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Research paper

# Biogeographic distribution of living coccolithophores in the Pacific sector of the Southern Ocean

Mariem Saavedra-Pellitero [a,*], Karl-Heinz Baumann [a], José-Abel Flores [b], Rainer Gersonde [c]

[a] Department of Geosciences, Universität Bremen, PO Box 33 04 40, 28334 Bremen, Germany
[b] Departmento de Geología, Universidad de Salamanca, Plaza de la Merced s/n, CP-37008 Salamanca, Spain
[c] Alfred Wegener Institute for Polar and Marine Research, Postfach 120161, 27515 Bremerhaven, Germany

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ABSTRACT

This paper adds to a series of studies addressing the distribution of living coccolithophores in the Southern Ocean (SO). We investigated plankton samples collected during *RV Polarstern* cruise ANT-XXVI/2 (from 27th November 2009 to 27th January 2010) along a broad E–W transect in the Pacific sector of the SO during austral summer. One hundred and fifty samples from twenty-nine stations were collected from the upper 150 m of the water column. Both coccoliths and coccospheres per sample were counted separately using a scanning electron microscope (SEM). The highest abundances of 640 · $10^3$ coccospheres/l were reached close to the Subtropical Front (STF) and increases in the numbers of coccospheres and coccoliths were found both at the Subantarctic Front (SAF) and the Polar Front (PF). However, the numbers decrease southward until almost a monospecific assemblage and sporadic record of *Emiliania huxleyi* (types B/C and C) south of the PF. Thirty-three coccolithophore species, including sixteen species found as isolated coccoliths, were identified of which *E. huxleyi* is clearly the most dominant coccolithophore taxon in the studied samples. Two main coccolithophore assemblages were established coincident with areas bounded by the oceanographic fronts: the Polar Front Zone (PFZ) and Subantarctic Zone (SAZ). In the upper photic zone of the SAZ, *Acanthoica quattrospina*, *Calcidiscus leptoporus*, *Coccolithus pelagicus* (sensu lato) HOL, *E. huxleyi* type A, *Ophiaster* spp. and *Syracosphaera* spp. among others were found. The PFZ was characterized by a reduced number of species, i.e., *Calciopappus caudatus*, *E. huxleyi* types B, B/C and C, as well as *Pappomonas* spp. and *Papposphaera* spp. The sea surface temperature measured in situ was the most prominent factor influencing coccolithophore diversity, distribution and assemblage compositions in the Pacific sector of the SO during austral summer. Coccolithophore biogeography in the study area showed marked differences with the northern high latitudes; the reduced presence of the cold water species *Coccolithus pelagicus*, abundant in the (sub) Arctic region, and the dominance of *E. huxleyi* type B/C and C in the SO contrasts with the dominance of *E. huxleyi* types A and B in the North Atlantic. Findings such as these cover existing gaps in an unexplored area of the SO as well as supporting previous research performed in neighboring areas. The current coccolithophore numbers and assemblage distribution in relation to the frontal dynamics of the SO provide valuable information for potential future paleoceanographic reconstructions.



## 1. Introduction

Coccolithophores, phytoplankton belonging to the division Haptophyta (Young and Bown, 1997; Young et al., 2003) are one of the most important producers of marine carbonate in the pelagic realm (Westbroek et al., 1993). Their distribution and diversity in the photic zone are affected by surface oceanic circulation and therefore by different parameters such as sea surface temperature (SST), sea surface salinity (SSS) and nutrient availability. Coccolithophores are present in a wide range of marine environments, from tropical to subpolar regions (Winter et al., 1994; Ziveri et al., 2004). Recent concerns about climate change and the effects of rising surface ocean temperatures and possibly increasing ocean acidification on marine organisms have triggered an increasing interest in coccolithophore ecology (e.g., Beaufort et al., 2008, 2011; Charalampopoulou et al., 2011). It is currently not known how coccolithophore populations may adapt to proposed changes in their environment if at all. However geographical shifts in the occurrences of coccolithophore species and assemblage compositions have been observed already (e.g., Cubillos et al., 2007; Winter et al., 2013). Thus, detailed knowledge of coccolithophore spatial variations, assemblage composition, and production are needed. Although general aspects of coccolithophore biogeography and habitat are known from taxonomic surveys of the plankton and of bottom sediments in various oceans (e.g., Winter et al., 1999; Andruleit et al., 2000; Gravalosa et al., 2008; Ho et al., 2012), little work has been

* Corresponding author. Tel.: +49 421 218 65192; fax: +49 421 218 65219.
*E-mail address:* msaavedr@uni-bremen.de (M. Saavedra-Pellitero).

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done on absolute numbers of single species relative to ecological parameters in natural populations. Records on coccolithophores from the surface waters of the Pacific sector of the Southern Ocean (SO) have been comparatively scarce so far.

Therefore the lateral and vertical coccolithophore compositions along a broad E–W transect of the SO were examined qualitatively and quantitatively. In addition, the complex relationship between coccolithophore taxa and environmental conditions was revealed by multivariate analysis. Comparison and combination of our results with living coccolithophore studies carried out in different sectors of the SO were performed. Although plankton assemblages from the photic zone only provide snap-shot insights into the living communities, they provide essential information on the occurrence and distribution of the species, and the ecology of different taxa. This is a prerequisite for the application of coccolithophores and their remains (organic and inorganic) in paleoceanographic reconstructions.

## 2. Material and methods

One hundred and fifty samples were obtained from 29 stations during the expedition ANT-XXVI/2 from 27th November 2009 to 27th January 2010 (Punta Arenas, Chile – Wellington, New Zealand) on board the *R/V Polarstern* within the area 44.8°S to 68.7°S and 80.1°W to 174.5°E (Fig. 1). For the study of the coccolithophore assemblages, 2 l of water were taken using a Rosette sampler with 24 × 12 l Niskin bottles (Ocean Test Equipment Inc.) attached to a conductivity–temperature–depth (CTD) device. The bottles were fired by an SBE carousel (SBE32). To survey the water column, a Seabird SBE 9plus sensor (Seabird Electronics Inc.) was used (Gersonde et al., 2011). Seawater samples were taken at different water depths (surface to deep) for precise multi-purpose oceanographic research and 4 to 7 samples per station were collected for coccolithophore studies from 10 to 150 m depth (Table 1).

### 2.1. Techniques for the preparation and identification of coccolithophore taxa

The samples were filtered through cellulose nitrate filters (0.45 μm pore size) onboard. The filters were dried in an oven at ~40 °C during 24 h and stored in Petri dishes. Once on land a small piece of the filter (<1 $cm^2$) was cut out, fixed on an aluminum stub and sputtered with gold/palladium. Coccolithophore assemblages were examined with Zeiss DSM 940A scanning electron microscope (SEM) at magnifications of 3000×, and 5000× when required.

Identification of species followed the taxonomic guide of Young et al. (2003) as well as the revised classification of Jordan et al. (2004) and www.nannotax.org. We distinguished four different morphotypes of *Emiliania huxleyi* in the study area. These are type A (*huxleyi*, Plate Ia), type B (*pujosiae*, Plate Ib), type B/C (Plate Ic) and type C (*kleijneae*, Plate Id). We have not separated *E. huxleyi* type O, a new morphotype based on molecular genetic studies recently described by Hagino et al. (2011). Specimens of this type could have been incorporated into B, B/C and/or C morphotypes in this research. *Emiliania huxleyi* type C and type B/C coccoliths look very similar; both types have delicate distal shield elements and a central area opened or covered by a thin plate (Young et al., 2003). Even though they have different sizes (type C, 2.5–3.5 μm and type B/C, 3–4 μm, Young et al., 2003), classification of the specimens was occasionally hindered by overlapping size ranges.

Coccospheres and coccoliths were counted in transects across the filter area separately; we counted a minimum of 400 coccoliths and 200 coccospheres per sample whenever possible. All the sampling points were considered when plotting the number of coccospheres/l and coccoliths/l. However, stations with less than 50 coccospheres or less than 100 coccoliths were excluded when plotting the percentages of the different species. Also we only show the coccosphere numbers and percentages for selected species in this work. In addition the presence or absence of diatoms was indicated based on SEM visual observations. When present, a semi-quantitative assessment at a magnification of

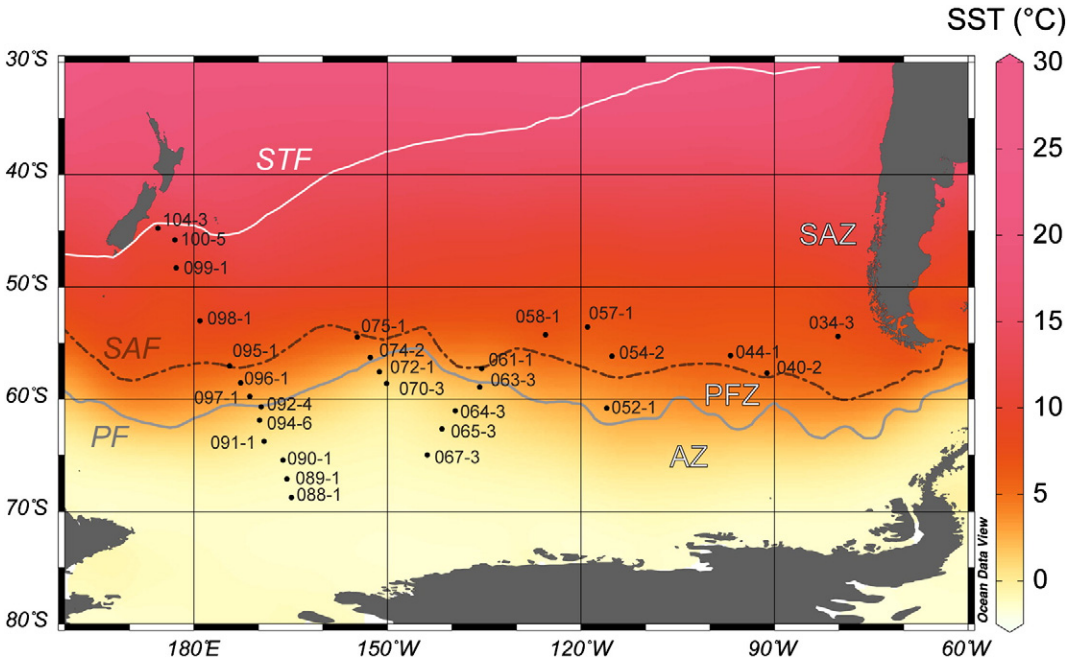


**Fig. 1.** Sea surface temperature (°C) annual average at 0 m depth in the study area and location of the ANT-XXVI/2 CTD stations plotted with Ocean Data View (ODV) software version 4.5. The different oceanographic fronts are indicated as follows: Subtropical Front (STF) with a white line, Subantarctic Front (SAF) with a brown dashed line and Antactic Polar Front (PF) with a gray line, according to Orsi et al. (1995). The areas between the fronts are referred to as Subantarctic Zone (SAZ), Polar Front Zone (PFZ) and Antarctic Zone (AZ).