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Tidal influence on particulate organic carbon export fluxes around a tall seamount

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ABSTRACT

As tall seamounts may be 'stepping stones' for dispersion and migration of deep open ocean fauna, an improved understanding of the productivity at and food supply to such systems needs to be formed. Here, the $^{234}Th/^{238}U$ approach for tracing settling particulate matter was applied to Senghor Seamount – a tall sub-marine mountain near the tropical Cape Verde archipelago – in order to elucidate the effects of topographically-influenced physical flow regimes on the export flux of particulate organic carbon (POC) from the near-surface (topmost $\leqslant$ 100 m) into deeper waters. The comparison of a suitable reference site and the seamount sites revealed that POC export at the seamount sites was ~2–4 times higher than at the reference site. For three out of five seamount sites, the calculated POC export fluxes are likely to be underestimates. If this is taken into account, it can be concluded that POC export fluxes increase while the passing waters are advected around and over the seamount, with the highest export fluxes occurring on the downstream side of the seamount. This supports the view that biogeochemical and biological effects of tall seamounts in surface-ocean waters might be strongest at some downstream distance from, rather than centred around, the seamount summit. Based on measured (vessel-mounted ADCP) and modelled (regional flow field: AVISO; internal tides at Senghor: MITgcm) flow dynamics, it is proposed that tidally generated internal waves result in a 'screen' of increased rates of energy dissipation that runs across the seamount and leads to a combination of two factors that caused the increased POC export above the seamount: (1) sudden increased upward transport of nutrients into the euphotic zone, driving brief pulses of primary production of new particulate matter, followed by the particles' export into deeper waters; and (2) pulses of increased shear-driven aggregation of smaller, slower-settling into larger, faster-settling particles. This study shows that, under certain conditions, there can be an effect of a tall seamount on aspects of surface-ocean biogeochemistry, with tidal dynamics playing a prominent role. It is speculated that these effects can control the spatiotemporal distribution of magnitude and nutritional quality of the flux of food particles to the benthic and benthic-pelagic communities at and near tall seamounts.

1. Introduction

A fraction of the biogenic particulate matter that is photoautotrophically produced in the upper sunlit layers of the ocean settles into deeper waters and constitutes food for heterotrophic organisms in the deeper waters and the seafloor. Often this downward 'export' of biogenic particulate matter from the topmost 10 s or 100 s of meters of the water column is quantified in terms of the export of particulate organic carbon (POC). On large quasi-horizontal scales on the order of 1000 s of kilometers, the combination of basin-scale current distribution and latitudinally dependent insolation indirectly control the distribution of primary productivity and POC export (e.g., Lutz et al., 2007; Watling et al., 2013). On

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quasi-horizontal scales on the order of 10–100 s of kilometers, physical-oceanographic features such as mesoscale eddies and fronts are known to influence POC export (e.g., Buesseler et al., 2008; Resplandy et al., 2012). Islands and island chains have also been shown to effects POC export through their effects on regional and local flow dynamics (e.g., Bidigare et al., 2003; Morris et al., 2007; Maiti et al., 2008; Verdeny et al., 2008). By contrast, very little is known about the influence of submarine mountains. Seamounts are often defined as tall (>1000 m from base to summit), relatively isolated submarine features, of which there are estimated to be well over 100,000 across the ocean (Wessel et al., 2010). About 2000 seamounts are thought to be at least 3000 m high, with the vast majority reaching water depths of $\leqslant$100 m.

Seamounts interact in systematic and complex ways with different flow components of ocean currents, including quasi-steady and oscillating ones (see, for example, reviews by White and Mohn, 2004; Lavelle and Mohn, 2010; Turnewitsch et al., 2013). As tall seamounts may be ‘stepping stones’ for dispersion and migration of deep open ocean fauna (Rowden et al., 2010), an improved understanding of the productivity and food supply to such systems needs to be formed. It has been argued that the fluid dynamics at seamounts that reach into the near-surface ocean could have a significant effect on local or regional water column biogeochemistry (Goldner and Chapman, 1997; Mullineau and Mills, 1997; Mohn and White, 2010). This could lead to seamounts acting as hotspots of high productivity and potentially high POC-export, at least in oligotrophic regions, a phenomenon described as the ‘seamount’- or ‘classic’- hypothesis (Dower and Mackas, 1996). Observed enhancements of primary production around seamounts have been attributed to a greater local upward mixing of deep, nutrient-replete waters (Rogers, 1994; Mouriño et al., 2001). However, as noted by Genin (2004), upwelling is unlikely to be a permanent feature and any enhancement of primary production might only be realised downstream of the seamount. Rowden et al. (2010) also argue that the paradigm that tall seamounts “have high production supported by localised bottom-up forcing, [is] not supported by the weight of existing evidence”.

This paper presents the first case study in which the distribution of export of POC from the surface waters near and over a tall seamount was investigated. For the particular situation at the time of the study, the three main objectives were (O1) to identify the predominant physical-oceanographic features at and near the seamount; (O2) to establish how POC export is distributed at the seamount compared to reference stations; and (O3) to scrutinize the results of O1 and O2 for a seamount effect on POC export. The core hypothesis is that a tall seamount can trigger enhanced localised POC export. The findings of this study illustrate the importance of the physical-oceanographic complexity that results from regional ‘background’ variability and seamount-controlled flow/topography interactions for an understanding of biogeochemical processes at tall seamounts. The results indicate that, in the case of Senghor Seamount, tidally generated internal waves are likely to have led to an abrupt and localised enhancement of POC export, with this biogeochemical signal being advected downstream and away from the seamount.

2. Material and methods

2.1. Environmental setting

The study was carried out at Senghor Seamount, a large, approximately conical feature on the Cape Verde Rise, centred at ~17.2°N, 21.9°W and ~110 km north-east of Sal Island of the Cape Verde archipelago and ~550 km west of the coast of Senegal (Fig. 1). The summit plateau is at ~105 m depth whereas the rise is at ~3200 m. The summit plateau has a maximum extent of ~5 km; at the base the seamount has an approximate diameter of 35 km. The seamount is situated amongst several well-studied oceanographic features, including the Cape Verde Frontal Zone (CVFZ; Zenk et al., 1991) to the north (N) and northwest (NW) (Fig. 1), the Mauritanian Upwelling Zone (Mittelstaedt, 1983) to the northeast (NE), and the Guinea Dome (Siedler and Zangenberg, 1992) and Shadow Zone (Luyten et al., 1983) to the south (S).

Current-flow data derived from nearby moorings (Müller and Siedler, 1992; Vangriesheim et al., 2003), Acoustic Doppler Current Profiler (ADCP) transects (Stramma et al., 2008), and satellite-altimetry-forced models (Lázaro et al., 2005) suggest that at depths shallower than ~800 m mean residual flow in the region is to the southwest (SW) at ~0.05–0.1 m s^{-1} which is consistent with the general direction of the North Equatorial Current (NEC) (Fig. 1). At depths greater than ~800 m, residual flow is to the south at only 0.005–0.01 m s^{-1}. Important sources of variability that are superimposed onto this mean residual flow are the seasonal migration of the wind-stress curl with the inter-tropical convergence zone (ITCZ) (Stramma and Siedler, 1988; Lázaro et al., 2005), baroclinic instabilities originating from the CVFZ), barotropic tidal oscillations (Siedler and Paul, 1991), and internal (baroclinic) tides (Siedler and Paul, 1991; Arbic et al., 2012).

Although the centre of the Mauritanian Upwelling Zone is located off Cape Blanc, i.e., well to the NE of Senghor Seamount, filaments of upwelled water have been observed to extend out westward driven by trade-winds and meso-scale eddies (Mittelstaedt, 1983; Pastor et al., 2008; Meunier et al., 2012). The filaments tend not to extend southward towards Senghor Seamount though. Nevertheless, satellite remote sensing data from MODIS-Aqua (acquired from giovanni.gsgc.nasa.gov) will be utilised to evaluate the extent of eutrophic waters during this study.

Primary production typically peaks in the first quarter of the year, following the wind stress maximum (Lathuilière et al., 2008; Ohde and Siegel, 2010); but spatially- and temporally-sporadic peaks in productivity have been observed later between April and June, and it has been speculated that they occur in association with dust deposition from the Sahara and Sahel regions (Ratmeyer et al., 1999b; Fitzsimmons et al., 2013). However, dust deposition in summer has been noted to be five-times lower than in December and January (Chiapello and Bergametti, 1995); and, using a remotely sensed optical aerosol depth index and chlorophyll-*a* concentration as proxies for dust deposition and productivity, respectively, Ohde and Siegel (2010) reported that the input of Saharan dust accounts for just 5% of the variability in observed chlorophyll-*a* concentrations. By contrast, there is some evidence to suggest that large amounts of dust particles that are incorporated into marine-snow aggregates could lead to increased mass densities of these aggregates and, as a consequence, higher settling speeds and POC export (e.g., Fischer et al., 2016).

2.2. The $^{234}Th/^{238}U$ approach to estimate POC export

The use of the thorium-234/uranium-238 ($^{234}Th/^{238}U$) pair of naturally occurring radionuclides to measure export flux is made possible due to the contrasting adsorption behaviours of the two elements (Bhat et al., 1968; Coale and Bruland, 1985, 1987; Buesseler, 1998). In oxygenated seawater the very long-lived ^{238}U (half life: $t_{1/2} \approx 4.468$ billion years) behaves chemically conservative and is removed only by alpha-decay to its daughter, ^{234}Th. If unperturbed, the two radionuclides remain in so-called radioactive equilibrium: i.e., over negligibly-short time scales relative to the half-life of ^{238}U, the rate of decay of ^{234}Th is matched by the rate of decay of ^{238}U. However, in seawater Th is highly particle reactive (e.g., Santschi et al., 2006) and readily scavenged by