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Investigation of deep sea shelf sandbank dynamics driven by highly energetic tidal flows

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ABSTRACT

In this paper we describe a numerical modelling study carried out to investigate the prevailing sediment dynamics of two large sandbanks located at a site designated for future development of tidal stream energy extraction, in the Inner Sound Channel of Pentland Firth, Scotland, UK. A calibrated and validated 3D Delft3D hydrodynamic model covering Pentland Firth channel was combined with a morphodynamic model. The sea bed changes occurring around the sandbanks during a period of two spring-neap tidal cycles are described and discussed in detail. It was found that both sandbanks, which are located in a deep shelf region (depths > 18 m), are morphodynamically active and their existence and integrity are strongly linked with the existing hydrodynamic regime.

1. Introduction

The tidal energy sector is a rapidly growing industry both in the UK and beyond (EOEA, 2012). The commercial interests are now moving towards deployment of large arrays of tidal energy extraction devices. In relation to the installation of large scale tidal turbine arrays numerous factors, many quite uncertain at the moment and linked to site specifications, will determine the array location and operating characteristics. One such factor that will play an important role in any decision making process is the associated impact of in-stream tidal energy converters on the ambient marine environment (Schlezinger et al., 2013; Fallon et al., 2014; Waggitt and Scott, 2014).

A particular concern is the extent to which changes to the tidal currents arising from energy extraction will impact the natural sediment transport regime and hence the sea bed morphology. Due to the sparseness of sediment data in most deployment sites, only very limited studies have so far included the impacts of tidal energy extraction on sediment transport and morphology (Neill et al., 2009; Neill et al., 2012; Robins et al., 2014). In-stream tidal turbines will decrease the flow velocities in the vicinity of the array layout, as well as notable reductions in current flows will occur even beyond the boundaries of the array (Neill et al., 2012). As bed shear stresses have a quadratic dependence on flow velocity, sediment transport has an even higher power of dependence on flow velocity (Soulsby, 1997). As a result, tidal energy extraction may have a much greater influence on the tidally induced sediment transport patterns than on the tidal currents. As part of the environmental impact assessment of new large scale tidal turbine array installations, it is essential that the existing sediment dynamics responsible for the maintenance mechanisms of the observed sea bed sedimentary structures in and around turbine array deployment sites are investigated and understood.

The selected site for this study is Pentland Firth, which divides the Scottish mainland from the Orkney Islands (Fig. 1). It is considered to be one of the most favourable sites for tidal energy harvesting in the UK, due to the prevailing extremely high tidal flows (Couch and Bryden, 2008). The main aim of this research is to understand the sediment transport and morphodynamic environment of the existing seabed in the Inner Sound Channel in Pentland Firth, where large scale tidal current turbine array installations may take place in future. We used a rigorously tested and widely used Delft3D coastal area model to investigate the response of sea bed sediment dynamics to 3D flow structure of the Inner Sound Channel. The existence, integrity and evolution of two large sandbanks in the Inner Sound Channel, which have significant morphological and ecological value, will be examined in detail by linking their morphodynamics with the existing flow regime. The type of sandbanks studied in this research is typical of the sand deposits that may form and exist closer to tips of islands and in areas where complex tidal current regimes force sediment to accumulate into finite spaces while the surrounding areas are largely sediment free (Bastos et al., 2003; Berthot and Pattiaratchi, 2006). As a result, even though the results presented in this study are site specific, the generic methodology employed in the investigation should have wider application.

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Fig. 1. "The Pentland Firth site." 58°42′58.97″ N and 3°06′53.47″ E. Google Earth. January 1, 2004. December 16, 2015; Upper left figure: "United Kingdom." 55°30′41.31″ and 3°21′25.69″. Google Earth. April 10, 2013. December 16, 2015.

In Section 2, an overview of the complex tidal flows inside the Inner Sound channel is given. In Section 3, the sediment coverage and characteristics inside Pentland Firth, Inner Sound channel are described. Section 4 explains the methodology used. In Sections 5 and 6 the morphodynamic environment of the two large sandbanks located in this area is modelled and discussed. Section 7 concludes the paper.

2. Overview of the hydrodynamics of Inner Sound Channel

Pentland Firth (PF), located between Orkney Islands and the north of Scottish mainland joins the Atlantic Ocean and the North Sea (Fig. 1). Differences in tidal range and phase at both ends of the PF result in tidal currents of up to 8 m/s in certain locations for 2.5 m head drop over a tidal cycle. This provides an abundant energy resource for tidal current turbine deployments (Baston and Harris, 2011). The Inner Sound channel separates the Island of Stroma in Pentland Firth and the Scottish Mainland (Fig. 1). Water depths between 25 and 30 m coupled with fast moving tidal flows in the Inner Sound Channel provide a very favourable collation of site characteristics for tidal energy extraction (Easton et al., 2010; Goddijn-Murphy et al., 2013). The complex 3D hydrodynamic environment of this area has been extensively investigated in previous work through numerical modelling studies (Baston and Harris, 2011; Baston et al., 2013; Chatzirodou and Karunarathna, 2014).

Chatzirodou and Karunarathna (2014) used a large scale 3D hydrodynamic model Delft3D (Lesser et al., 2004) to reproduce the dynamics of tidal flows in Pentland Firth. A shelf wide flow model developed by Baston et al. (2013) was used to obtain boundary conditions for this large scale model. The model was able to capture the existing hydrodynamics of Pentland Firth during a period of two spring-neap tidal cycles (09/09/2001–09/10/2001). Results from this large scale hydrodynamic model produced appropriate boundary conditions for a nested higher resolution hydrodynamic and morphodynamic model covering the Inner Sound channel (Fig. 2), which will be used in this study.

The detailed hydrodynamic study of the Inner Sound Channel revealed that at spring ebb phase, a channel flow was formed and travelled further offshore from the western side of the Island of Stroma. Strong ebb currents exited the North-West part of Inner Sound with 200°–250° flow direction. At spring flood phase, a tidal jet was formed to the south of the ebb channel flow and travelled eastwards in a constrained path located in the middle part of Inner Sound channel. Maximum flood flows were observed inside the central part of the tidal jet whereas decreasing velocity gradients were observed further eastward (Chatzirodou and Karunarathna, 2014). Overall, a distinct