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Coccolithophore species as indicators of surface oceanographic conditions in the vicinity of Azores islands

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ABSTRACT

During summer 2008 and spring 2009, surface oceanographic surveys were carried out around three islands of the Azores archipelago (Terceira, São Miguel and Santa Maria) to assess the phytoplankton distribution and associated physico-chemical processes. The Azores archipelago is a major feature in the biogeochemical North Atlantic Subtropical Gyre (NAST) province although its influence on the productivity of the surrounding ocean is poorly known. Surface phytoplankton was studied by microscopy and HPLC (High Precision Liquid Chromatography). The mean values for biomass proxy Chlorophyll *a* (Chl*a*) ranged from 0.04 to 0.55 μg L^{-1} (Chl*a* maximum = 0.86 μg L^{-1}) and coccolithophores were the most abundant group, followed by small flagellates, Cyanobacteria, diatoms and dinoflagellates being the least abundant group. The distribution of phytoplankton and coccolithophore species in particular presented seasonal differences and was consistent with the nearshore influence of warm subtropical waters from the south Azores current and colder subpolar waters from the north. The satellite-derived circulation patterns showed southward cold water intrusions off Terceira and northward warm water intrusions off Santa Maria. The warmer waters signal was confirmed by the subtropical coccolithophore assemblage, being *Discosphaera tubifera* a constant presence under these conditions. The regions of enhanced biomass, either resulting from northern cooler waters or from island induced processes, were characterized by the presence of *Emiliania huxleyi*. Diatoms and dinoflagellates indicated coastal and regional processes of nutrient enrichment and areas of physical stability, respectively.

1. Introduction

The Azores archipelago (36°–39′ N, 25°–31′ W) consists of nine volcanic islands forming three groups (western, central and eastern) located within the North Atlantic Subtropical Gyre biogeochemical province (NAST; Longhurst et al., 1995). The archipelago lies in a transition zone between the North Atlantic Current (NAC) to the northwest, the Azores Current (AC), a jet-like current, ca.34° N, to the south, and a region of weak circulation to the northeast (Juliano and Alves, 2007). Related to the main jet of the Azores Current there is an important thermohaline front, separating fresher and colder waters to the north and warmer and saltier water masses to the south (Gould, 1985). The islands are not in the direct eastward path of the main jet, but are affected by the recirculation patterns and eddies that originate from its meandering. Due to convergent southward and northward flows from the NAC and AC, respectively, strong thermal gradients are typical of the region (Lafon et al., 2004). Topographically-induced turbulence significantly modifies the physical and biological conditions adjacent to islands, which often result in higher marine productivity (Bakker et al., 2007; Hasegawa et al., 2008). In the NAST province, wintertime mixing provides the seasonal replenishment of nutrients to the euphotic zone while in spring, thermal stratification favours phytoplankton growth, which progressively leads to surface nutrient depletion by late summer. In the North Atlantic, blooms and seasonal mass flux of coccolithophores are known to occur (Holligan et al., 1993; Broerse et al., 2000; Sprengel et al., 2000) and most of the annual production takes place during spring (Schiebel et al., 2011).

Coccolithophores are a calcareous nannoplanktonic group which widespread distribution in the ocean, range from oligotrophic subtropical gyres to temperate and high latitude eutrophic regimes.

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The importance and motivation for studying coccolithophore dynamics, is that according to particular environmental conditions characteristic assemblages are found, which can be distinguished by their coccolith types and coccosphere morphology. As the group is known to be driven by oceanographic changes, reflecting on a fine scale, ecological patterns, and may be sensitive to climate change and ocean acidification (Broerse et al., 2000; Tortell et al., 2002; Rost et al., 2003; Smyth et al., 2004; Andruleit, 2007; Silva et al., 2008; Tyrrell, 2008) it is always relevant to gather ecological information on individual species to determine which are capable of providing key significant responses. In this sense, *Emiliania huxleyi* is probably one of the best-studied phytoplankton species that is of relevance in the ocean. It is the most predominant coccolithophore and blooms have been reported from different settings of the North Atlantic and Pacific (Beaufort and Heussner, 2001; Beaufort et al., 2008), under conditions of high turbulence, during an early stage of the phytoplankton succession in spring, as well as during calm and stratified conditions following the spring bloom. i.e., during May–July in the North Atlantic (Silva et al., 2008, 2009; Schiebel et al., 2011). On the other hand, in warm waters depleted in nitrate and under very high light intensities, as off Bermuda (N Atlantic) the coccolithophore assemblage is different and species such as *Discosphaera tubifera* are observed (Haidar and Thierstein, 2001).

The present work is an output of project CAMAG, characterization of coastal water masses in the vicinity of the islands of Terceira (Central group), São Miguel and Santa Maria (Oriental group). Our aim is to assess the abundance and diversity of the phytoplankton assemblage and describe the major physical patterns and regional processes by using coccolithophores as indicators of surface oceanographic changes and seasonal variations.

2. Methods

2.1. Surveyed area and sampling strategy

During summer 2008 (July–August) and spring 2009 (May–June) three surveys were carried out, covering three islands of the Azores archipelago, Terceira (TER, Central group), São Miguel (SM, Oriental group) and Santa Maria (SMA, Oriental group) (Fig. 1). As sampling was defined in the context of CAMAG project (related to the European Water Framework Directive), 44 samples were collected on board a small vessel, using a Niskin bottle to collect the surface water layer for phytoplankton microscopy observation and cell counting, pigment analysis and nutrient concentrations. Details on the water samples processing for the different analysis are described below. During summer, five stations were sampled around Terceira (stations 1,4 and 5 in the south; station 3 in the north and station 2 in the east), eleven around São Miguel (stations 1–5 and station G in the south and stations 6–10 in the north) and two in Santa Maria (station 1 and 2, in the south and east, respectively). During spring, four additional sites were sampled around Terceira (stations I1, P1 and P2 in the south and station I2 in the east), and two both in São Miguel (stations IN in the north and IS in the south) and Santa Maria (stations I1 and I2 in the south and east, respectively) (Fig. 3). Most of the stations were near the coast with 40 m depth, some stations were at ca.100 m depths (I1 at Terceira and IN and IS at São Miguel, I1 and I2 at Santa Maria) and a few at depths greater than 200 m (G at São Miguel, P1 and P2 at Terceira).

2.2. Physico-chemical parameters

Surface temperature was determined *in situ* with a Multiparameter Water Quality Portable Meter Hanna HI-9828. Water for nutrient determination was filtered through a 0.45 μm Millipore filter and stored at −4 °C for subsequent colorimetric analyses with a Tecator FIAstar™ 5000 Analyser. Nitrite (NO_2^-) plus nitrate (NO_3^-) were determined according to Grassoff (1976), phosphate (PO_4^{3-}) was determined according to Murphy and Riley (1962) and silicate ($Si(OH)_4$) according to Fanning and Pilson (1973). The detection limit for seawater analysis was 0.5 μM for silicate, 0.11 μM for nitrite + nitrate and 0.1 μM for phosphate.

2.3. Phytoplankton analysis

The phytoplankton assemblage was identified and counted through microscopy (Section 2.3.1) and photosynthetic pigments

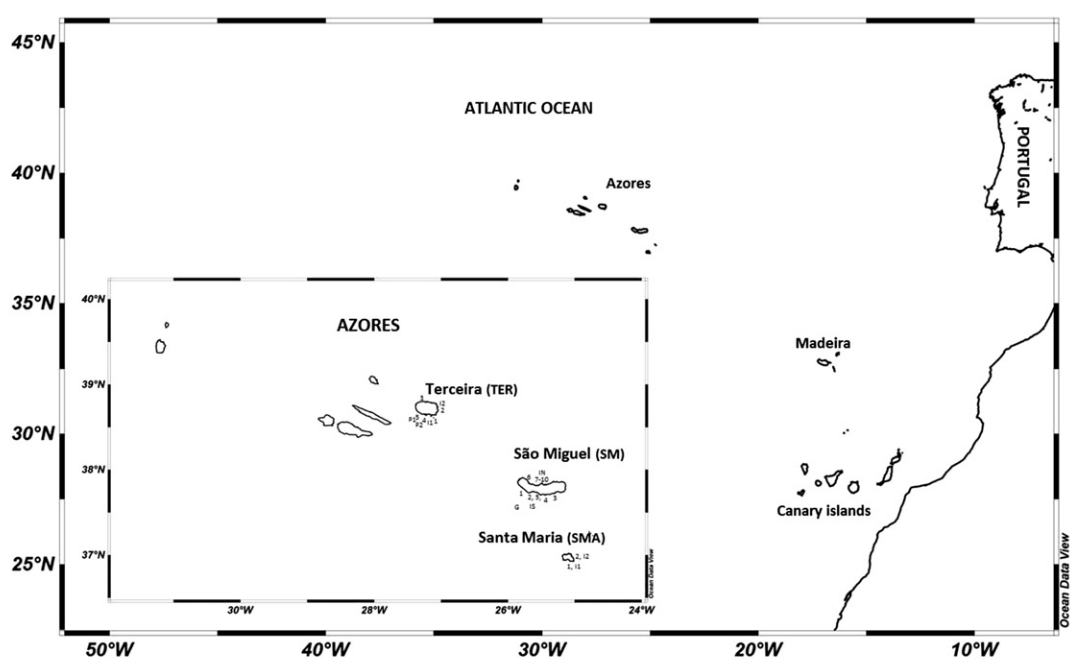

Fig. 1. Location of the Azores archipelago in the NE Atlantic Ocean context. The islands and stations sampled are highlighted: Terceira (TER, Central Group), São Miguel (SM, Oriental Group) and Santa Maria (SMA, Oriental Group).