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ScienceDirect
Continental Shelf Research 27 (2007) 258–274
CONTINENTAL SHELF RESEARCH
www.elsevier.com/locate/csr

Identification of coccolithophore blooms in the SE Atlantic Ocean off Namibia by satellites and in-situ methods

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Received 31 January 2006; received in revised form 4 October 2006; accepted 10 October 2006
Available online 8 December 2006

Abstract

Sporadic occurrences of milky turquoise waters visible in true colour satellite imagery in the Benguela upwelling system off Namibia are characterized by high reflectances due to enhanced scattering properties. Previous opinion was that the features are due to increased reflectances by elemental sulphur (S^0) resulting from upwelling or eruptions of hydrogen sulphide-enriched waters.

In March/April 2003, a remotely sensed offshore plume was identified as a coccolithophore bloom for the first time in this region, followed by satellite imagery and intensively investigated using ship-borne measurements. Different methods were applied such as high-performance liquid chromatography (HPLC) pigment analysis, electronic disperse X-ray analysis, scanning electronic microscopy as well as spectral particle absorption and reflectance measurements. Ocean colour satellite data of the SeaWiFS and MERIS sensors were used to investigate the blooms. The SeaWiFS coccolithophore algorithm identified the bloom in March 2003. MERIS-derived spectral reflectances which were in a good agreement with in-situ measurements were used to study the occurrence of blooms in the first half of the year 2004. The observed offshore plumes can be optically divided into two groups. Far offshore the plumes are dominated by coccolithophores *Emiliania huxleyi* (Type-C) increasing the reflectance by scattering. Directly outside the active upwelling area the spectral shape of reflectance is affected by absorbing phytoplankton, but the magnitude is the result of scattering by coccolithophores and possibly diatom frustules. The coccolithophore bloom water was characterized by high calcite content, the occurrence of the marker pigment 19′-hexanoyloxyfucoxanthin as well as by a double maximum in the blue spectral range of the specific absorption of phytoplankton. The coccolithophore bloom develops as a phytoplankton succession during a low wind period in a stable stratified water body with a shallow top layer under high solar radiation with the starting conditions of low silicate and high N/P ratios. In the area off Namibia the sporadic occurrence of milky turquoise water may have two different causes. The features nearshore are due to sulphur discolouration but the further offshore plumes are caused by coccolithophores. The occurrence of coccolithophores is not as sporadic as the blooms which are visible in satellite data. These results improve the interpretation of milky turquoise water identified by ocean colour satellite data in the SE Atlantic Ocean off Namibia because they verified the occurrence of coccolithophores in that region for the first time with different methods.

Keywords: Upwelling area off Namibia; Coccolithophore bloom; Satellite remote sensing; In-situ measurements

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0278-4343/$ - see front matter
doi:10.1016/j.csr.2006.10.003

1. Introduction

The Benguela upwelling system is one of the most intense upwelling areas in the world ocean resulting in high phytoplankton production (Carr, 2002; Chapman and Shannon, 1987). Satellite-derived sea surface temperature (SST) and Ocean colour maps show strong distinct features with high spatial and temporal variability.

SST data allow the study of the intensity, the horizontal extent and the temporal variability of the upwelling processes. These transport cold and nutr ient rich intermediate water into the euphotic zone inducing a high biological production (Chapman and Shannon, 1987).

Ocean colour satellite data permit the investigation of the development of light-absorbing phytoplankton such as diatoms and dinoflagellates in terms of derived chlorophyll concentrations, but also partly show features which are caused by the strong scattering by suspended material. Weeks et al. (2004b) discuss image features arising from scattering material induced by sulphur eruptions due to the oxidation of hydrogen sulphide produced during calm conditions in the bottom water at the shelf. The trade winds generate offshore transport of surface water (Ekman offshore transport) which induces an onshore compensation current in the deeper layer towards the coast. After a low wind period and the formation of hydrogen sulphide the compensation current transports the hydrogen sulphide enriched waters towards the coast and into the surface layer. There it will be oxidized to elemental sulphur which changes the water colour to milky turquoise. This is a common interpretation of features occurring in true colour images from the Namibian waters derived from ocean colour sensors like Sea-viewing Wide Field-of-view Sensor (SeaWiFS) and Moderate Resolution Imaging Spectroradiometer (MODIS) (Weeks et al., 2004b). The formation of toxic hydrogen sulphide is an important process in the world ocean which has strong effects on the coastal ecosystem including fish and marine invertebrates populations and is therefore of special economic importance (Diaz and Rosenberg, 1995; Emeis et al., 2004). Hydrogen sulphide enters the atmosphere and has been recognized by local collaborators due to its noxious smell (pers. commun.). Therefore, the understanding of the formation of hydrogen sulphide and its transport to the coast is essential. The identification and investigation by satellite data are presently the only method to analyse the occurrence systematically (Weeks et al., 2004b; Ohde et al., 2006).

During an interdisciplinary hydro-bio-geochemical cruise with the aim of investigating the formation of hydrogen sulphide and sulphur, a reflective offshore plume was studied in detail and followed by near real-time satellite data. In-situ investigations identified a coccolithophore bloom of *Emiliania huxleyi* for the first time in front of the upwelling area off Namibia.

Weeks et al. (2004a) found turquoise discolouration further south off the coast of the Republic of South Africa which they identified as blooms of coccolithophores (see also Mitchell-Innes and Winter, 1987). These blooms have been mainly associated with sub-polar regions as the global maps by Brown and Yoder (1994) based on SeaWiFS have shown. Coccolithophores are the most productive calcifying organism on earth and play an important role in the marine carbon cycle because of their effect on carbon and carbonate content. The current state of the art of coccolithophore research, particularly of the species *Emiliania huxleyi*, is summarized in a monograph edited by Thierstein and Young (2004). The optimal growth conditions for coccolithophores are high incident solar radiation, stable stratification of the surface layer, silicate depletion, specific nutrient conditions, and reduced grazing by zooplankton. These conditions are described by several authors and summarized by Tyrrell and Merico (2004) or Rost and Riebesell (2004). For coccolithophore growth Nanninga and Tyrrell (1996) determined that the mixed layer depth must always be less than 30 m so that the developing coccolithophores remain under high solar radiation (Iglesias-Rodriguez et al., 2002). This is an advantage of *Emiliania huxleyi* which shows a lack of photo-inhibition in the PI curve (Balch et al., 1992; Nanninga and Tyrrell, 1996). *Emiliania huxleyi* is a fast growing phytoplankton which can develop well in eutrophic environments if the fastest growing diatoms are somehow excluded when the dissolved silicate has been exhausted (Humborg et al., 1997). *Emiliania huxleyi* is able to synthesize enzyme alkaline phosphotase so that they can start growing if phosphate is exhausted and use dissolved organic phosphorus (Riegman et al., 2000). The development starts during high N:P ratios but during the bloom the ratio may be highly variable (Fanning, 1992; Tyrrell and Taylor, 1996; Townsend et al., 1994).