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A relationship between the decrease in solar constant and the north-south flow in the California Current

M. G. LARRAÑETA and A. VAZQUEZ

Instituto de Investigaciones Pesqueras. Muelle de Bouzas. Vigo. Spain.

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SUMMARY: The following hypothesis is exposed: Variations of the oceanic currents depend mainly on these two factors: (a) the variation of the solar energy flux; and (b) the energy dissipated from Earth's variable rotation. In oceanic currents having an E-W direction the main factor will be polar motion, but in currents N-S this factor will be variations of the solar energy flux. Previously the authors had studied the effect of polar motion in marine ecosystems of the North Atlantic Ocean, where currents have a W-E main direction. Now an essay is carried out to test if in N-S currents the variation of the solar energy flux acts as a perceptible factor. Percent of decrease in solar constant and coefficient of variation for the first Empirical Orthogonal Function in the California Current, as an example of N-S current, have been used. Relationship between these two factors appears to be significant, and the time lag between changes of the solar energy flux and response of the current flow seems to be about 3-9 months. A seasonal variation of the velocity of the Kuroshio seems to confirm this solar energy role in oceanic currents.

RESUMEN: UNA RELACIÓN ENTRE EL DESCENSO DE LA CONSTANTE SOLAR Y EL FLUJO NORTE-SUR EN LA CORRIENTE DE CALIFORNIA. — Se expone la siguiente hipótesis: Las variaciones de las corrientes oceánicas dependen principalmente de estos dos factores: (a) la variación del flujo de la energía solar; y (b) la energía disipada de las variaciones de la rotación de la Tierra. En corrientes oceánicas con una dirección predominantemente E-O el factor principal será el movimiento polar, pero en las corrientes N-S este factor será las variaciones del flujo de la energía solar. Previamente los autores habían estudiado el efecto del movimiento polar en los ecosistemas marinos del Océano Atlántico norte, donde las corrientes tienen una dirección principal O-E. Ahora se realiza un ensayo para probar si en las corrientes N-S la variación del flujo de la energía solar actúa como un factor perceptible. Para ello se ha usado el descenso en la constante solar y el coeficiente de variación para la primera Función Ortogonal Empírica en la Corriente de California, como un ejemplo de corrientes N-S. La relación entre estas dos variables aparece como significativa, y el lapso de tiempo entre el cambio en el flujo de la energía solar y la respuesta del flujo de corriente parece ser de 3-9 meses. Una variación estacional de la velocidad del Kuroshio confirmaría este papel de la energía solar en las corrientes oceánicas.

INTRODUCTION

It has been suggested by LARRAÑETA and VÁZQUEZ (1982) that hydrographical and ecological phenomena in oceanic areas, such as that of the North Atlantic Ocean, could be related to factors of cosmic scale, the variation of the solar energy flux and variation of the Earth's rotation. In fact, changes in the current flow may be related to changes in energy input into the current oceanic system, and changes of the geographical pattern to horizontal forces, among them those of the energy dissipated from polar motion.

The two components of the Earth's rotations that would concern this matter would be polar motion and changes in the speed of rotation. Speed of rotation, or rotation rate, is measured by the length-of-day (l.o.d.); polar motion, or wobble, is the motion of the rotation axis with respect to the Earth's crust.

As a first approach it may be supposed that variation of the l.o.d. could affect to some extent the mean latitudinal position of the current. Changes in rotation rate are very small, of the order of 10^{-8} s d^{-1}. Geophysicians use the parameter m_3 to measure perturbations of rotational velocity, being

$$m_3 = (w_3 - \Omega)/\Omega$$

where w_3 is the instantaneous rotational velocity, and Ω is the mean angular velocity. Time series show decade changes in m_3 of about 4×10^{-8} in about 10 yr, or of about 10^{-7} in 30 yr (in LAMBECK, 1980).

Nevertheless, it has been suggested that periods of increasing strength of the atmospheric zonal circulation (type-I) are accompanied by periods of a rotational acceleration while periods of decreasing circulation (type-II) are accompanied by rotational deceleration. For both types of circulation the migration in latitude and changing intensities are global phenomena, occurring at all longitudes and in both hemispheres, although the trends in different regions are not always in phase. Both easterly and westerly winds increase with the type-I circulation and decrease during the type-II circulation (LAMBECK, pp. 278-279).

On the other hand, several authors, as CUSHING and DICKSON (1976) and MALMBERG and SVANSSON (1982), have related variations of westerly winds with climatic, hydrographical and ecological changes in the Northeast Atlantic Ocean.

In a previous paper (LARRAÑETA and VÁUQUEZ, 1982) a possible meaning of the polar motion in the ecology of the North Atlantic cod was examined. It was supposed that the main current crossing the Atlantic Ocean has northern-southern oscillation, amplified by a dynamic of meander, which can be graduated by Earth's crust oscillations of different annual amplitude, resulting in ecological changes in fish populations.

This theory of polar motion and solar energy being the two "first" factors of the North Atlantic ecosystems was not dismissed when LARRAÑETA and VÁZQUEZ (1982) compared principal component analysis (V_1 and V_2) of recruitment data of 18 fish stocks of the Arctic and North Atlantic Oceans, by GARROD and COLEBROOCK (1978), with variations of the polar orbit radius (R) and the percent of decrease in solar constant (ΔS_0) (Fig. 1).

The inclination of the Earth's rotation axis on the ecliptic determines the annual seasonal cycle and, with this, the annual biological cycle. Any variation of the crust position with respect to the rotation axis will be a formal cause of variation of the annual biological cycle, and admitted that ecological phenomena begin when variation o fthe biological cycles takes place, a logical relationship between astrophysical and ecological phenomena could be admitted. Ecological cycles could have their first causes in astrophysical events. This connection has been vaguely established when relating ecological periods with climatic ones, and these with sunspot cycles. Our previous paper (1982) has been a design to relate geophysical and ecological phenomena in an oceanic area. At present we try to follow this exploration.

GEOPHYSICAL FACTORS AND OCEANIC CURRENTS

According to Larrañeta and Vázquez's hypothesis for west-east currents, as it is the Gulf Stream-North Atlantic system, the greater the polar motion, the greater the meander of the system will be, and also the warm water dispersion against European coasts. So, the greater the polar motion radius, the greater the strengthening of the Norway Current will be. Supporting this theory, a significant correlation between polar motion radius and strength of year classes of the NE Arctic cod has been found (Larrañeta and Vázquez, 1982). The authors have not studied the possible effect of the l.o.d. changes on the North Atlantic and NE Arctic areas.

If the possibility that W-E oceanic currents are affected by polar motion is accepted, the question arising now will be how currents with predominant north-south direction will be affected by these geophysical prenomena.

Coming back to Figure 1, let us observe that fish stocks studied by Garrod and Colebroock belong to a predominant east-west direction current system, a general ecosystem where the first principal component has been related to variations of the polar motion radius, and the second to percent decrease in solar constant. But if the current system had a predominant north-south direction, it seems reasonable to suppose that polar motion effect had been very smooth or null because a north-south current will not act as a gyrostatic mechanism against polar motion. Therefore, it is presumable that percent decrease in solar constant will come to play the role of a first principal component.

In the dynamics of an oceanic current system, as a whole, the most important parameter will be the quantity of movement of the total body of water. The blocking action of the continents ensures that any zonal flow is matched by a return flow either nearly along the surface or at a different depth (Lambeck, 1980). So, into each unit of current system the body of water will rotate at a velocity depending on the input of solar energy, and this will specially be evident in a north-south current area, as for example the California Current.

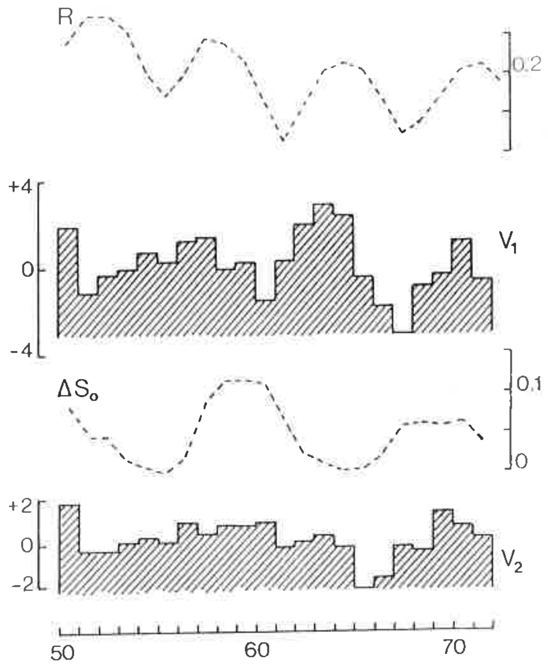

FIG. 1.—V_1 and V_2, principal components of recruitment data for 18 North Atlantic fish stocks (GARROD and COLEBROOCK, 1978). R, radius of the polar orbit. ΔS_0, percent decrease in solar constant (LARRAÑETA and VÁZQUEZ, 1982).

THE CALIFORNIA CURRENT

The variations of the zooplankton biomass of the California Current system have been recently studied by BERNAL (1979, 1981), BERNAL and McGOWAN (1981), CHELTON (1982) and CHELTON, BERNAL and McGOWAN (1982). CHELTON (1981) has also shown physical features of the California Current.

Because of their magnitude and areal extent, the periods with very high or low biomass are very important ecological events that cannot be the result of the unforced, free response of the local epipelagic ecosystem (BERNAL, 1979). During these unusual periods, changes in horizontal advection, as well as other physical processes associated with an external input of nutrients, must be acting as forcing functions for the epipelagic ecosystem (BERNAL, 1979).

Hydrographic characteristics between years of high and low biomass act as an indicator of advection of northern waters, from the subarctic and transition zones. The northern area is defined by a surface water "fresher" than 33.4 ‰. There are years showing intrusions of northern waters much farther south than the normal range.

BERNAL (1981) has found that long-period fluctuations of the zooplankton biomass are coherent with interannual changes in flow pattern occurring in the Eastern Boundary Current, and has also found that coastal upwelling is not the principal physical mechanism responsible for the input of nonregenerative nutrients into the ecosystem. BERNAL and McGOWAN (1981) have presented additional indirect evidence that fluctuations in zooplankton volume are related to changes in the transport of the California Current.

CHELTON *et al.* (1982) show the same picture. They have examined thirty years of temperature, salinity, steric height and zooplankton data to explore the potential causes of large scale biological variability in the California Current. According to these authors the physical and biological properties are all found to be dominated by a pronounced interannual signal with very large spatial scale, while wind-forced coastal upwelling of nutrient rich deep water plays a relatively minor role in controlling the large scale zooplankton biomass. Increases in the southward transport lead to increases in zooplankton biomass, while decreases in the transport result in abnormally low zooplankton biomass.

These authors have found that these large scale interannual fluctuations are in many cases related to El Niño phenomena in the eastern tropical Pacific, although occasionally there are strong events off the coast of California with no eastern tropical Pacific counterpart. The authors say they cannot find any immediate explanation for the cause of these "anomalous" events.

Summarizing, the California Current system appears to be influenced by very large scale phenomena that show oceanic features.

Projecting now our theory about oceanic ecosystems on the California Current, and taking into account that the main direction of the current system is north-south, the first principal component will be related to solar flux. To test the validity of this theory, only data of coefficients of temporal variation for the first Empirical Orthogonal Function (EOF) of dynamic height in the California Current and percent decrease in solar constant caused by sunspot blocking have been compared.

EOF data represent dominant modes of variability of the steric height field and therefore dominant patterns of flow in the California Current (BERNAL, 1981). Positive values mean strengthening of the southward flow, and vice versa.

Coefficients associated to the EOF have been calculated by D. B. CHELTON, from the Jet Propulsion Laboratory, California Institute of Technology, and used by BERNAL (1981), who has transmitted them to us. Statistically, EOF explains a 35 % of the total variance of the density field between 1950 and 1969. For these determinations, the density field has been related to 200 decibar level (BERNAL, personal communication). Data on percent decrease in solar constant were sent by J. E. EDDY, from the High Altitude Observatory, Boulder, Colorado.

RESULTS

A regression analysis of EOF on ΔS_0, using annual average values, is shown in Table 1, and it was used instead of a correlation analysis because ΔS_0 was considered not a random variable. F-test shows a significant regression at the 0.025 level when the lag between ΔS_0 and EOF data is one year. In Figure 2 annual mean values of ΔS_0 and EOF for the interval 1949-1968 are shown.

To study more in detail the time lag between input of the solar energy and velocity response in the California Current, coefficient of determination (r^2) with monthly data has been calculated, introducing lags from 0 to 27 months between ΔS_0 and EOF. At a time lag of 27 months regression becomes not significant at 0.001 level. Owing to the number of data increases with monthly values the probability levels decrease. Figure 3 shows the cross-determination functions, for time lag from 0 to 27 months. At a lag of about

TABLE 1

Regression analysis of EOF on ΔS_0, using annual mean values, in the California Current.

Lag in years	r^2	*N*	*F*
0	.192	19	4.03
1	.312	19	7.70 *
2	.174	18	3.38
3	.014	17	0.22

* Significant at the 0.025 level.

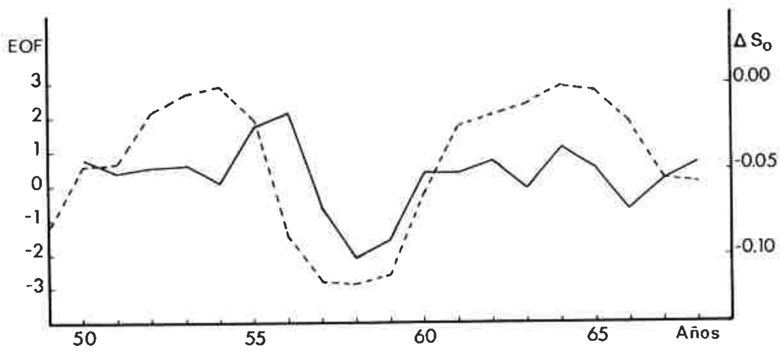

FIG. 2. — Annual mean values of ΔS_0 and EOF (solid line).

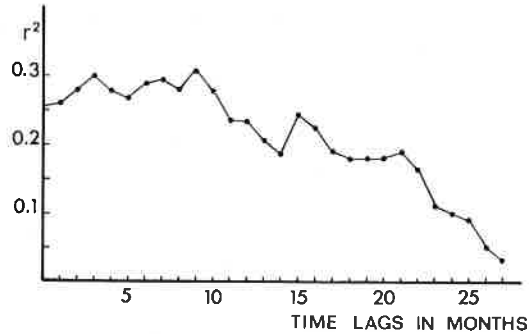

FIG. 3. — Cross-determination functions of EOF on ΔS_0; time lags in months.

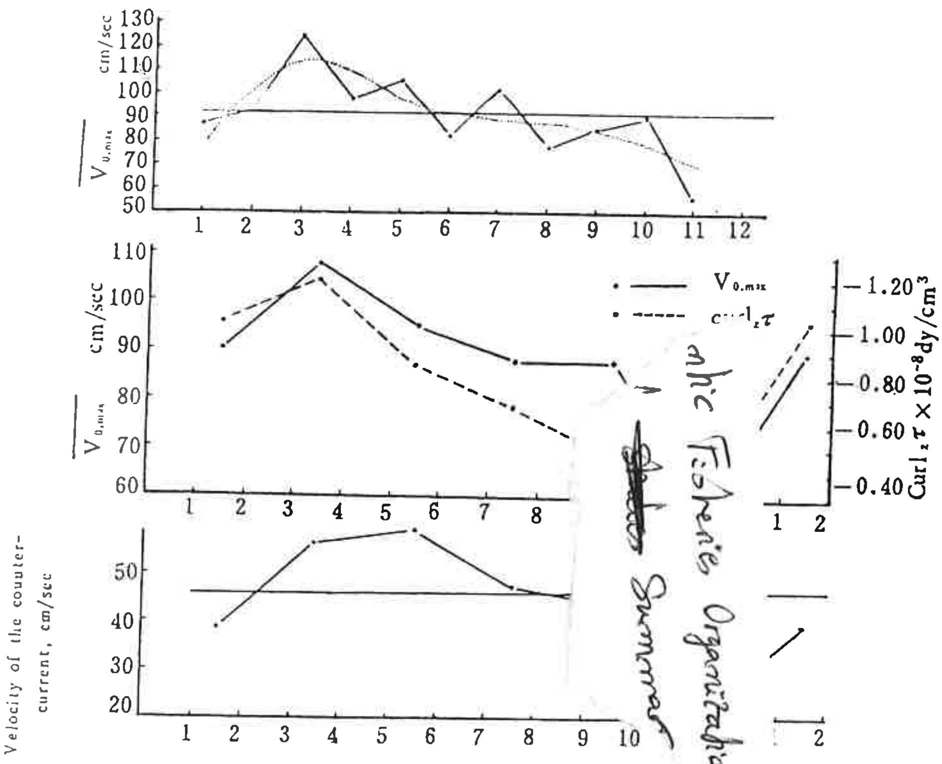

FIG. 4. — Interannual and seasonal variations of the maximu… …ice velocity of the Kuroshio and its counter-current (GUAN, 19…

9 months the coefficient of determination reaches the highest value (0.318), and afterwards a decreasing takes place. So, it seems that a time lag of 9 months, or perhaps between 3 and 9 months, is the normal lag between a solar energy input change and the California Current flow response.

Another way to prove that changes in solar energy flux will produce changes in oceanic current velocity is to show the existence of a seasonal cycle in current velocity, as "seasonal" means *solar*, because of the inclination of the Earth's rotation axis on the ecliptic.

Available EOF data for California Current have not produced any significant seasonal cycle by taking, for example, monthly average values; we think that this may be a consequence of the nature of these data because they are anomalies from monthly average field of dynamic heights.

Looking at literature, GUAN (1981) has observed a seasonal variation of the maximum surface velocity of the Kuroshio (Fig. 4). GUAN relates these variations to the wind-stress curl observed two months earlier over the Subtropical Pacific, according to the Sverdrup-relation. This relationship will of course be true, but if wind-stress curl shows a seasonal variation it will also be a solar cycle. How seasonal solar energy variations act on the dynamics of oceanic current is not a matter of this paper, but it is reasonable to suppose that winds will play some motor role by using solar energy. According to SEDYKH (1978), there is a seasonal run of the Ekman transport off the northwest African coast. Ekman transport depends on the current velocity. Here it would also seem that the currents depend on the solar energy flux.

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