dredging, the sediment release can be considered as a continuous source, which is very hard to implement artificially in field experiments. Therefore, the present work collected data in initial-stage plume streaks from satellite images, field measurements, and explain physics by a numerical study.

2. Methods of observation and simulation

The dredging site (34.2°N, 128.4°E) is located about 50 km from the coast of South Korea, which is in the Exclusive Economic Zone (EEZ) of Korea. The mean depth is > 80 m (Fig. 1(a)). Sand mining intermittently took place, usually once or twice a week depending on the weather. We conducted field observations on the 19th of May (late spring) and the 18th of October (late autumn) 2015, while the seabed was being dredged and plumes were forming from the overspilled material. Times when Landsat 8 passed over this area were considered in determining the dates of field measurements. During the field measurements in the spring, Landsat 8 passed over this area and so a satellite image could be acquired (Fig. 1(b)). We also scheduled similarly the field measurement synchronizing with Landsat but a plume was not observed and so we didn't include here for late autumn.