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Linking benthic hydrodynamics and cold-water coral occurrences: A high-resolution model study at three cold-water coral provinces in the NE Atlantic

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ABSTRACT

Observations from numerous cold-water coral locations in the NE Atlantic show energetic near-bottom flow dynamics along the European continental margin at individual coral mounds and mound clusters. Dynamics are largely controlled by tide-topography interaction generating and enhancing periodic motions such as trapped waves, freely propagating internal tides and internal hydraulic jumps. In this study, linkages between key abiotic parameters and cold water coral occurrences are explored across entire cold-water coral mound provinces using an integrated modelling and observational approach. The 3-D ocean circulation model ROMS-AGRIF was applied to simulate near-bottom hydrodynamic conditions at three provinces in the NE Atlantic (Logachev mounds, Arc mounds and Belgica mounds) adopting a nested model setup with a central grid resolution of 250 m. Simulations were carried out with a focus on accurate high-resolution topography and tidal forcing. The central model bathymetry was taken from high-resolution INSS (Irish National Seabed Survey) seafloor mapping data. The model was integrated over a full one-year reference period starting from the 1st January 2010. Interannual variability was not considered. Tidal forcing was obtained from a global solution of the Oregon State University (OSU) inverse tidal model. Modelled fields of benthic currents were validated against available independent in situ observations. Coral assemblage patterns (presence and absence locations) were obtained from benthic surveys of the EU FP7 CoralFISH programme and supplemented by data from additional field surveys. Modelled near-bottom currents, temperature and salinity were analysed for a 1-month subset (15th April to 15th May 2010) corresponding to the main CoralFISH survey period. The model results show intensified near-bottom currents in areas where living corals are observed by contrast with coral absence and random background locations. Instantaneous and time-mean current speeds at mound clusters in the Logachev province exceeded typical values in non-coral areas by up to a factor of three. Currents at cold-water coral locations in the Arc and Belgica mound provinces were less energetic, but still elevated compared to non-coral locations. An analysis of dynamical processes associated with oscillatory flow interacting with topography suggests that these motions are locally important food supply mechanisms to cold-water corals by promoting large amplitude local vertical mixing and organic matter fluxes. It is shown that their presence varies considerably between provinces based on the interplay of topographic slope, flow magnitude and ambient stratification.

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1. Introduction

The Porcupine Bank, Porcupine Seabight and Rockall Bank are areas of abundant occurrences of the scleractinian cold-water coral (CWC) *Lophelia pertusa* and associated faunal communities. The majority of these occurrences are found in connection with large CWC mound structures or they appear as individual coral colonies along the European continental margin (Fig. 1a). Giant mounds can be up to 380 m high and several kilometres long and are in the NE Atlantic Ocean exclusively found in the Porcupine Bank, Porcupine Seabight, and Rockall Bank (De Mol et al., 2002; Van Weering et al., 2003; Huvenne et al., 2005; Wheeler et al., 2007). The majority of coral mounds along the Irish continental margins occur between 600 and 1000 m water depth (Kenyon et al., 2003; Roberts et al., 2009; White and Dorschel, 2010). Since CWCs in the NE Atlantic

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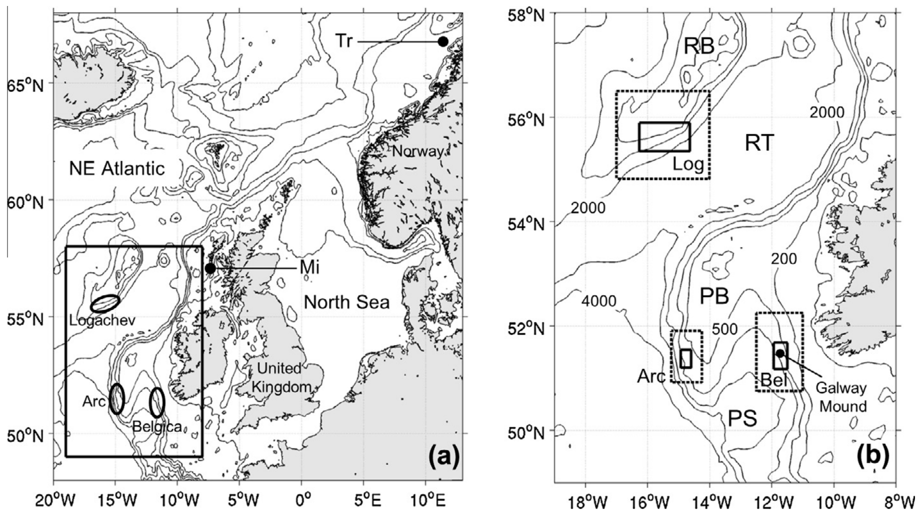

Fig. 1. (a) Distribution of mound provinces along the NE Atlantic continental margin, indicated by grey circles. Additional CWC reefs mentioned in the text are indicated by black dots (Mi – Mingulay, Tr – Traena). (b) Location of model domains used in the present study covering the Logachev (Log), Arc (Arc) and Belgica (Bel) CWC provinces. Dashed rectangles indicate the large-scale domains (parent grids) and solid rectangles represent the local high-resolution model domains (child grids). Major bathymetric features are the Rockall Bank (RB), Rockall Trough (RT), Porcupine Bank (PB) and Porcupine Seabight (PS). The 200 m, 500 m, 1000 m, 2000 m, 3000 m and 4000 m depth contours are shown based on the ETOPO-1 bathymetry grid. The black dot in (b) indicates the location of the acoustic current meter (ACM) time series used for model-data comparison.

appear most abundant on elevated topography, flow acceleration has been considered as an important condition for CWC growth (e.g. Genin et al., 1986). Stronger continuous or periodic flow enhances delivery of particles such as larvae and food to coral and other suspension feeding organisms in the mound communities, and prevents smothering of the corals through sediment deposition (e.g. Dorschel et al., 2005; White, 2007). Oceanographic influences at CWC sites occur at a vast range of spatial and temporal scales. At the largest spatial scale, pelagic productivity and oceanic biogeochemical characteristics fundamentally control the global distribution of CWCs (e.g. Freiwald, 2002; Davies et al., 2008). At intermediate scales of 10–100 km, a combination of suitable flow conditions and supply of nutrients is required to sustain the local coral population. For example, along the Norwegian continental margin, the poleward along-margin flow enhances a downwelling flux of organic material to benthic communities (Thiem et al., 2006).

Clusters of carbonate mounds may be found at depths of the permanent thermocline, where enhanced current dynamics are often present (White and Dorschel, 2010), or where there is a concentration of organic matter and a suitable delivery method (White et al., 2005; Mienis et al., 2007). Smaller scale ‘hotspots’ of CWC communities may be found where complex interactions between diurnal tidal currents and the local topography may generate trapped wave dynamics and tidal amplification. Topographic trapping and resonant amplification of diurnal tidal oscillations have been frequently described at isolated seamounts (e.g. Brink, 1995; Beckmann and Haidvogel, 1997; Lavelle and Mohn, 2010) and submarine banks (e.g. Huthnance, 1974; Mohn and Beckmann, 2002; White et al., 2007). Recent studies highlight the potential importance of trapped wave dynamics for local mixing and organic matter fluxes at carbonate mound systems in the NE Atlantic (White et al., 2007; White and Dorschel, 2010). Another distinctive dynamical feature at continental slopes, ridges and seamounts are freely propagating internal tides (e.g. Garrett and Kunze, 2007; Klymak et al., 2012; van Haren and Gostiaux, 2012). Internal tides are generated for super-inertial tidal frequencies and may strongly enhance turbulent mixing and modify the thermohaline structure (e.g. Cacchione et al., 2002; Frederiksen et al., 1992). Characteristic topographic interactions with internal tides depend on topographic steepness and background stratification and may trigger very efficient food supply mechanisms for CWC communities, such as downwelling induced by hydraulic control processes (e.g. Davies et al., 2009), or the critical resonance of internal waves (e.g. Frederiksen et al., 1992; Hosegood et al., 2004).

Resolving key environmental factors for CWC distribution in the deeper Atlantic requires a rare combination of hydrodynamic model studies, in situ measurements and data on the spatial distribution and food preferences of corals. In several locations, daily migrating zooplankton has been proposed as a major food source of the CWC community while elsewhere food is considered to mainly consist of suspended particles or a combination of both (Duineveld et al., 2004, 2007; Becker et al., 2009; Kiriakoulakis et al., 2005). Hydrography clearly has a different role and importance for food transport in these cases. The EU-funded CoralFISH program offered the opportunity to conduct in situ measurements at several principal Atlantic CWC locations such as the Logachev mounds, the Arc mounds and the Belgica mound province. Within the framework of the CoralFISH program which was focused on interactions between fish, fisheries and CWCs, long-term observations were made on fish abundance using baited cameras on benthic landers. Current meters attached to these landers yielded unique long-term data series in and outside coral reef framework. Likewise, during the CoralFISH remotely operated vehicle (ROV) dives new data were collected on the distribution of corals in relation to topography.

Our focus is on a comparative description of oceanographic conditions at three NE Atlantic CWC provinces based on a 3-D hydrodynamic downscaling modelling approach. The study areas comprise the Logachev mounds (SE Rockall Bank), Arc mounds (Western Porcupine Bank) and Belgica mounds (Northern Porcupine Seabight), which were repeatedly surveyed as part of CoralFISH field activities (Fig. 1a and b). The main objective of the present study is to quantify the intrinsic variability and spatial structure of near-seabed dynamics driven by tide-topography interaction and their relative importance in these areas. The model setup and experimental strategy are described in Section 2. Further, modelled near-bottom flow and hydrographic conditions at CWC presence and absence locations are compared, followed by a more detailed analysis of key processes based on established

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