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Links Between North Atlantic Sardine Recruitment And its Environment

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Abstract

The year class strength of the Iberian sardine is regulated by hydroclimatic conditions in the North Atlantic. The low recruitment values of recent years have been caused by reduction of the reproductive stock. The reproductive strategy of the sardine,with autumn and spring spawning seasons, produces two recruitment periods each year.

This reproductive strategy is adapted to the oceanographic regime in the area, with coastal upwelling between April and September, and a northerly surface coastal current in winter. Variations in the intensity and timing of the winter current affect the success of the autumn spawning and can lead to recruitment failure at the end of spring. Variations in the intensity and timing of the northerly wind component, which generates upwelling, control the success of spring spawning.

On the basis of oceanographic data and yearly recruitment from 1975 to 1997, we try to analyze the recruitment variability induced by the marine climate to the Iberian sardine stock

Introduction

Species are distributed in the sea depending on temperature, isobath, type of sea bottom, type of food, etc., so that although species coexist, each has its preferential location.

For the area ilustrated in Fig. 1, Robles, Porteiro and Cabanas (1992) describe sardine biology and its relationship with the oceanography. According to these authors, in the reproducing and feeding periods, sardine biology appears to be adapted to the conditions in the area; even when sardine is distributed throughout the area, it tends to be distributed by age class: the recruits being off the west coast, Class 1 in Portuguese waters and members of Class V and oldest in the Bay of Biscay (Porteiro *et al*, 1986, 1997).

Iberian sardine has two spawning areas, in the Portuguese coast in winter and in the Bay of Biscay in spring (García *et al*, 1988), with significant interannual variations. As regards the Galician coast, the largest abundance of eggs and larvae are found in the Artabro Gulf (La Coruña) (Solá *et al*, pers.comm.).

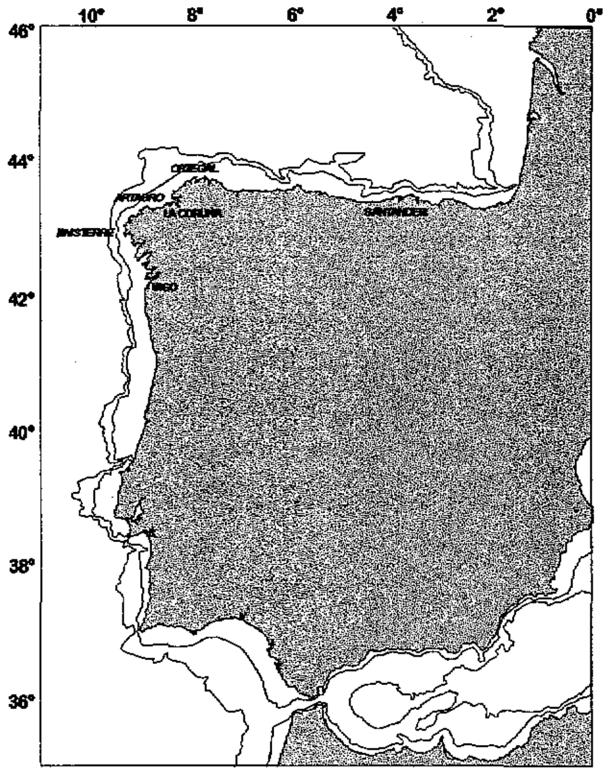

Fig. 1. Study area (200 m and 1000 m isobaths are shown)

Despite the fact that sardine has a wide area and spawning period, survival is generally low and the population is maintained thanks to the years when recruitment is high since most spawning takes place in oceanographically favourable periods, according to the optimal environmental window theory (Cury and Roy, 1987; Roy, 1994).

Temperature is the conditioning factor for spawning; in the case of sardine, this should over 13°C (Lluch-Belda et al., 1991). Along the Portuguese coast, maximum spawning occurs at temperatures of between 14°C and 16°C; in the Bay of Biscay at temperatures of between 12.5°C and 15°C (Chesney and Alonso, 1988; Solá *et al.*, 1990). Along the west coast of the Iberian peninsula, the temperature is always higher, even in winter due to the presence of warm, saline surface water from more southerly latitudes which flow northward near the coast (Frouin et al., 1990). In the Bay of Biscay, temperatures rise to 13°C in March as solar radiation increases.

In studies on the influence of the physical environment on biological communities, finding an index to globalize atmospheric and oceanographic variability would make it possible to introduce an environmental variability into the models for studying the water ecosystem. On a regional oceanic scale in the North Atlantic, the North Atlantic Oscillation Index (NAO), which measures the difference in atmospheric pressure normalized at sea level between the Azores and Iceland (Rogers, 1984), is used to relate with biotic resources; in these context Santos et al. (1998) relate the NAO variability with the dynamics of small pelagic off Portugal. This index is one of the best to reflect annual hydroclimatic variability in North Atlantic surface waters since the strength and position of the Azores anticyclone and the low pressure from Iceland during those months will largely affect the hydrodynamic conditions of the upper layer of the ocean for the rest of the year. A further index which reflects the hydroclimatic variability in the North East Atlantic is the GULF index (Taylor, 1996) which reflects the northerly latitude reached by the Gulf current.

A similar index, derived from the difference in pressures at sea level between Darwin (Australia) and Tahiti, is used for the Pacific: the SOI (Southern Oscillation Index). Correlation is low $R^2<0.25$ between the indices which reflect the climatologies of both oceans; nevertheless, when there are notable anomalies (e.g., years with a marked El Niño effect) in the Atlantic a similar anomaly with a lower intensity develops which is reflected in the biological communities.

In the Atlantic, the fact that the NAO index is high indicates that there is an easing off of polar winds from Siberia over Northern Europe and an intensification of Arctic winds over the Labrador Sea, which brings as a result an increase in westerly winds (warm and humid) in mid zones and, consequently, temperate winters in Europe. This is the opposite phenomenon to when the NAO is low (Alheith J., and Hagen, E., 1997).

Material and Methods

For the period 1976-1997, the following series are used in the analysis which follows:

- Annual sardine recruitment estimated by V.P.A. (REC).
- NAO (North Atlantic Oscillation Index) climatological indices (Hurrell, 1995) averaged on an annual basis and in periods relevant to sardine: December-March: NAO_DJFM, and March-May (spawning): NAO_MAM, and April-September (feeding). SOI (Southern Oscillation Index) (Tremberth, 1984) and GULF (northern latitude reached by the Gulf Stream) (Taylor, 1996).
- Surface temperature of sea water and air at point 43ºN 11ºW (COADS).
- Ekman transport deduced from geostrophic wind at point 43ºN 11ºW in different periods of the year chosen in terms of their influence on the non-exploited stage of the resource: October-December (TEOD), March-May (TEMA), April-September (TEAS).
- Thermohaline characterization in spring on the north-east platform of the Iberian peninsula derived from analysis of horizontal distributions of salinity and temperature at 20 and 100 m and on the 100 m isobath profile off the NW of the Iberian peninsula. Results obtained (Cabanas J.M., u.d.) with data taken in pelagic evaluation cruises. Table 1 shows the maximum and

minimum temperature and salinity levels, the presence of fronts and eddies, and trends in coastal circulation.

Climatological indices are tested to see if variations at climatological level are reflected, and the manner in which they are reflected, in the abundance and distribution of the resource.

Ekman transport is calculated for different periods in terms of its meaning as regards the biology of the species. The periods October-December (TEOD) and March-April (TEMA) are when spawning takes place; therefore, it is important to maintain larvae near the coastline. The period April-September (TEAS) is when upwelling occurs, relevant for feeding conditions in recruits and adults.

Thermohaline characterization off the NW of the peninsula (Galicia) in spring shows us the presence of relevant hydrographic structures in an important zone for the success of sardine spawning in the Bay of Biscay:

MONTH-YR		TEMP.	SALINITY	FRONT	EDDIES	CIRCULATION
04-1987	*	13.7-12.5	35.30-35.70		Artabro	
	**	13.5-12.0	35.75-35.65			ocean-coast/south-north
04-1988	*	13.1-12.4	35.60-35.60	Finisterre	Artabro	south-north
	**	12.5-12.0	35.70-35.65			
04-1990	*	14.0-13.2	35.80-35.65	Finisterre		ocean north-south
	**	13.5-12.7	35.80-35.70			north-south
04-1991	*	12.9-12.2	35.80-35.60			
	**	12.9-12.0	35.80-35.75			north-south
04-1992	*	13.1-12.2	35.85-35.80			
	**	12.6-12.2	35.80-35.75			
04-1993	*	14.1-13.0	35.90-35.70	Finisterre	Artabro	North-west coast
	**	13.3-12.6	35.85-35.75	Ortegal		
04-1994	*	13.3-12.2	35.65-35.60			south-north
	**	12.6-12.1	35.75-35.65			
04-1995	*	13.9-12.7	35.80-35.50	Finisterre	Artabro	south-north along coast
	**	13.2-12.4	35.90-35.60			north-south along slope
04-1996	*	13.9-12.5	35.85-35.60	Finisterre	Artabro	southwest-north
	**	13.5-12.5	35.80-35.65			
03-1997	*	14.7-13.5	35.80-35.65		Artabro	southwest-north.
	**	14.0-13.0	35.80-35.72			

* maximum and minimum temperature and salinity level at 20 m
** maximum and minimum temperature and salinity level at 100 m.

Table 1: Thermohaline characterization off the NW of the peninsula

Results

Explanation of stock variability due to hydroclimatological changes involves taking the following into consideration:

- The biomass of the reproducing stock. The stock-recruitment ratio in short life cycle pelagic species is low. Part of the rest of the variance in recruitment may be due to environmental factors. Variance which increases when the distribution area or environmental conditions change as regards turbulence, available food, etc.

- Thermohaline and dynamic characteristics of the water on the platform which may be globalized by an index deriving from a variable from a sufficiently long time series.

Testing the existing correlation beween the existing environmental variables and recruitment shows that there is low correlation. Table II shows the basic statistic of the most representative variables, illustrated in Fig. 2 once normalized.

Variable	N. cases	Average	Minimum	Maximum	Std. D .
REC. (xE3)	22	10650400	2201620	25563000	6264492
GULF	21	0.25	-1.51	2.26	0.97
NAO_DJFM	22	1.13	-3.88	5.07	2.23
NAO_MAM	20	0.98	-3.20	4.10	1.97
SOI_DJFM	22	-1.17	-6.18	1.9	1.87
SOI_MAM	22	-.98	-3.03	1.83	1.32
SST	19	15.3	14.9	16.0	.27
TEMA	22	-69	-511	582	294

Table II: Basic statistic of the variables

Spectral analysis of the abiotic variables reveals a significant spectral density at 3 years, coinciding with that found by Fromentin J.M. and Ibáñez, F. (1994) when analyzing climatic variables in the Bay of Biscay. Spectral density during recruitment presents a high spectral value at 4.5 years. Taking this into account, and smoothing off the series by a centred moving average (range 3), the results show significant correlations ($p<0.05$) with: the temperature of the air and water, the GULF and NAO indices for March-May and Ekman transport in March-April:

	AT	SST	NAOmam	GULF	TEMA
RECRUIT	-0.52	-0.56	-0.66	-0.78	0.55

With these variables, a multiple correlation is tested without managing to increase it significantly as these variables are intercorrelated.

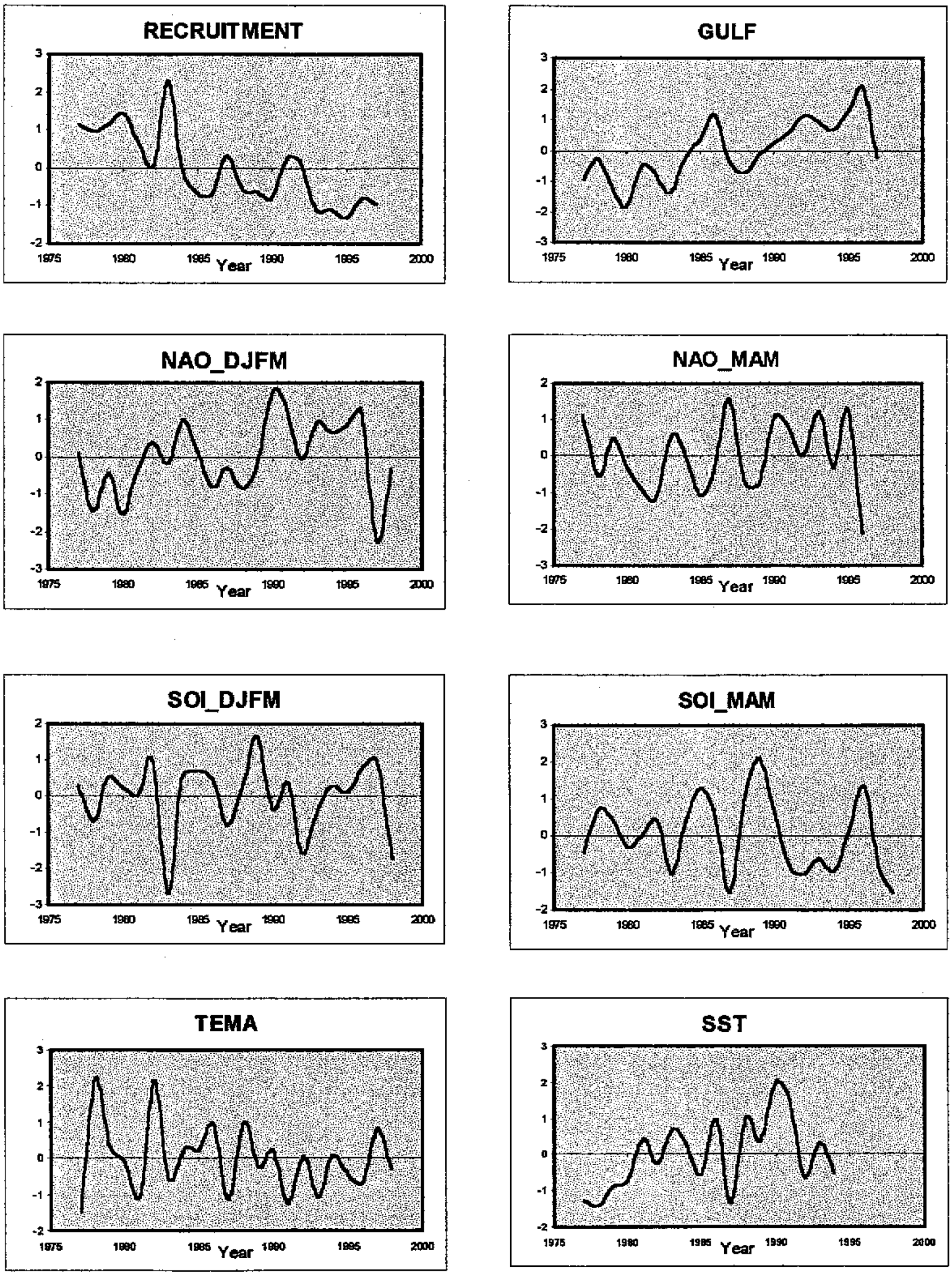

Fig. 2 Interannual variation of normalized variables

Analysis of the Principal Components (PPA) in the system gives 86% of an explanation with three components, of which the first accumulates 61%. Performing the PPA with the system comprising the variables: REC, SST, TEMA, NAO; with two factors 83% of the explanation is achieved, the first being the one most related to the variables giving 64% of the explanation. Thus, the system is quite homogenous and interrelated.

It appears that:

- The correlation between the NAO-DJFM and SOI indices is small. Likewise, the correlation between the SOI and recruitment. The SOI, however, in years with high Niño activity, is a good predictive index on recruitment. It is as if beyond a threshold of this climatic anomaly oceanographic conditions in the Atlantic (not detected by the NAO) which favour larval survival (which extend the optimal environmental window period) which is also favoured if the NAO is low.

- The negative correlation between recruitment and the NAO index is explained by the fact that it is in years with low NAO (cold winters in high latitudes) when stock concentration in mid latitudes is favoured (favourable conditions as regards temperatures and winds), while at the same time the period with favourable environmental conditions is extended (optimal environmental window).

- The positive correlation with transport towards the coast in March-April is related to the larvae remaining on the platform in the planktonic period of the same. The (small or insignificant) correlation with transport in April-September (upwelling), is more related to adult feeding. Since, however, sardine has a long spawning period, it exerts a two-fold influence: good conditions for producing food are poor for larval survival.

In spring on the platform, during the period analyzed, a rise in salinity is noted in the 1980's to 1992 (Pérez et al., 1995) when it starts to decrease and there is a gradual temperature increase in the surface waters (Lavín et al, 1996, Afonso-Dias et al, 1996) which may induce a change in habitat of the species.

Furthermore, two centres of action are observed, one to the south/southwest of Galicia, and the other to the north in the Bay of Biscay which condition the characteristics of the water on the platform. The predominance of one over the other depends on atmospheric forcing; water interchange may occur with a south-north circulation along the coast and north-south on the shelf (1995), which would also explain the trend to form whirlpools in Artabro Bay (Cabanas, u.d.). For the period 1987-1997, we may infer the years when, in spring, there are:

	YEAR					
EDDIES	1987	1988	1993	1995	1996	1997
FRONTS	1988	1990	1993	1995	1996	
S-N CIRC	1987	1988	1994	1995	1996	1997

The best recruitments occurred in 1983, 1987 and 1991. (In 1983, there were good recruitments in general throughout the Atlantic for most species), and in 1987 and 1991, there was no Finisterre/Ortegal front, which appears to be the greatest hindrance for spawning feasibility in the Bay of Biscay; the same situation occurred in 1992 and 1994, although in the latter year recruitment was very poor.

The combination of factors such as the east-west transport, the presence of fronts and the characteristics of upwelling exert an influence on larva food during their driftring stage (Lasker, 1978). Phytoplankton and microzooplankton, which are the main food for larvae, have to be in adequate concentrations to be taken advantage of, requiring environmental conditions which make a relative stability possible in the photic layer (Dickson et al., 1988). Winds of over 6 m/seg. Produce turbulence and scattering of food and the larvae so that the likelihood of survival is reduced. The "optimal environmental window" concept (Cury and Roy, 1989), is very useful for drawing together the effects of turbulence and generation/aggregation of food, as these synthesise physical and biological processes which condition larval survival.

Discussion

In the case of Atlanto-Iberian sardine, as there are two areas and two spawning seasons, the best recruitments occur when both spawnings are viable. When one fails, spawning is less; and this will depend on the oceanographic conditions in winter-spring.

The NAO index gives us an overall indication of the type of thermohaline characteristics, coastal dynamics, transport along the platform, abundance of plankton, etc.; these affect larval survival, condition recruitment, the food and the distribution area of the adults of the different species in the area. Small variations in the sequence of climatic events give very widely varying results in the distribution of adults and in annual recruitment.

Long term changes in temperature and salinity and, thus, in zonal oceanic circulation, lead to changes in the characteristics of plankton and, in general, in the pelagic trophic chain. This in turn leads to species migration and replacement by others, which changes catch yield in the species normally exploited. Robles et al (1992) found a positive correlation between recruitment and sea level indicates that in years with high sea level (due to Ekman transport towards the coast), recruitment is good. This fact coincides with the results obtained when analyzing the role of surface transport in larval survival.

Factors which influence recruitment include the NAO index, indicative of the climatic conditions in the east Atlantic, Ekman transport on the platform and water temperature, which explain 75% of the variability due to abiotic factors.

On a smaller scale, the presence of anticyclonic eddies and currents parallel to the coast help to maintain larvae and their food aggregated (areas of larval retention); areas which are generally in the vicinity of the headlands and in the Rias.

The negative correlation between recruitment and the NAO index indicates more favourable conditions for survival in low NAO situations than in the latitude of the Iberian peninsula conducive to more stable conditions in the upper layer with the presence of moderate westerly winds and, further north, periods of cooling in the surface waters, which means that sardines shift further south, thus increasing their density off the Iberian coast..

References

Alheith, J., Hagen, E., 1997. Long-term climate forcing of European herring and sardine populations. *Fish. Oceanogr.* 6(2), 130-139

Chesney, E., and Alonso, M., 1988. The role of physical oceanographic processes in the early life history of sardines, *Sardina pilchardus*, along the Galician coast of Spain. ICES Early Life History Symposium 1988, Paper nº 25

Cury, P., and Roy, C., 1989. Optimal environmental Window and pelagic fish recruitment success in upwelling areas. *Can. J. Fish. Aquat. Sci.*, 46: 670-680

Dias, C.A., Amorín, E., Das Dores Vacas, E.M., 1992.- Sea-surface temperature: seasonal variation between the Iberian coast and the Madeira islands. 1981-1987. *ICES Mar. Sci. Symp.* 195, 177-186

Dickson, R.R., Kelly, P.M., Colebrook, J.M., Wooster, W.S., Cushing, D.H., 1988. North winds and production in the eastern North Atlantic. *J. Plankton Res.* 10(1): 151-169.

Frouin ,R., Fiuza ,A., Ambar, I., Boyd, T. 1990.- Observations of a poleward surface current off the coast of Portugal and Spain during winter. Journal of Geophysical Res. 95(C1): 679-691

García, A., Franco, C., Solá, A., Alonso, M. 1988. Distribution of sardine (*Sardina pilchardus*, Walb) egg and larval abundance off the Spanish North Atlantic coast (Galician and Cantabrian areas) in April 1987. ICES CM 1988/H:27

Hurrell, J. W., 1995: Decadal trends in the North Atlantic Oscillation: Regional temperatures and precipitation. Science, 269, 676-679.

Lasker, R., 1978. The relation between oceanographic conditions and larval anchovy food in California Current: Identification of factors contributing to recruitment failure. *Rapp. P-v Reun. Cons. int. Explor. Mer.* 178: 375-387.

Lavin, A., Valdés, L., Gil, J., Moral, M. 1997. Seasonal and interannual variability in properties of surface water off Santander (Bay of Biscay) (1991-1995). *Oceanolog. Acta* (in press)

Porteiro, C., Pastor, X., Alvarez, F., Miquel, J. ,1986.- Acoustic abundance estimation of sardine (*Sardina Pilchardus*, Walb.) off Cantabrian and Galician waters. March 1986. ICES C.M. 1986/H:20

Porteiro C. And Pestana G., 1997 Atlantic Iberian sardine (*Sardina Pilchardus*, Walbaum). WD GLOBEC/SPACC W.G. Dartmouth, June 1997

Perez, F. F., Rios, A. F., Kimg, B.A., Pollard, R.T, 1995.- Decadal changes of T-S relationship of the Eastern North Atlantic Central Water. *Deep Sea Res.* 1 42(11/12), 1849-1864

Robles, R., Porteiro, C., Cabanas ,J.M., 1992.- The stock of Atlanto-Iberian sardine: possible causes of variability. *ICES Mar. Sci. Symp.* 195, 418-423

Rogers, J.C., 1984. The association between the North Atlantic oscillation and Southern Oscillation in the Northern Hemisphere. Mon.Wea. Rev. 112, 1999-2015

Santos, A.M.P., Borges, M., Pestana, G., Groom, S. 1998.- North Atlantic Oscillation (NAO) and small pelagic fish dynamics off Portugal. GLOBEC, Open Science Meeting. Paris. 17-20 March, 18 pages.

Taylor, A.H. 1996. North-south shifts of the Gulf-Stream:ocean-atmosphere interactions in the North Atlantic. Intern. Journal of Climatology, 16, 559-583

Trenberth, K.E. 1984. Signal versus Noise in the Southern Oscillation. Monthly Weather Review 112:326-332