Seasonal and inter-annual variability in properties of surface water off Santander, Bay of Biscay, 1991–1995

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Abstract – The annual cycle of temperature, salinity and nutrients of surface waters (up to 100 m depth) was studied from June 1991 to December 1995 in a cross-shelf section over the continental shelf waters off Santander (southern Bay of Biscay). The time series showed that the temperature followed the expected seasonal warming and cooling pattern, which determines a seasonal process of stratification and mixing of the water column. The stratification period occurs annually between May and October in a layer of about 50 m depth from the neritic station beyond to the shelf-break. In the period between November and April the water column remained mixed. During spring and summer low salinity values were found in the surface due to continental runoff and advection from oceanic waters. In late autumn and winter, the salinity pattern was governed by an influx of salty water associated with the poleward current. As in other temperate latitudes, nitrates showed the highest values in winter throughout the water column and the lowest values at the surface during the stratified period. Wind-induced upwelling events were observed mainly in summer, which are characterised by low temperatures (< 12 °C), high salinity and nutrient concentrations. The inter-annual variability of temperature showed a warming trend in the upper layers but this sign was not found at 100 m depth. In salinity a decreasing trend was observed throughout the water column, and this feature corresponds to the relaxing of the high salinity anomaly detected in the North Atlantic at the beginning of the 1990s. Both trends were coherent in the cross-shelf section from the coast to the slope. © Elsevier, Paris

Bay of Biscay / hydrographical conditions / surface water / time series

Résumé – Variabilité saisonnière et interannuelle des caractéristiques de l'eau superficielle au large de Santander, golfe de Gascogne, de 1991 à 1995. Les cycles annuels de température, de salinité et de nutriments dans les eaux superficielles (jusquà 100 m de profondeur) ont été étudiés de juin 1991 à décembre 1995 sur une radiale traversant le plateau continental de Santander, dans le sud du golfe de Gascogne. Les séries temporelles montrent que la température suit le rythme saisonnier qui détermine la stratification et le mélange de la colonne d'eau : entre mai et octobre, stratification dans les cinquante premiers mètres, de la station néritique jusqu'à la rupture de la plate-forme ; de novembre à avril, mélange de la colonne d'eau. La salinité superficielle est faible au printemps et en été en raison du ruissellement des eaux continentales et de l'advection des eaux océaniques ; à la fin de l'automme et en hiver, la répartition des salinités est déterminée par le flux d´eau salée associé au courant dirigé vers le pôle. Les concentrations en nitrates sont, comme aux autres latitudes tempérées, maximales en hiver dans la colonne d'eau et minimales à la surface pendant la période stratifiée. Les upwellings sont observés principalement en été, avec des températures inférieures à 12 °C et des valeurs élevées de salinité et de nutriments. La variabilité interannuelle de la température indique un échauffement superficiel qui n'est plus observé à 100 m de profondeur. La salinité présente une diminution dans toute la colonne d'eau, correspondant à l'atténuation de l'anomalie de salinité élevée détectée dans le nord de l'Atlantique au début des années 90. Les deux tendances sont cohérentes le long de la radiale traversant le plateau continental, de la côte jusqu'à la pente. © Elsevier, Paris

golfe de Gascogne / hydrologie / eau superficielle / série chronologique

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1. INTRODUCTION

In the oceanic regions surrounding the Cantabrian coast of the Iberian Peninsula four water masses can be distinguished: surface water, eastern North Atlantic central water, Mediterranean overflow water and deep water [4, 9, 15]. The properties of the upper layer (up to 100 m depth), also called surface water, are closely related to the local climatological regime and coastal singularities, as well as by the circulation regime in the Bay of Biscay, as more saline waters come from the western corner of the Iberian Peninsula in winter and less saline water advects from the central eastern part of the bay in summer [6, 11, 12, 20]. These features modify the properties of the surface water and explain part of the inter-annual variability.

Local studies on the surface water characteristics of the southern coast of the Bay of Biscay are available in the literature [4, 14, 25, 26]; however, all of these restrict the study period to seasonal or single annual cycles, and none has focused on the inter-annual variability of the surface water. Only Valencia [27] has made a study of variability in a period (1986–1990) prior to our own (1991–1995) in a single shelf station in the eastern corner of the Bay of Biscay. Variations in the upper layer properties (temperature, salinity, density and nutrients) exert an important influence on a wide range of biological processes that occur in the photic layer (subsurface chlorophyll and primary production maximum, vertical fluxes of plankton to deeper waters, etc.).

The purpose of this paper is to describe the seasonal cycle and inter-annual variability of the water properties of the surface layer (up to 100 m depth) in a cross-shelf section off Santander during the period 1991–1995.

2. METHODS

The data analyses in the results were obtained in a cross-shelf section located off Santander (43° 30′ N, 3° 47′ W). Hydrographic parameters (temperature and salinity) were sampled monthly during the study period (November 1991 and December 1995) as well as nutrients from June 1991 in a transect of three stations (coastal, neritic and oceanic of 25, 110 and 855 m depth respectively) (*figure 1*). The oceanic station (station 6) was sampled from August 1992. Data from four more stations in the section were included in June 1995 to describe an upwelling event.

The hydrographic measurements of temperature and salinity were carried out using a CTD SBE 19 (Sea Bird Instruments) from the beginning of the time series to December 1994 and a CTD SBE 25 thereafter. Accuracy of the systems was better than ± 0.01 °C and ± 0.001 (S/m). Inter-comparison of both instruments was performed. Nutrients were sampled using Niskin bottles of 5 L at surface, 5, 10, 20, 30, 40 and 60 m depths. In April 1994 bottles at 75 and 100 m were added. Occasionally, salinity samples for CTD calibration were also taken. Nutrient analysis of nitrates, nitrites, ammonia, phosphates and silicates was performed in the laboratory by an Autoanalyzer Technicon AAII following Strickland and Parsons [23]. Accuracy of the nitrates was better than ± 0.1 µM. Only nitrate results as indicators of nutrient properties are presented in this paper.

Meteorological data of the historical time series (35 years) on air temperature, precipitation and winds in Santander were provided by the Centro Meteorológico de Cantabria y Asturias (Instituto Nacional de Meteorología).

3. RESULTS

The historical time series of mean air temperature in the Santander Observatory from 1961 to 1995 is shown in *figure 2*. This period corresponds to a standard statistical period in meteorology, 1961–1990, plus the sampling period (1991–1995). During the first 20 years of the series, temperature was quite constant at around 14 °C. Since 1980 there have been three warm periods with relative maximums in 1983, 1989 and 1995 when annual average temperature was 15 °C or higher. Our sampling series corresponds to the last warm period, when temperature increased with time, from 1991 at 14.3 °C, reaching an annual mean value of 15.5 °C in 1995. With respect to precipitation, the period 1991–1995 was 10 % drier than the 30-year average, whereas June and October 1992, September 1994 and from December 1994 to March 1995 were particularly wet. Concerning the number of days of easterly winds (favourable upwelling) for the period, if velocities greater than 4 $m \cdot s^{-1}$ are required, we found a very low number for the period from 1991 to 1995 compared with the meteorological series (1960–1990), with 1991 and 1995 being the largest in the series with 118 and 100 days, and those of the intermediate years being lower.

The annual cycle in temperature of station 2 (the most coastal station) is shown in *figure 3a*. Due to the shallow water column, wind and tidal forces mixed the water

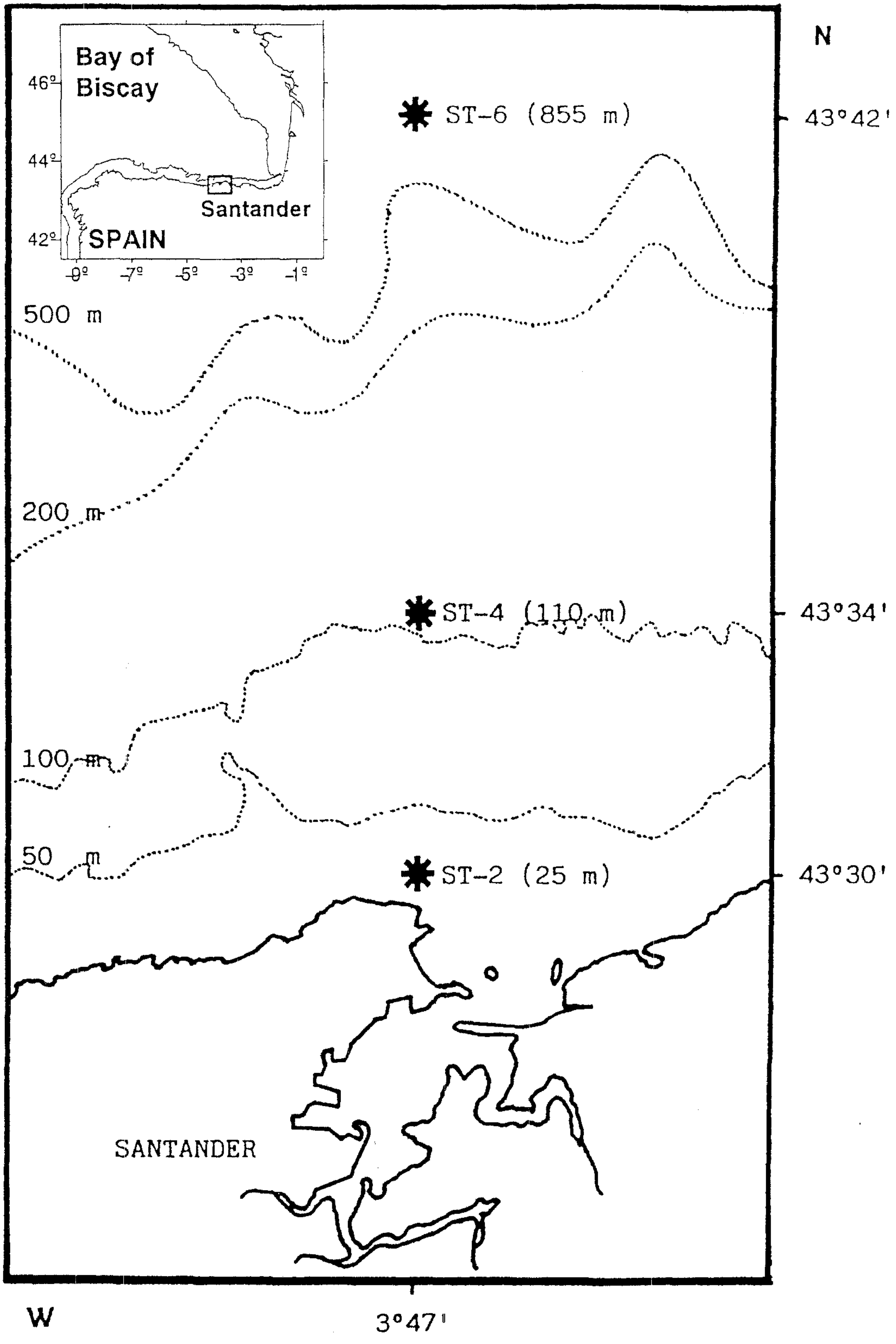

Figure 1. Location of the stations.

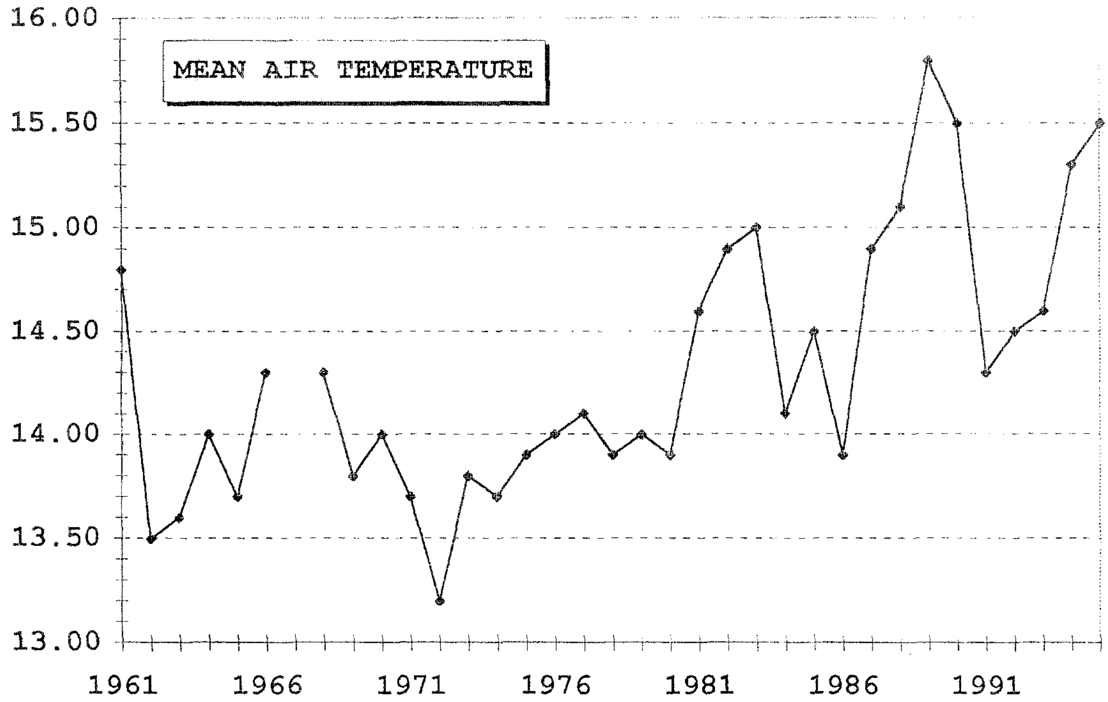

Figure 2. Mean air temperature for the period 1961–1995 (*source:* Centro Meteorológico de Cantabria y Asturias, INM).

column throughout the year and temperature stratification was rarely produced. Only when temperatures reached the annual maximum was a weak stratification observed. Lower temperatures ranged from 12 to 13 °C in winter (January–February), and higher temperatures were observed in summer (July–August) when temperature ranges varied from 18 to 21 °C. In early summer 1995 an influx of cool water was detected (11.97 °C at 24 m temperature versus an average of 16.5 °C in previous years). Winter temperatures increased through the time series from < 12 °C in 1992 to nearly 13 °C in 1995.

Figure 3b shows the salinity distribution in the time series of station 2. Signs of local climatological and hydrographical features can be observed, superimposed on the general pattern of homogeneity of the water column. Low salinity waters were detected mainly in autumn 1992, summer 1994 and winter 1995 (related to continental runoff) and high salinity waters were detected in winter 1992. The pattern of nitrates through the time series (*figure 3c*) presented high values during winter and early spring (November to March). During spring and summer (associated to biological activity) values were below 1 μM. Nevertheless, high values appeared occasionally at the bottom, in May 1992, August 1994 and June 1995, when upwelling events were detected in the outer sampling stations.

The annual cycles of temperature through the time series at station 4 (located in the central part of the shelf) are shown in *figure 4a*. As in other temperate seas, temperature followed the expected seasonal warming and cooling pattern. Stratification of the water column started in May, and maximal gradients of stratification were obtained in summer when a warmer layer up to 50 m developed over the thermocline over the shelf. In October–November the water column mixed and the values of both salinity and temperature were quite similar from the surface to 100 m depth. In late autumn, when mixing reached the bottom, temperatures were warmer than 14 °C in 1991 and 1992, between 13 and 14 °C in 1994 and 1995 and cooler than 13 °C in 1993. During the stratified period, the bottom temperature was between 12 and 12.5 °C depending on the year, and surface temperature increased progressively, reaching its highest in August (the maximal temperature observed was 21.6 °C in August 1995).

The salinity distribution shows a stratified pattern through the time series (*figure 4b*). Seasonal variability in the upper 30 m is determined by the continental runoff

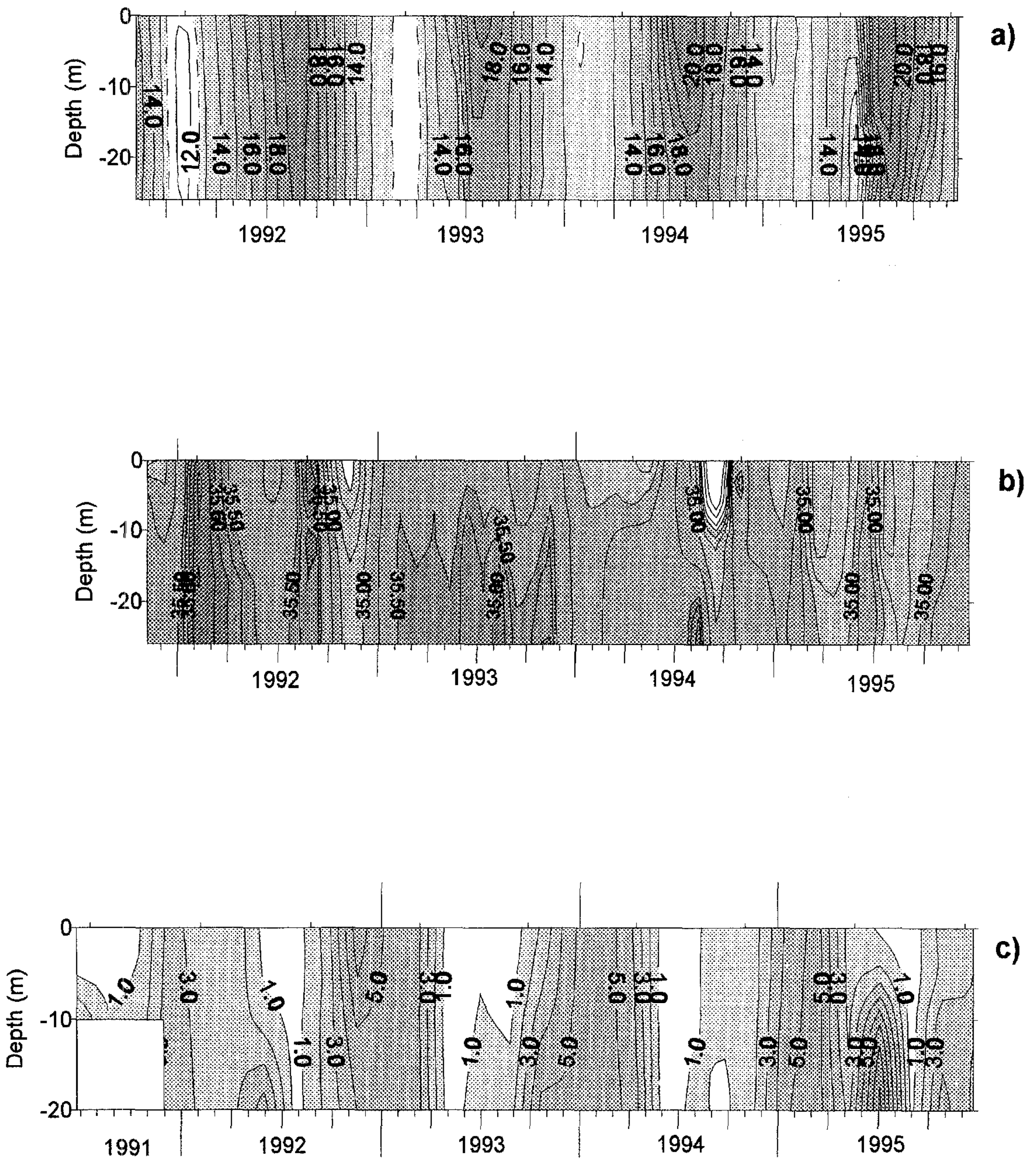

Figure 3. Distribution of (a) temperature (°C), (b) salinity and (c) nitrates (μM) at station 2.

(mainly in spring) and influx of less saline water from the central Bay of Biscay (in summer). After the mixing process an increase in salinity was detected every year below the upper 30 m to the bottom, the signal of the poleward current. High salinity values were also detected at the bottom during the stratified period and were related to upwelling events. With the exception of autumn–winter 1991–1992, high concentrations of nitrates in the mixing period alternated with low values in the upper layers and high values in the lower layers during the stratified period

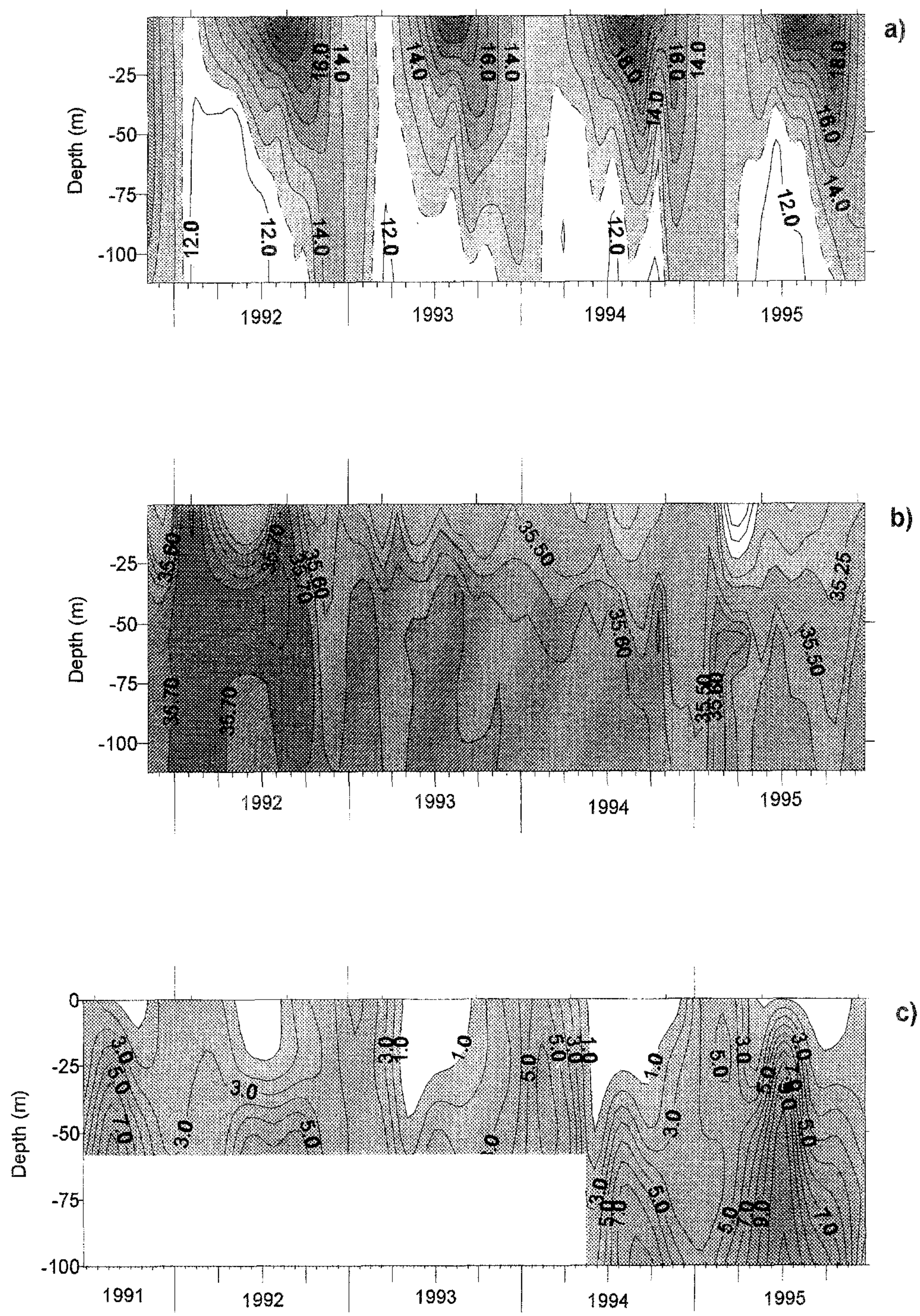

Figure 4. Distribution of (a) temperature (°C), (b) salinity and (c) nitrates (μM) at station 4.

(*figure 4c*). Upwelling processes are associated to waters enriched with nutrients, resulting in higher concentrations of nitrates at the bottom than at the surface.

At station 6 (located over the slope) the seasonal temperature cycle was similar to that of station 4 as shown in *figure 5a*, but the gradient of stratification was higher.

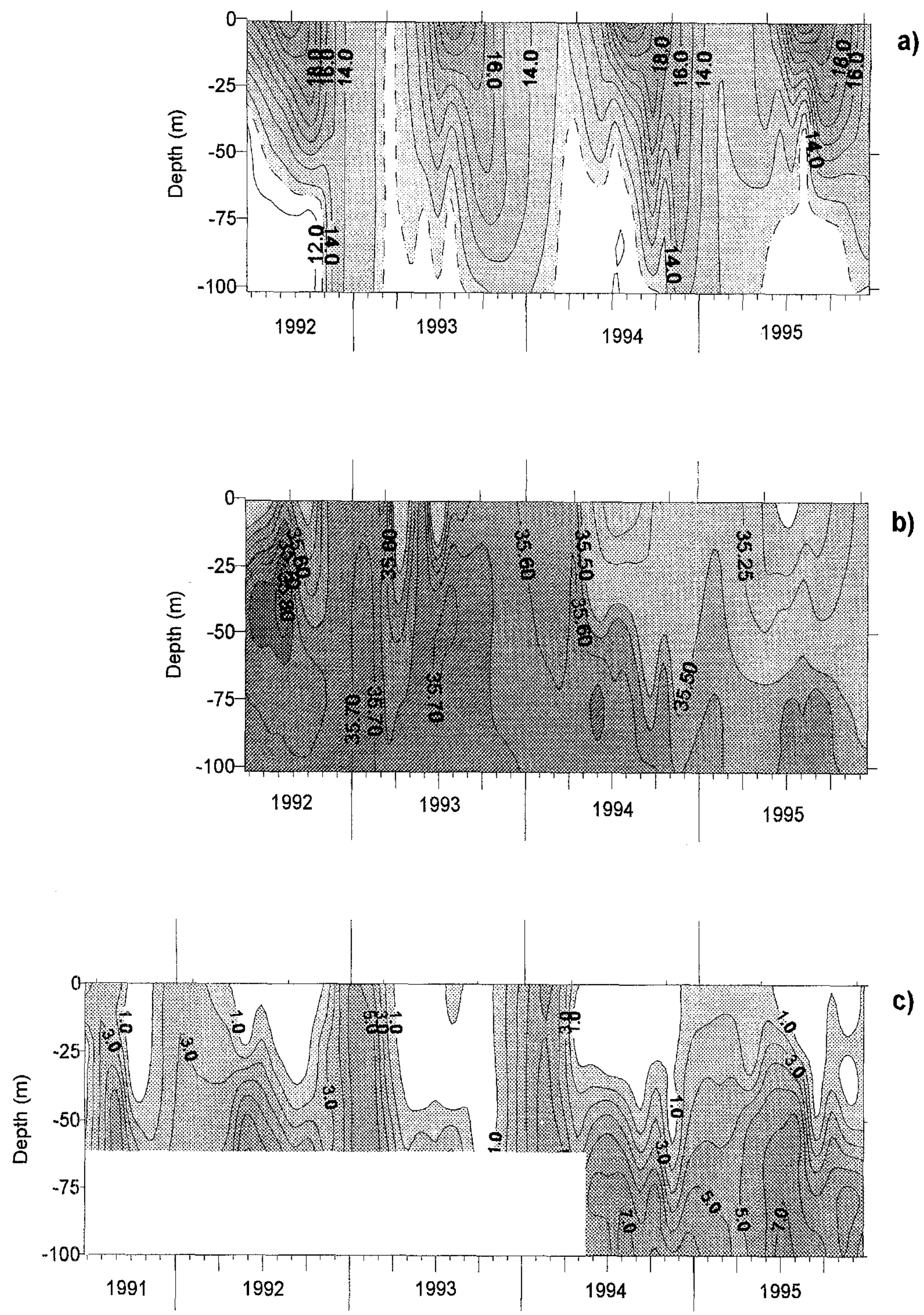

Figure 5. Distribution of (a) temperature (°C), (b) salinity and (c) nitrates (µM) at station 6.

Although the sign of upwelling was also detected, it was associated with the 12.5 °C isotherm rather than with the 12 °C isotherm as occurs in the shelf (station 4), suggesting that upwelling of subsurface water progresses from the shelf-break to the platform; thus, a weaker sign in the slope (station 6) is observed. In general, salinity

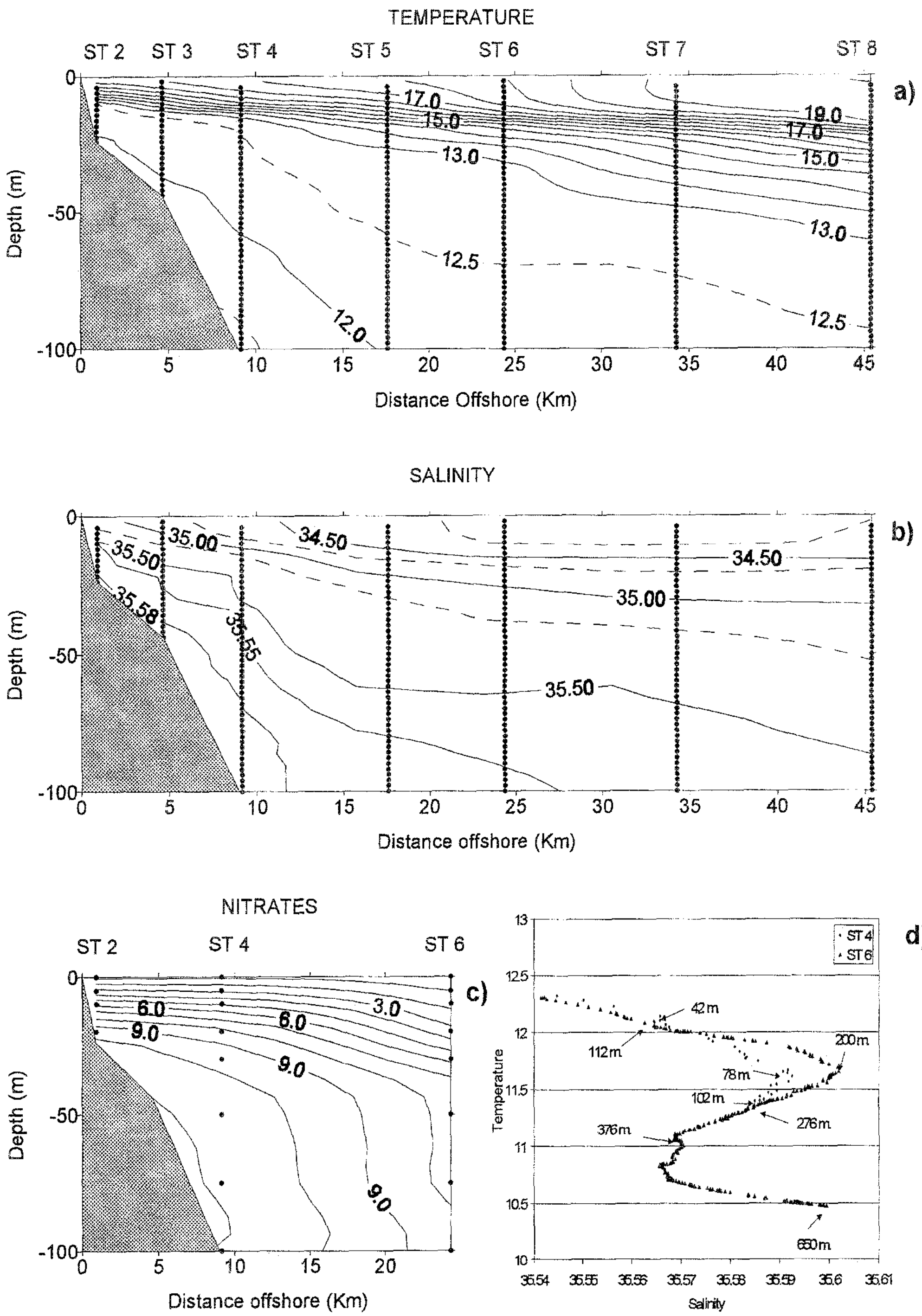

Figure 6. Sections of June 1995 of (a) temperature, (b) salinity, (c) nitrates and (d) T/S diagram of stations 4 (shelf) and 6 (shelf-break).

(*figure 5b*) was higher than at station 4 during 1992 and 1993. The salinity pattern at this station was characterised by a lower influence of continental runoff in the upper layers than in station 4 and with a stronger sign of the poleward current in winter. Nevertheless, in December 1995 a very different picture was noted when the

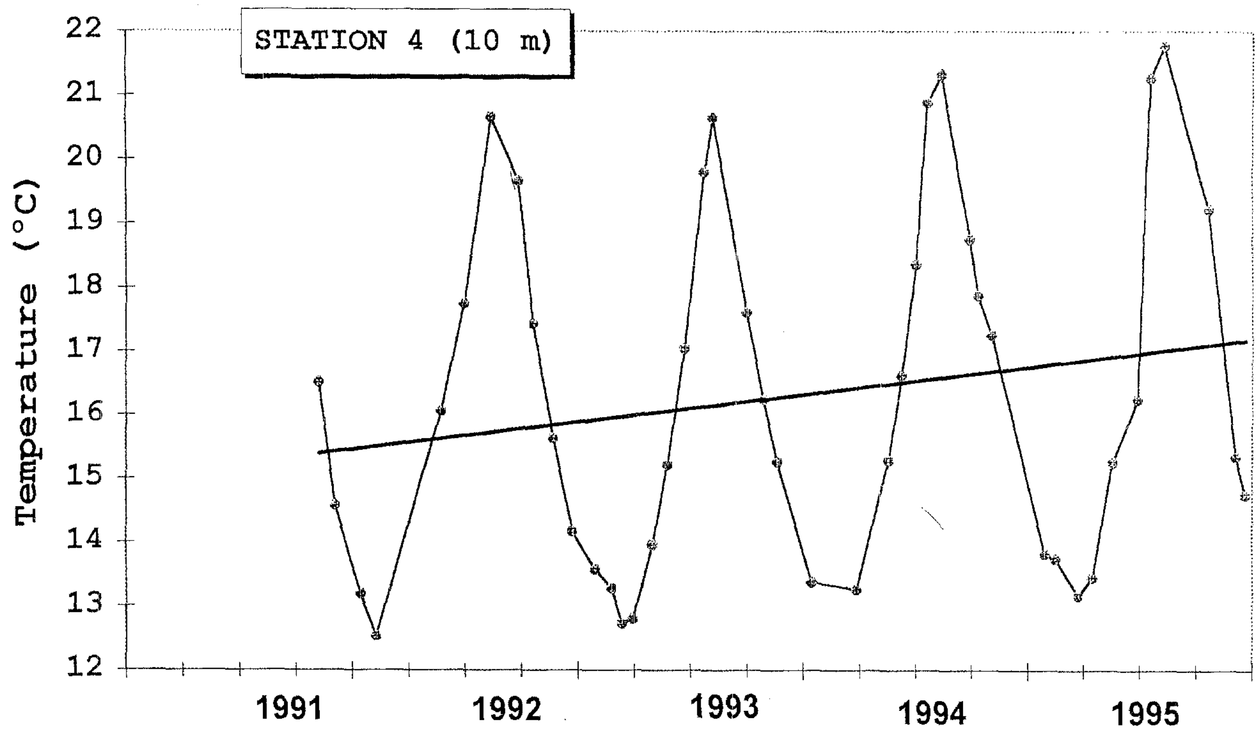

Figure 7. Temperature (°C) and trend at 10 m depth at station 4 (November 1991–December 1995).

more saline water was confined to the area over the shelf, with less saline water over the slope. Nitrate distribution (*figure 5c*) shows a similar dynamic to that of station 4, but since it is located over the shelf-break (855 m), enrichment of nitrates in the photic layer are due to advection from shallower stations (where nitrates have been upwelled from the bottom) or to remineralisation of organic matter.

4. DISCUSSION

As in other neritic areas of the southern Bay of Biscay, the annual sequence in the parameters that describe the water properties follows the seasonal cycle of temperate seas. In the data reviewed from sampling off San Sebastián, Asturias and La Coruña [4, 10, 25, 26, 27] similar patterns are noted in both seasonality and in the range of values of the different parameters.

Two of the main factors explaining part of the inter-annual variability are as follows: 1) runoff, which reduces surface salinity, the importance of which is greater in more coastal stations and whose periodicity and intensity are associated with the local climatology; and 2) intrusion of water masses advected from other areas of the bay. Among the latter, the two main hydrographical features observed in the time series were the upwelling events in summer and the inflows of the poleward current in winter.

Upwelling processes related to the eastern wind during summer, and similar to those detected off Santander, have been described in the western part of the southern Bay of Biscay [5, 16]. A good example of an upwelling event in the area was detected in the June 1995 sampling. Temperature, salinity and nitrate distribution are given in *figure 6a, b* and *c*. Data from four more stations in the section are included, and the locations of these stations in the section are also given in the figure. In June 1995 the winds were mainly easterly, the upwelling index [2] was positive throughout the month and a value of 615 $m^3 \cdot s^{-1} \cdot km^{-1}$ of coast for the monthly mean was calculated. On the sampled day (26 June), the value was 1 015 $m^3 \cdot s^{-1} \cdot km^{-1}$, and values were higher from 22 June. The subsurface waters over the shelf progressed towards the surface, the thermocline and halocline reached the surface at the inshore stations and the upwelled water

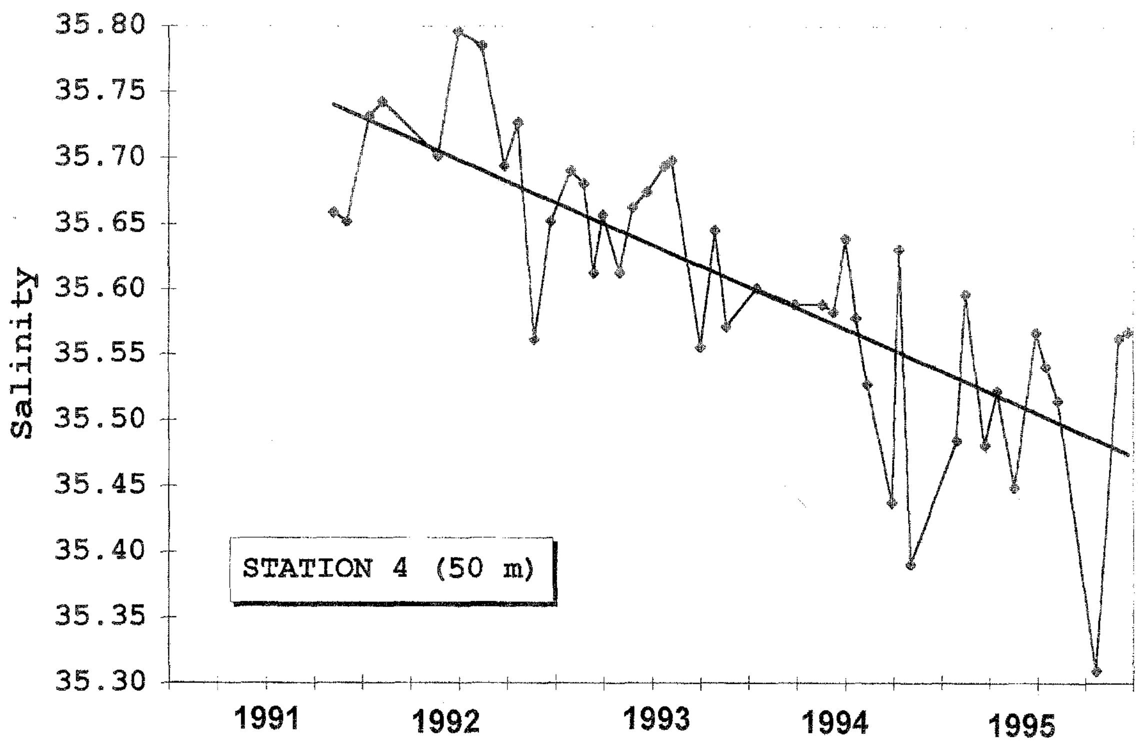

Figure 8. Salinity and trend at 50 m depth at station 4 (November 1991–December 1995).

only reached shallow layers at the inner stations, leaving the photic waters of the ocean outside its influence (beyond station 6).

Variability in nitrate concentrations during spring and summer is mainly governed by upwelling episodes. As indicated by the meteorological conditions, easterly winds were more frequent in 1995 and 1991. In spring–summer of these years concentrations at 100 m depth were higher, reaching concentrations of 9.7 µM at 20 m depth at station 4 and 3.5 µM at station 6. The year 1992 was intermediate, and in 1993 and 1994 we found water with low nitrate concentration (< 1 µM) from mid-spring to mid-autumn, deepening from surface to 30 m at station 4 and 35 or 40 m at station 6. Nitrites were low at most of the depths in the June 1995 sampling, indicating that nitrates came mainly from new production. T/S conditions at the bottom of station 4 (102 m) during the upwelling event were 11.39 °C and 35.58. To find these conditions at station 6 we would have had to reach 264 m, and 316 and 294 m at stations 7 and 8, respectively. Unfortunately, we did not have nitrate measurements at these depths. Treguer et al. [24] presented low values, but at 45° N and 7° 58' W over deep waters Fraga et al. [10] found 11.75 µM at 300 m depth, a value which is quite consistent with those measured in the present work. The T/S diagram shown in *figure 6d* presents the characteristics of stations 4 and 6. Bottom water of station 4 has similar characteristics to the upper part of the North Atlantic central water [9, 15], at *t* station 6. A time lag on the response of phytoplankton and zooplankton to any input of energy occurred [7]. The phytoplankton coupling to the inflow of nutrients due to upwelling was measured in the same sampling [17], but the response of zooplankton was not evidenced in this sampling (perhaps due to the instabilities produced or to the offshore advection of shelf waters), but a large increase in the production was observed in the following month [17].

A periodic poleward flow (warmer and saltier than the surrounding water) was recently detected over the slope of the Atlantic coast of the Iberian Peninsula [11, 12, 20]. In spite of the periodicity, this current has its own variability, [21, 22] and, in fact, the indication of this current detected through the time series was different every year, e.g. the indication was very weak in winter 1993–1994 (mainly in salinity), but quite strong in December 1995. According to Díaz del Río et al. [6], working with data from current meter measurements in the shelf-break from November 1995 to January 1996 at 6° W, eastward flow at velocities of up to 40 $cm \cdot s^{-1}$ at 75 m depth was observed, which are unusually high in this area. The warmer sign was also detected by satellite pictures [18] in December 1995. Current meter data, sea surface temperature and hydrological data all converge on the same result, the poleward current.

Even when the seasonal cycle and the main variability factors are considered, a trend remains in the values of temperature and salinity in the time series. With respect to temperature, data have been fitted at 10, 20, 50 and 100 m depth at station 4 and station 6 to study the trend of the period (for purposes of illustration, only the 10 m plot in station 4 is shown in *figure 7*). There is a tendency for temperature to increase. This rate of increase is higher in the shallow layers, and at 10 m depth the rate was 0.45 °C/year. As we go deeper the trend lessens and disappears at 100 m depth. This pattern is even more intense in the shelf-break (station 6) than over the shelf (station 4). This warming trend is consistent with the data reported in sea surface temperature at different locations of the Bay of Biscay by Koutsikopoulos et al. [13], Valencia [27] and off the Portuguese coast by Afonso et al. [1]. This observation, registered in Santander and in the Bay of Biscay, can be explained in the context of the variation of air temperatures in the area, which, as seen in the results, increased during the sampling period, and even before (from the beginning of the 1980s).

A similar analysis was performed for salinity values and a decreasing trend was found for salinity with time. This trend was found at both stations (neritic and oceanic) and throughout the water column (100 m), although intensity diminished with depth. As we have indicated, salinity is affected by advection of low salinity water because of runoff making a lot of noise in the upper layer values. To reduce variability we used 50 m to present the trend (*figure 8*). As an example, the rate of decrease in salinity at 50 m depth was quantified at 0.06/year. Ellett and Turrell [8], in the northern North Atlantic (Rockall Trough and the Faroe-Shetland Channel), reported high salinity values in late 1989 and 1990, values which were higher than at any time since the high salinity anomaly period of the late 1960s. Becker et al. [3] reported high salinity values in the English Channel southern North Sea. Pérez et al. [19] observed an abrupt increase in salinity in 1991 in the north and north-western part of the Iberian Peninsula. High salinity waters detected during winter 1991–1992 may have been due to advection of the high salinity water which was moving around the North Atlantic and reached the Bay of Biscay at that time. Valencia [27] found an increasing trend in salinity in the southern Bay of Biscay between 1986 and 1990. Taking this into consideration, the decreasing trend in salinity could correspond to the relaxed period of the high salinity anomaly detected in the North Atlantic in the late 1980s and beginning of the 1990s.

The present study reveals interesting results in the seasonal cycle of surface water, its variability factors and trends. There is a tendency for temperature to increase in the period 1991–1995, and at 10 m depth the rate of increase is of 0.45 °C/year. The trend reduces with depth and disappears at 100 m depth. The trend in salinity is the opposite. We calculated a rate of –0.06/year at 50 m depth, and the trend was found at both neritic and oceanic stations, but it diminished with depth. The increasing tendency in temperature was detected by Valencia [27] for a previous period (1986–1990), confirming the clear warming in the upper waters of the southern part of the Bay of Biscay. The tendency for salinity is justified as the passage of a high salinity anomaly around 1991 for the area. Nevertheless, because of the sampling strategy followed during this work it should be noted that some other hydrographical features, whose periodicity is of days or weeks, are missing, and with them a part of the variability. Further analysis of the data series together with satellite pictures will permit the reconstruction of the time series and the detection of most of the episodic upwelling events as well as other sources of variation such as fronts, eddies, etc., which can be linked to variability and changes in the structure of the pelagic ecosystem in the area.

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REFERENCES

[1] Alfonso Dias C., Vacas M.D., Amorin A., Sea surface temperature seasonal variations between the Iberian coast (Lisbon) and the Madeira Islands (Funchal) in the period 1981–1986, ICES C.M. (1989) C:33.

[2] Bakun A., Coastal upwelling indices, west coast of North America, 1946–71. NOAA Tech. Rep., NMFS SSRF -671, U.S. Dept. of Commerce (1973) 103 p.

[3] Becker G., Corten A., Dooley H., Recent high salinity in the English Channel/Southern North Sea, ICES C.M. (1992) C:6.

[4] Botas J.A., Fernández E., Bode A., Anadón R., Water masses off the Central Cantabrian Coast, Scient. Mar. 53 (4) (1989) 755–761.

[5] Botas J.A., Fernández E., Anadón R., A persistent upwelling off the Central Cantabrian coast (Bay of Biscay), Estuar. Coast. Shelf S. 30 (1990) 185–199.

[6] Díaz del Río G., Lavín A., Alonso J., Cabanas J.M., Moreno-Ventas X., Hydrographic variability in Bay of Biscay shelf and slope waters in spring 1994, 1995 and 1996 and relation to biological drifting material, Fish. Res. (1998) (submitted for publication).

[7] Duarte C.M., Time lag in algal growth: generality, causes and consequences, J. Plankton Res. 12 (4) (1990) 873–884.

[8] Ellett D.J., Turrell W.R., Increased salinity levels in the NE Atlantic, ICES C.M. (1992) C:20.

[9] Fraga F., Mouriño C., Manriquez M., Las masas de agua de las costas de Galicia: junio–octubre, Res. Exp. Cient. 10 (1982) 51–77.

[10] Fraga F., Mouriño C., Pérez F.F., Rios A.F., Marrasé C., Campaña GALICIA VII. Datos básicos. Datos Informativos, Inst. Inv. Pesq. (12) (1985) 50 p.

[11] Frouin R., Fiuza A., Ambar I., Boyd T., Observations of a poleward surface current off the coasts of Portugal and Spain during winter, J. Geophys. Res. 95 (C1) (1990) 679–691.

[12] Haynes R., Barton E.D., A poleward flow along the Atlantic Coast of the Iberian Peninsula, J. Geophys. Res. 95 (C7) (1990) 11425–11441.

[13] Koutsikopoulos C., Beillois P., Leroy C., Taillefer F., Temporal trends and spatial structures of the Sea Surface Temperature in the Bay of Biscay, Oceanol. Acta 21 (2) (1998) 331–340.

[14] Lavín A., Cabanas J.M., Díaz del Río G., Hydrography in N-NW Spanish coastal waters, MPH Saracus 0488 Cruise, Bol. Ins. Esp. Oceanogr. 8 (1) (1992) 41–55.

[15] Lavín A. Condiciones hidrográficas de la zona Galicia-Cantábrico Abril–Mayo 1990, Inf. Tec. Ins. Esp. Oceanogr. 109 (1992) 58 p.

[16] Molina R., Contribución al estudio del upwelling frente a la costa nordoccidental de la Peninsula Ibérica, Bol. Ins. Esp Oceanogr. (1972) 152.

[17] Moral M., Patrones de distribución espacial del mesozooplancton y su variabilidad estacional e interanual en ralación con los factores ambientales en la plataforma continental frente a Santander, Memoria IEO (1997) 106 p.

[18] Moreno-Ventas X., Lavín A., Valdés L., Hydrodinamic singularities observed by satellite imaginery in the continental margin of the Bay of Biscay, in: 2° Simposium Internacional sobre el Margen Continental Iberico Atlántico, Cádiz, 1997.

[19] Pérez F.F., Ríos A.F., King B.A., Pollard R., Decadal changes of θ-S relationship of the Eastern North Atlantic Central Water, Deep-Sea Res. 42 (11/12) (1995) 1849–1864.

[20] Pingree R.D., Le Cann B., Structure, strength and seasonality of the slope currents in the Bay of Biscay Region, J. Mar. Biol. Assoc. U.K. 70 (1990) 857–885.

[21] Pingree R.D., Le Cann B., Three anticyclonic Slope Water Oceanic eddies (SWODDIES) in the Southern Bay of Biscay in 1990, Deep-Sea Res. 39 (7/8) (1992) 1147–1175.

[22] Pingree R.D., Winter warming in the southern Bay of Biscay and Lagrangian eddy kinematics from a deep-drogued Argos Buoy, J. Mar. Biol. Assoc. 74 (1994) 107–128.

[23] Strickland J.D.H., Parsons T.R, A practical handbook of seawater analysis, Bull. Fish. Res. Bd. Canada 167 (1972) 1–310.

[24] Treguer P., Le Corre P., Grall J.R., The seasonal variations of nutrients in the upper waters of the Bay of Biscay region and their relation to phytoplankton grown, Deep-Sea Res. 26A (1979) 1121–1152.

[25] Valdés L., Alvarez-Ossorio M.T., Lavín A., Varela M., Carballo R., Ciclo anual de parámetros hidrográficos, nutrientes y plancton en la plataforma continental de La Coruña (NO, España), Bol. Ins. Esp. Oceanogr. 7 (1) (1991) 91–138.

[26] Valencia V., Motos L., Urrutia J., Estudio de la variación temporal de la hidrologia y el plancton en la zona nerítica frente a San Sebastián, Inf. Tec. Gob. Vasco 20 (1988) 81 p.

[27] Valencia V., Estudio de la variación temporal de la hidrologia y el plancton en la zona nerítica frente a San Sebastián entre 1988–1990, Inf. Tec. Gob. Vasco 52 (1993) 105 p.