Saharan dust-induced chlorophyll blooms in the north-west African Upwelling

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ABSTRACT

During the period 2000-2005, the atmospheric dynamic showed a significant influence on the dust inputs dynamic and, as a result, on the primary production of the northwest African Upwelling System since 2000 to 2005. In this period, the annual mean sea level pressure became higher, ranging from 1014 to 1015 mb. Mean annual zonal wind intensity became higher (from 1.1 to 1.8 m s^{-1}), while the mean annual meridional wind reduced from 6.2 to 5.3 m s^{-1}. Mean annual satellite-derived AVHRR/NOAA Sea Surface Temperature recorded in the northwest African Upwelling becomes warmer with 18.3°C to 18.8°C in Cape Ghir, and from 19.5°C to 20.3°C north Canary Islands waters. Chlorophyll data from SeaWiFS/OV-2 showed a different pattern trend. Mean annual CHL levels increased at eutrophic-like waters of Cape Ghir from 0.65 mg m^{-3} to 0.9 mg m^{-} However, data were significantly reduced from 0.59 mg m^{-3} to 0.31 mg m^{-3} in oligotrophic-like waters of the Canary Islands. Changes observed in the role of CHL during the last 6-years period could be associated to intensive dust deposition and the exceptional weather warming observed in this area since 2000. However, it is addressed to a single 7 years period and conclusions on

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possible links between dust deposition and marine biochemistry activity cannot be generalized.

INTRODUCTION

Photosynthesis in the ocean is the most important biochemical process of conversion of Inorganic Carbon (IC) into biomass (Organic Carbon, *OC*). The *OC* generated through this primary production (photosynthetic) process is transferred to the higher trophic layer in superficial waters where most marine life develops. However, the excess of unused *C* (rejected) undergoes a progressive sinking to the bottom. In the deep ocean layers, this rejected *OC* can go through two processes: it is either recycled by the heterotrophic flora and transformed into reusable IC or it stays fixed as a sedimentary stratum at the bottom [*Aristegui et al., 2003; Basterretxea G. and J. Arístegui, 2000*]. This cycle, however, requires some additional nutrients in high concentrations, mainly Nitrogen (N) and Phosphorus (P). The availability (upwelling system) or non-availability (oligotrophic oceanic waters) of any of these macronutrient elements (N and P) depends on the vertical mixing supply to upper waters or by diazotrophic Nitrogen-fixing processes.

However, the absence of other available key nutrients such as Iron (Fe) and Manganese (N) can also limit the conversion of IC into *OC*. This micronutrients limitation is associated to its extremely low solubility (nanomolar levels) and are mostly supplied in the NE Atlantic by the exogenic dust deposition events [*Prospero and Carlson, 1991; Lenes et al., 2001; Zeebe and Archer, 2005, Liu and Millero, 2005; Capone et al., 1997; Kremling and Streu, 1993*]. Thus, long-term trend changes on the concentration of these trace elements would change the primary production role in both poor oligotrophic and rich eutrophic oceanic areas. In this paper, we focus in preliminar long-term trend of geophysical and meteorological indicators in the northwest African waters during the warmest 6-years period of the century (2000-2005), and how this changes influence the dust deposition input and, for instance, the primary production role in both areas.

METHODOLOGY

Meteorological parameters, satellite images data and model dust deposition inputs were collected from january 2000 to December 2006 over the northwest African waters at two stations located at Cape Ghir (upwelling station) and north Canary Island (**Figure 1**).

Wind components at 10 m height have been obtained from the European Centre for Medium-Range Weather Forecasts (ECMWF) T511 L60 operational analysis at 00, 06, 12 and 18 UTC. The Dust REgional Atmospheric model (DREAM) was designed to simulate and/or predict the atmospheric cycle of mineral dust aerosol [*Pérez et al., 2006a, 2006b; Papayannis et al., 2007; Pérez et al., 2007*]. The model incorporates advanced parameterizations of all the major phases of the atmospheric dust cycle, such as emission, diffusion, advection and deposition. All the model components are described in *Nickovic et al. [2001].* Satellite-derived parameters were obtained during the event: Sea Surface Temperature (SST) images were supplied by the Jet Propulsion Laboratory (JPL) PODAAC Pathfinder. Satellite-derived SeaWiFS/OV-2 chlorophyll-a (CHL) images were extracted from the NASA Ocean Colour Web. Data were projected on SMI cylindrical equidistant at different ground resolutions [*Coca and Ramos, 2004*].

RESULTS AND DISCUSSION

Mean sea level pressure, AVHRR/NOAA SST and wind components obtained from the ECMWF showed the warmest 7-years period reported since 1912. From 2000 to 2006, the annual mean sea level pressure becomes higher ranging from 1014 to 1015 mb. This change on the atmospheric circulation influenced the zonal and meridional wind components dynamic. Mean annual zonal wind intensity became higher during the 7-years period (from

1.1 to 1.8 m s^{-1}). However, the mean annual meridional wind becomes lower from 6.2 to 5.3 m s^{-1}) (shown in **Figure 2**).

The increase of the east-west component of the wind together a reduction of the north trade wind component would be translated into a change of the annual flux of Saharan dust over the northwest African Upwelling system. Annual average dry flux of Saharan dust can range from 0.03 to 0.08 g m^{-2} d^{-1} or 1.7 x 10^6 tons yr^{-1} as inferred from the experimental dry deposition (Torres *et al.*, 2002). Our DREAM model derived data showed that at the north Canary Islands station, the annual dry dust deposition data reduced from 0.12 mg m^{-2} d^{-1} (2000) to 0.10 g m^{-2} d^{-1} (2006) north Canary Islands. However, in the Cape Ghir location station DREAM model derived data showed that annual dry dust deposition data increased from 0.025 mg m^{-2} d^{-1} (2000) to 0.040 mg m^{-2} d^{-1} (2006) (shown in **Figure 3**).

Mean annual satellite-derived AVHRR/NOAA SST recorded in the northwest African Upwelling becomes warmer. It ranged between 18.3ºC (2000) to 18.8ºC (2006) in the coastal eutrophic station located at Cape Ghir and from 19.5ºC (2000) to 20.3ºC (2006) in the oceanic oligotrophic station north Canary Islands waters (**Figure 4a,b**). Some authors [*Ramos et al.*, 2005] revealed that in the canarian waters, the SST ranges between 17º C in winter to 24º C in summer. However, some areas at the south of the canarian waters presented SST peaks during this period (2004) of 28.5º C, records never reported before.

Arístegui et al. [1997] and *Basterretxea and Arístegui* [2000] investigated the mean annual cycles of CHL in this area. The authors concluded that in the canarian oligrotrohic waters, values of mean annual CHL oscillated around 0.4 mg m^{-3}. However, in the rich eutrophic upwelled waters of Cape Ghir the mean annual CHL levels arised to 0.8 mg m^{-3}. As a result of the progressive increase of the SST observed in both Canary Island and Cape Ghir waters during 2000-2005, it could be expected a progressive reduction of the mean annual CHL concentration in both locations. Our CHL images from the SeaWiFS/OV-2 showed a different pattern trend. Mean annual CHL levels increased (like dry dust deposition) at Cape Ghir from 0.65 mg m^{-3} (2000) to 0.9 mg m^{-3} (2006) indicating a process of progressive eutrophization on the upwelling sector. However, in the Canary Islands waters the mean annual CHL levels becomes significantly reduced from 0.59 mg m^{-3} (2000) to 0.31 mg m^{-3} (2006) (like dry dust deposition), indicating a process of progressive tropical-like ocean landscape **(Figure 5a,b)**.

Annual fluxes changes of Saharan dust could produce a significant impact on the bigeochemical cycle of trace elements, providing a source of nutrients required for N_2-fixing diazotrophic cyanobacterial growth [Capone *et al.*, 1997; Lenes *et al.*, 2001]. Thus, *Ramos et al.*, [2005] reported in 2004 the development of an extensive and inedit bloom of the diazotrophic cyanobacterium *Trichodesmium erythraeum* Ehrenberg in the northwest African Upwelling never described before [*Hood et al.*, 2002]. The early stages of this anomalous diazotrophic event and its possible relationship to episodic Saharan dust deposition may represent the dominant source of these new CHL pool observed in the Upwelling System location. However, in oceanic oligotrophic waters the reduction of the dust fluxes observed in this work could generate a significant reduction of the CHL levels and as a direct consequence, this sector would become poorer.

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FIGURES

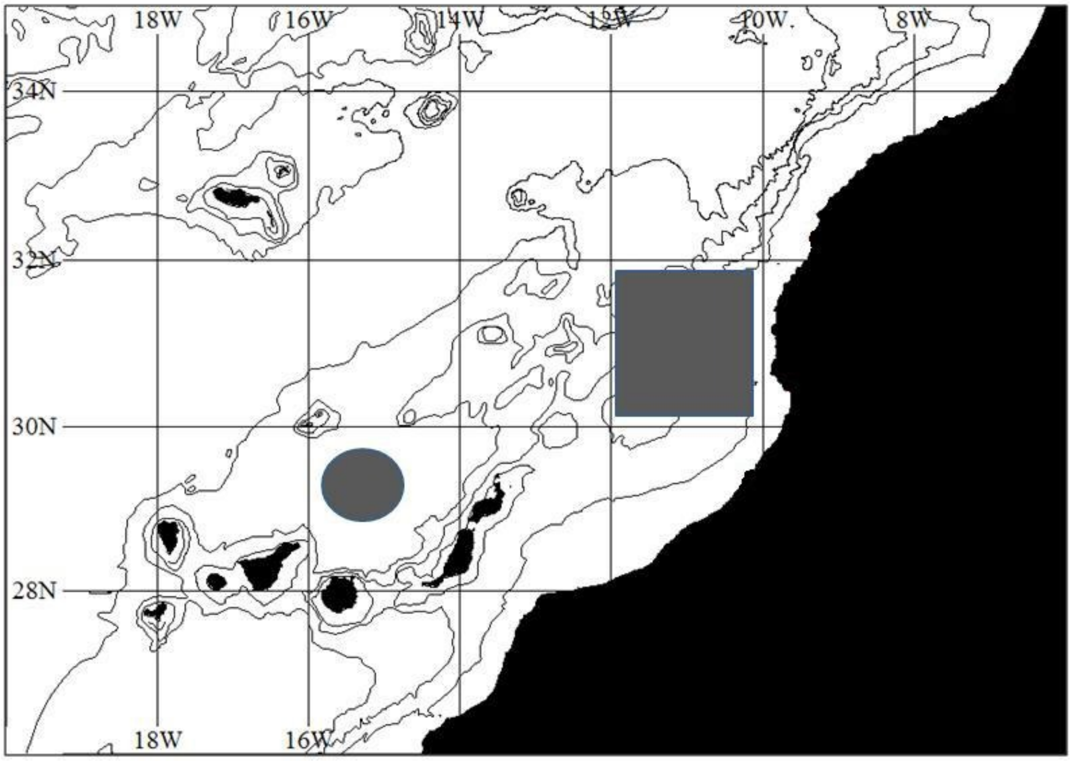

Figure 1. The northwest African Upwelling area. Data sets of dust deposition, SST and CHL were extracted from oligotrophic waters located to the north of the Canary Islands (circle box) from upwelled waters located off Cape Ghir (square box).

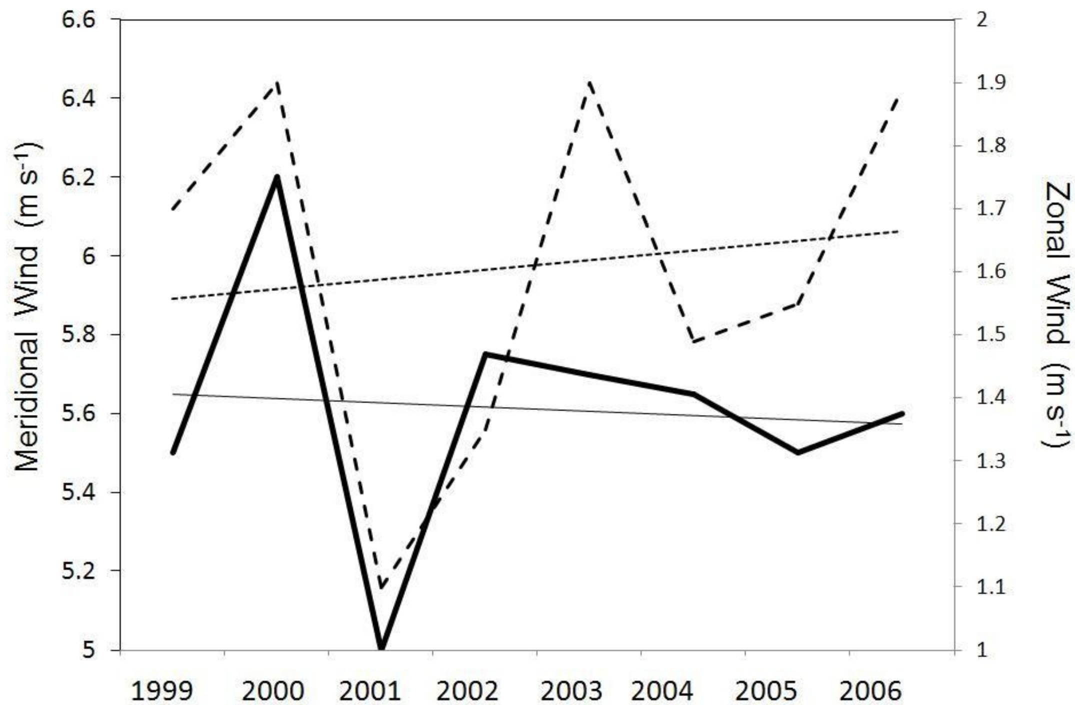

Figure 2. Annual mean meridional (solid line) and zonal (dashed line) wind speed series in the Northwest African Upwelling area from 1999 to 2006.

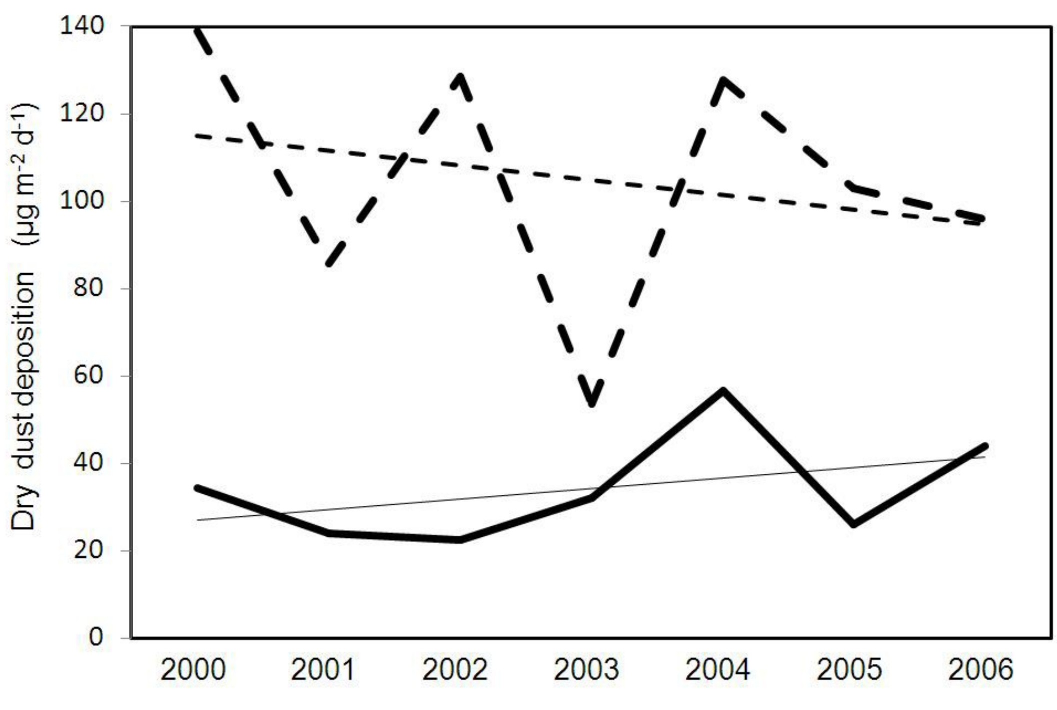

Figure 3. Annual mean DREAM-modelled dry dust deposition at Cape Ghir (solid line) and north of the Canary Islands (dashed line) from 2000 to 2006.

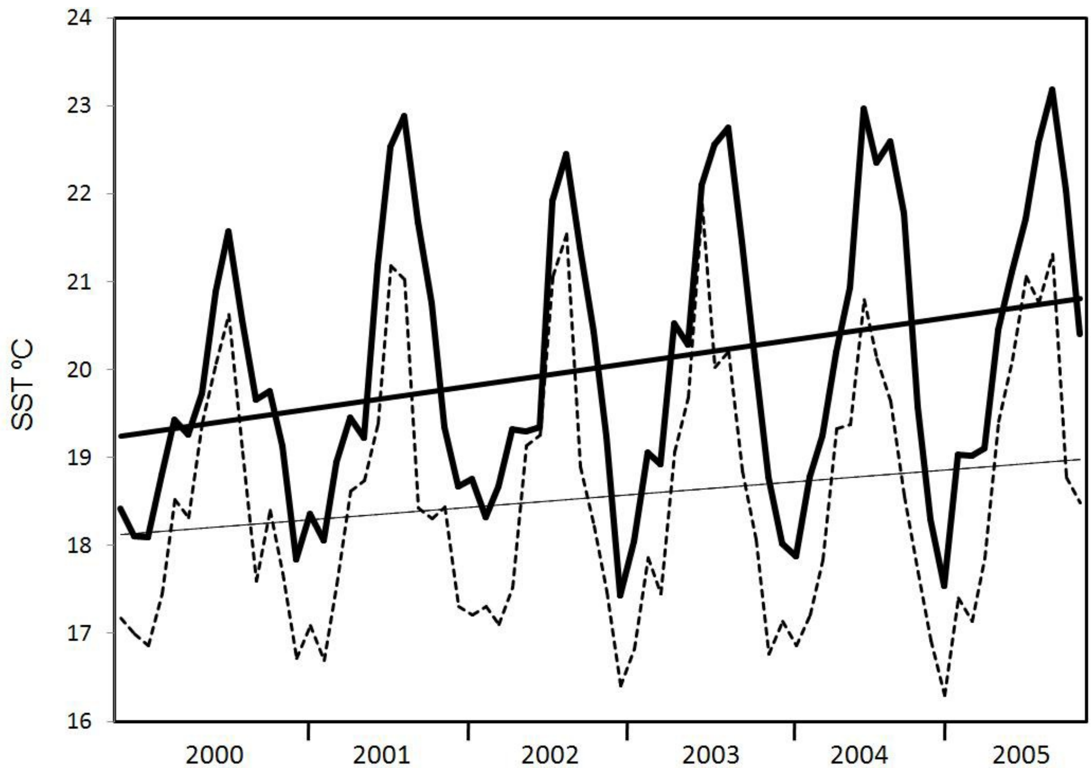

Figure 4a. Annual mean satellite-derived AVHRR/NOAA SST data series at Cape Ghir (dashed line) and north of the Canary Islands (solid line) from 2000 to 2005.

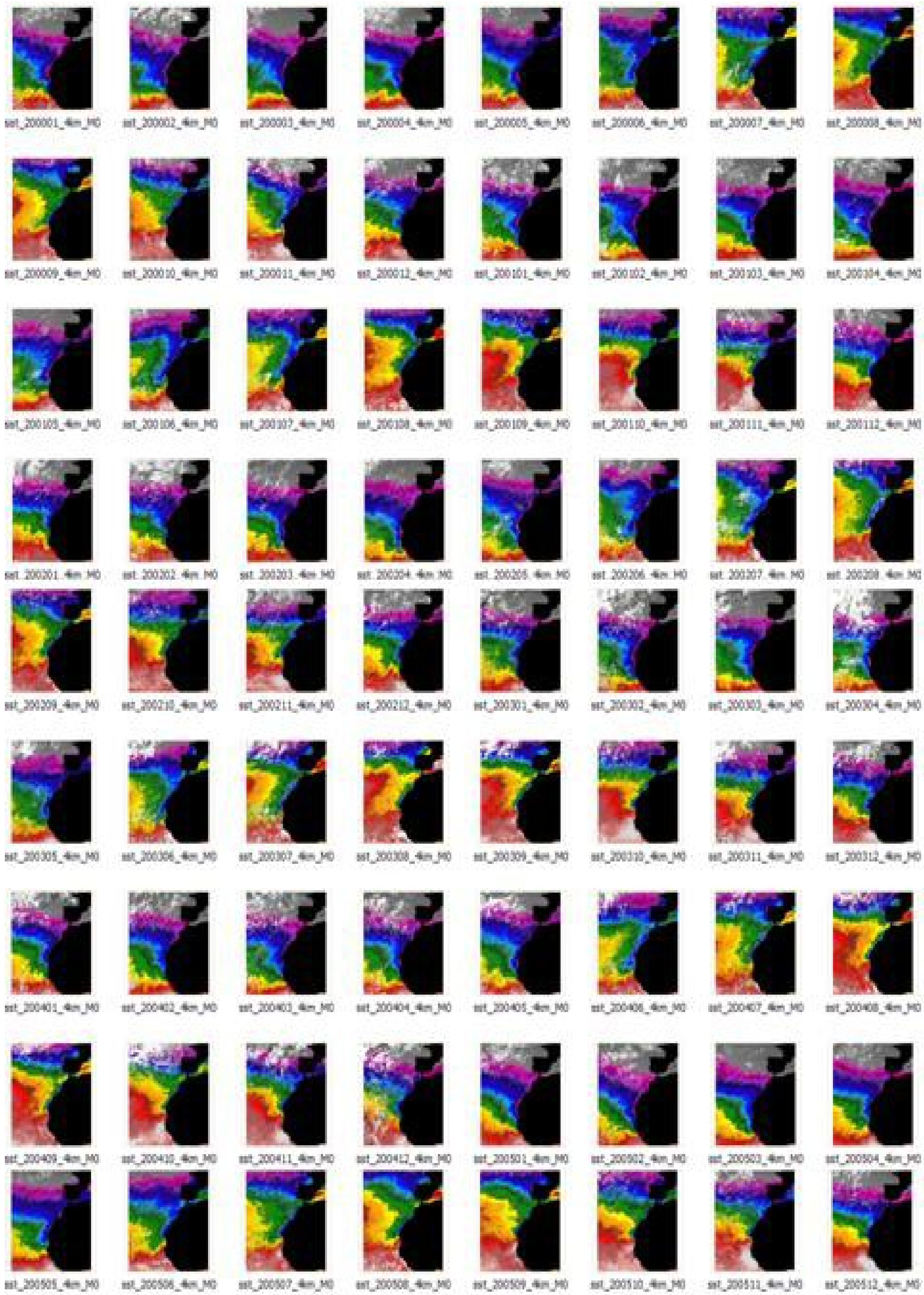

Figure 4b. Monthly mean satellite-derived AVHRR/NOAA SST images series in the NE African upwelling system from 2000 to 2005.

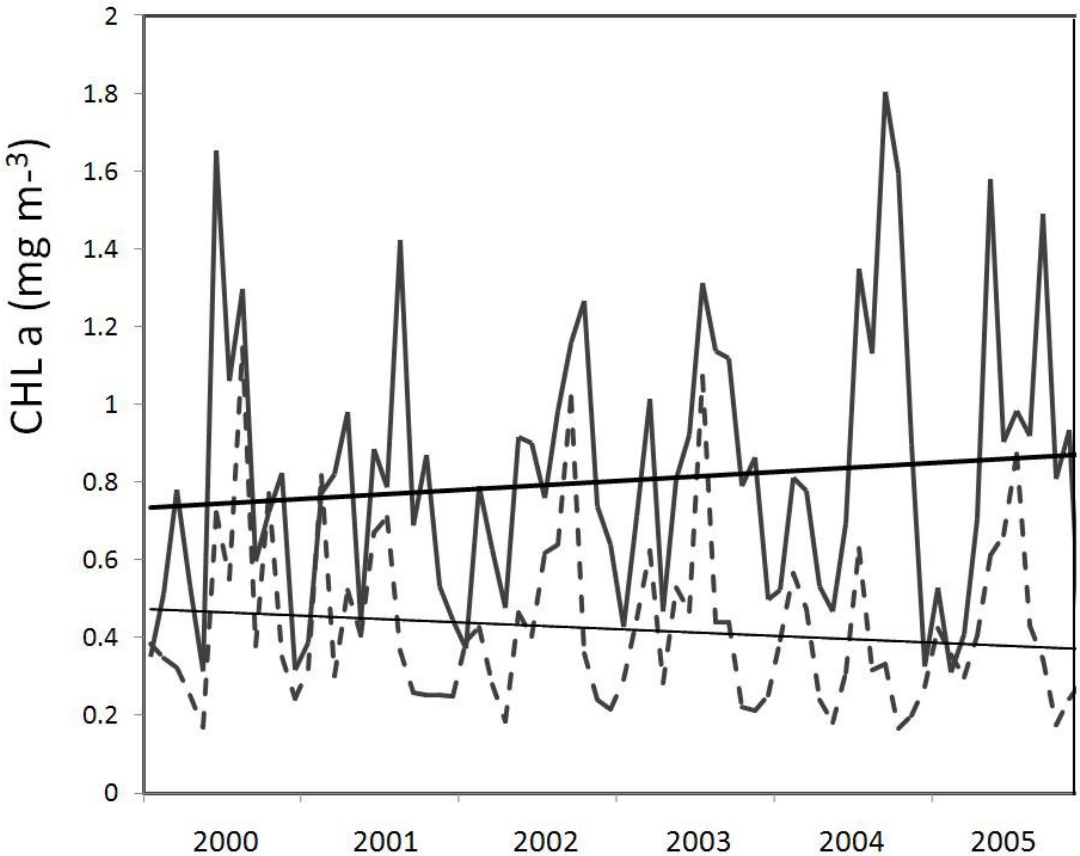

Figure 5a. Annual mean satellite-derived SeaWiFS/OV-2 CHL data series obtained at Cape Ghir (solid line) and north of the Canary Islands (dashed line) in the Northwest African Upwelling area from 2000 to 2005.

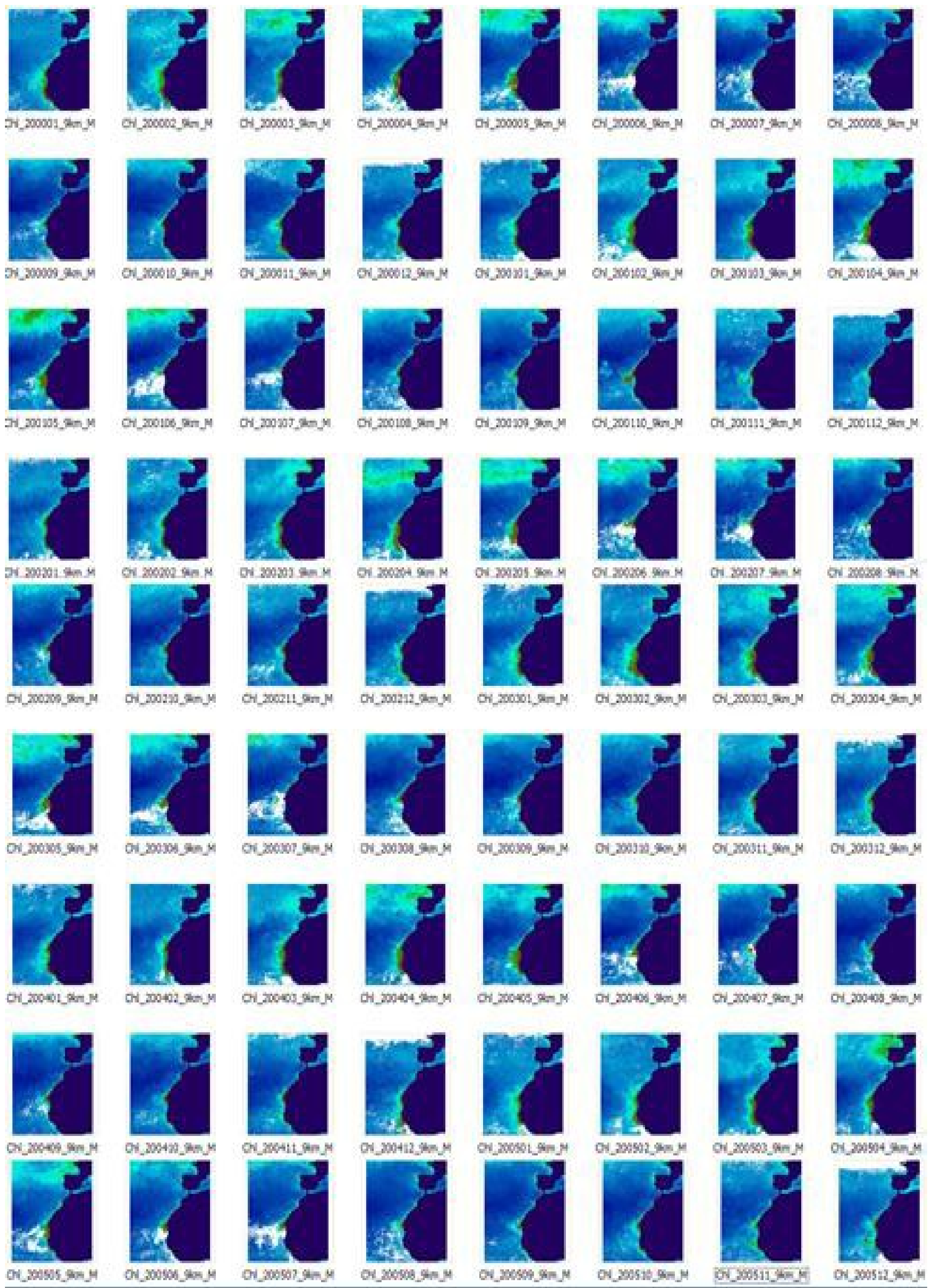

Figure 5b. Monthly mean satellite-derived SeaWiFS/OV-2 CHL images series obtained in the Northwest African Upwelling area from 2000 to 2005.