Continental Shelf Research 30 (2010) 1907–1923

Contents lists available at ScienceDirect

Continental Shelf Research

journal homepage: www.elsevier.com/locate/csr

Research papers

The COPAS'08 expedition to the Patagonian Shelf: Physical and environmental conditions during the 2008 coccolithophore bloom

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ARTICLE INFO

Article history:
Received 16 April 2010
Received in revised form
27 August 2010
Accepted 30 August 2010

Keywords:
Patagonian Shelf
Coccolithophore bloom
Hydrographic province

ABSTRACT

Here we present observations of the hydrography of the Patagonian Shelf, shelf break and offshore waters, with reference to the environmental conditions present during the period of peak coccolithophore abundance. Analysis of a hydrographic dataset collected in December 2008 (austral spring/summer), as part of the Coccolithophores of the Patagonian Shelf (COPAS) research cruise, identified 5 distinct surface water masses in the region between 37°S and 55°S. These water masses, identified through salinity gradients, displayed varying mixed layer depths, macronutrient inventories and chlorophyll-*a* fluorescence. Subantarctic Shelf Water (SSW), located to the north of the Falkland Islands and extending north along the shelf break, was also host to a large coccolithophore bloom. The similarities between the distribution of calcite, as seen in remote sensing data, and SSW indicate that the coccolithophore bloom encountered conditions conducive to bloom development within this water mass. Analysis of chemical and environmental data also collected during the COPAS cruise revealed that many of the commonly cited conditions for coccolithophore bloom development were present within SSW (e.g. low N:P ratio, high N:Si ratio, shallow mixed layer depth). In the other water masses present on the Patagonian Shelf greater variability in these same parameters may explain the more diffuse concentration of calcite, and the smaller size of possible coccolithophore blooms. The distribution of SSW is strongly influenced by the latitudinal variation in shelf break frontal width, which varies from 20 to 200 km, and consequently strong hydrographic controls underlie the position of the coccolithophore bloom during austral summer.

1. Introduction

The southwest corner of the Atlantic Ocean is recognised as a complex and dynamic environment where riverine, coastal, subtropical and subpolar waters interact. Within the relatively narrow region between 35–55°S and 45–65°W the general circulation of the South Atlantic's western boundary is dominated by the influences of the Falklands (Malvinas) Current, which transports cold and fresh subantarctic waters northwards, and the Brazil Current, which carries warm and saline subtropical waters southwards (Gordon, 1989; Piola and Gordon, 1989; Spadone and Provost, 2009). The collision of these two currents results in the Brazil/Falklands Confluence, a complex and energetic region of water mass interaction and mixing (Brandini et al., 2000; Oliveira et al., 2009), which ultimately results in the offshore movement of both currents between 36 and 38°S (Olson et al., 1988; Gordon, 1989; Provost et al., 1995).

To the southwest of the confluence zone lies the Patagonian Shelf, a broad continental shelf, ranging in width from ~180 km at 38°S to ~850 km at 51°S. The Patagonian Shelf contains a large marine ecosystem of significant regional and global importance (Costanza et al., 1997; Rodhouse et al., 2001; Wang et al., 2007), is recognised as a strong seasonal CO_2 sink associated with highly productive shelf waters (Bianchi et al., 2005; Schloss et al., 2007; Bianchi et al., 2009) and is thought to be one of the most productive shelf regions globally (Longhurst, 1995). The Patagonian Shelf is also known for its strong tidal regime (Glorioso and Flather, 1997; Glorioso, 2002) and for the seasonal occurrence of patches of high reflectance water that can be seen in remote sensing data that are thought to indicate extensive blooms of the coccolithophorid *Emiliania huxleyi* (Brown and Yoder, 1994; Brown and Podesta, 1997; Tyrrell and Merico, 2004). Analysis of these reflective patches via the derivation of calcite concentrations from satellite data (Gordon et al., 2001; Balch et al., 2005) reveals that they peak between November and January when incident solar irradiance reaches its annual maximum intensity and mixed layer depths shoal (Signorini et al., 2006, 2009). As with other regions where coccolithophore blooms are found (e.g. Iceland Basin) there can be significant interannual variability

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0278-4343/$ - see front matter © 2010 Elsevier Ltd. All rights reserved.
doi:10.1016/j.csr.2010.08.013

in bloom size, duration and location (Raitsos et al., 2006; Signorini et al., 2009), yet despite the apparent environmental similarities to these other regions, *in-situ* verification is limited (Gayoso, 1995; Tyrrell and Merico, 2004). Furthermore, *in-situ* studies of the planktonic community of the Patagonian Shelf break are rather less numerous than studies of the hydrographic environment (Olguin et al., 2006; Schloss et al., 2007; Garcia et al., 2008), thus presenting an incomplete picture of planktonic community structure and associated environmental controls in this region.

The hydrography of the shelf is recognised for its complexity, which results from the combined influences of continental runoff (freshwater discharges), low salinity water input from the Pacific via the Magellan Strait, the subtropical Brazil Current and the Southern Ocean influenced Falklands Current (Martos and Piccolo, 1988; Carreto et al., 1995; Bianchi et al., 2005; Perillo et al., 2005). As a consequence distinct environmental zones have been proposed, which include low salinity shelf or coastal waters ($S<33.4$), Subantarctic Shelf Water ($33.4<S<33.8$) and the Falklands Current system ($S>33.8$) (Martos and Piccolo, 1988; Carreto et al., 1995; Bianchi et al., 2005). Frontal systems separate these various environmental zones (Carreto et al., 1995; Rivas, 2006; Rivas et al., 2006) but it is the dominant shelf break front that is more widely known on account of its strong thermal and biological signatures, which feature strongly in several detailed investigations using remote sensing data (Garcia et al., 2004; Rivas et al., 2006; Romero et al., 2006; Signorini et al., 2006, 2009; Franco et al., 2008).

Despite the importance of the shelf break front as a focus for intense biological productivity, there are limited *in-situ* datasets available with which to address underlying mechanistic questions such as the role and origin of upwelling along the shelf break (Matano and Palma, 2008), or the importance of intrusions of the Falklands Current onto the Patagonian Shelf (Piola et al., 2010). Here we present hydrographic observations from the Patagonian Shelf, shelf break front and confluence region collected in December 2008 as part of the Coccolithophores of the Patagonian Shelf (COPAS) research cruise. The aims of this manuscript are to provide a detailed account of the hydrographic and environmental conditions present along the shelf during the time of peak coccolithophore abundance, to determine whether coccolithophore bloom distribution, as seen in remote sensing data, is associated with identifiable hydrographic gradients, and to investigate what environmental controls may be active at this time.

2. Methods

2.1. *In-situ sampling*

Sampling on the Patagonian Shelf was undertaken during December 2008 onboard the R/V *Roger Revelle* as part of the COPAS 2008 research cruise. The *Roger Revelle* left Montevideo, Uruguay on December 4 and arrived in Punta Arenas, Chile on January 2, 2009 having sampled 152 stations on route (Fig. 1). Stations were typically spaced ~40 km apart and, including repeated profiles, a total of 163 conductivity-temperature-depth (CTD) profiles were made during the cruise. Maximum sampling depths varied depending upon bathymetry and full depth profiles were obtained where possible over the shelf (< 200 m). In deeper waters, profiles were often restricted to the upper 1000–2000 m, although several full depth (> 5000 m) CTD casts were conducted. Water samples for a variety of analyses were collected from up to 12 depth horizons on each CTD cast with the majority of horizons located within the upper 100 m of the water column in most instances. All values of chlorophyll-*a* reported in this study were obtained with a WETLabs fluorometer (x) calibrated against *in-situ* chlorophyll-*a* (y) samples ($y=0.311x+0.2263$;

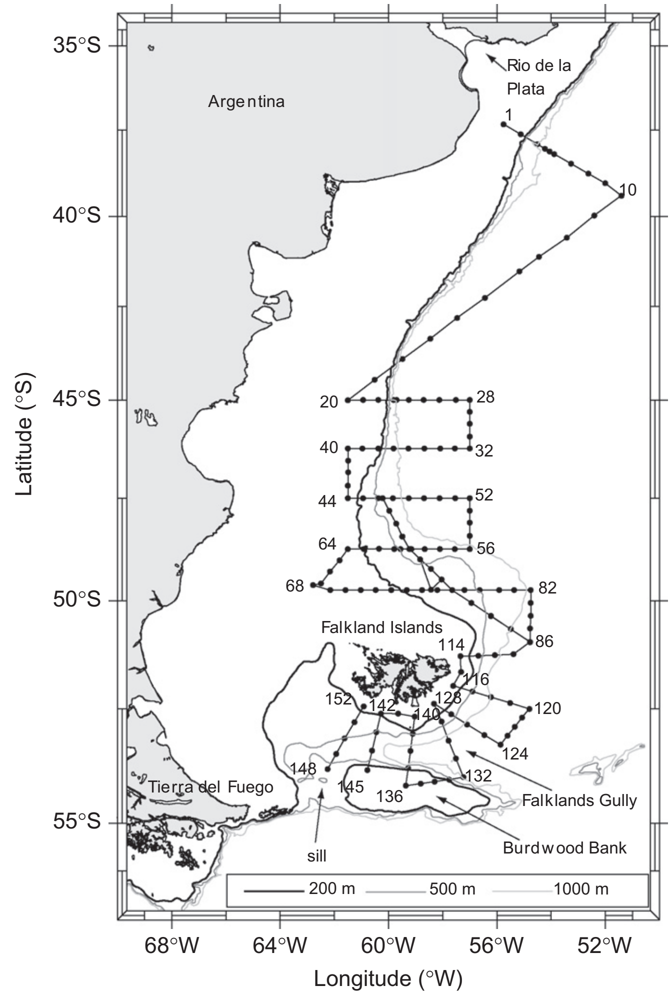

Fig. 1. Map of the Patagonian Shelf study region showing the location of CTD stations. Selected bathymetric contours and regional features are indicated.

$R^2=0.85$, $p<0.001$ ($n=57$)), which will be reported in full elsewhere (Balch, *unpublished*).

2.2. *Current measurements*

A vessel mounted RDI 150 kHz narrowband Acoustic Doppler Current Profiler (VM-ADCP) was operated continuously throughout the cruise providing ocean current information to a depth of 400 m. The instrument was configured to sample with a vertical bin resolution of 8 m and ensembles were averaged over 15 min periods. All data acquisition was accomplished with the University of Hawaii Data Acquisitions System (UHDAS) whilst processing of the data was undertaken within the framework of the Common Ocean Data Access System (CODAS) database and supplied open source processing tools (http://currents.soest.hawaii.edu/docs/adcp_doc/index.html). The duration of east–west transects to the north of the Falkland Islands was typically ~36 h whilst the north–south transects to the south of the islands were < 16 h. Consequently VM-ADCP data were detided to remove barotropic tidal oscillations following the method described by Egbert et al. (1994) and Egbert and Erofeeva (2002).

2.3. *Remote sensing observations*

Level-3 processed 4 km gridded MODIS Aqua datasets of ocean colour (chlorophyll-*a*), sea surface temperature and calcite