AUTOMATIC MONITORING OF UPWELLING OFF THE COAST OF GALICIA (N. W. SPAIN)

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RÉSUMÉ

L'upwelling a été étudié en comparent les mesures du transport de Ekman avec les données de la temperatura superficialle de la mer, obtenue avec les satellites NOAA. Nous decrivons ici une méthode automatique pour évaluer l'upwelling en utilisant des images infrarouges succesives. Elle est basée dous une méthode qui est très utilisée pour la mesure des courants marins (2,3), blocs de glace et images. Nous calculous un vecteur déplacement pour chaque area de 32x32 points de la première carte termique (fig.3).Le vecteur est idenfiqué comme un déplacement de dans dimensions, avec le maximun dous cette area, et l'area correspondant de le seconde carte termique 64x64 points, où la correlation croissée se calcule jusqu'à un déplacement de 16 points en tous les deux axes.

ABSTRACT

The upwelling of cold benthic waters has been usually studied by comparing measurements of Ekman transport with sea surface temperature (SST) data obtained from NOAA satellites. We describe here an automatic method for evaluating the movement of upwelling fronts from successive infrared images; it is based on a method that is widely used for measuring the movement of marine currents, [2,3] pack ice[4] and clouds[5].
The solution is to calculate a displacement vector for each 32x32 pixel area of the first map (fig. 3.). This vector is identified as the two-dimensional lag giving peak cross-correlation between this 32x32 pixel area and the corresponding area of the second map (64x64 pixels, since the cross-correlation function is calculated up to a lag of ±16 on both axes).

1.- INTRODUCTION

The main objective of this paper is to calculate numerically the evolution (appearance-disappearance) of upwelling, phenomenon according to which the cold waters coming from the sea depths reach the surface bringing the adequate quantity of basic nutrients (phosphates and nitrates mainly) to set about the functioning of the food chain (1). It is for this reason that it constitutes the main sea event when, even occupying only 1% of the marine surface, it provides 50% of the fishing catches.

We consider that the best way to evaluate the growth (or the decrease) phenomenon of this event through infrared images is to measure the movement of the cold waters near the coast. To do this we have decided to use the correlation algorhythms between succesive images. These movements are not related to the marine currents associated to the Galician estuaries, for which reason they may not be measured with derivation buoys indicating temperatures, because the appearance or disappearance of upwelling does not carry away shallow waters. In our paper we will show a new simple way of evaluating the movement of waters in a particular temperature, in a quick, efficient and objective way, without the need of an operator, who could be introducing considerable mistakes for mere inspection purposes. The alghorythm will also enable us to work with very great quantities of data so that we may carry out a control of the evolution of the Iberian upwelling day by day while it lasts.

The correlation methods have been widely used to evaluate speeds of superficial currents around the Isle of New Zealand (2), by making a contrast between the results obtained from the derivation buoys. A map of currents has been elaborated using the same method in the Pacific Ocean to the East of the Vancouver Island, by correlating these currents with the winds found in the zone in the Summer of 1985 (3). Another interesting application of a different nature is the one carried out by Ninnes (5) in the study of the movement of clouds in AVHRR images.

The method has also been used to evaluate the movement of ice blocks (4), by checking the results obtained with isobaric maps from which the address and speed of the winds responsible for the movement of the ice had been extracted.

2.- IMAGES

The images with which we are going to work come from the series of satelites NOAA , and have been obtained by means of their high resolution sensor AVHRR (Avanced Very High Resolution Radiometer). As will be seen further on, the method will allow us to use images from different satellites, (as far as they present the same areas of work and have suffered the same type of geometric correlation) because it is invariant to low frequency noise . The only relevant variations will be the ones on the average grey levels in each window of the image to be processed, that is the different structures the images present; this is what we are ultimately interested in correlating.

The resuls that we are presenting in this paper are the ones obtained while processing two succesive images (August 4th and 5th, 1992). As we can see in table 1, they correspond to different satellites, but they have been obtained by means of the same type of radiometric sensor (Advanced Very High Resolution Radiometer).

3.-METHODOLOGY

3.1.-PREPROCESSING OF THE IMAGES

The images obtained from the polar satellites present a vision of the Earth which depends to a great extent on the orbit where they belong. In this way, the successive orbits always present different though overlapping vision fields. If we wish to process images of successive days (and even from different satellites), we have to attain the same projection of the region in question for all, so that the pixels with the same subindex correspond with the same portions of the Earth. For this reason the first step has been to choose a standard of interest (a zone corresponding to the West coast of Spain) and to correct the images geometrically according to an UTM projection. Thus, both of them present an identical aspect over which equal regions of the Earth can be situated in equal points. Once corrected a latitude/longitude grid may be overlapped, which will enable us to know which terrestrial coordinate we are referring to at any moment.

As our interest lies on marine areas, and with the aim of obtaining a shorter processing time, we have masked the zones corresponding to land. We have also done away with those portions of images that presented clouds. This process has been realized by means of non supervised classification algorythms (6,7) looking for the different groups of pixels with similar characteristics in two bands: band 2 of AVHRR corresponding to the visible position, and band 4 corresponding to the thermic infrared. In this way the algorythm finds a matrix with numeirc values different from cero only in those points which correspond to sea zones. This will considerably reduce the time of calculation in the images that present cloud formations or in those that include parts associated to land, either islands or continents.

3.2.-ALGORYTHM OF MAXIMUM CROSS-CORRELATION

The concept of random variable associated to an image (8) has been introduced for the first time in our paper . In the paragraph above we have chosen a standard on which we are going to work with images of successive days. Our standard is an random process, and each image obtained at a certain instant t, an random bidimentional variable associated to that process: at each point of this variable 2D a grey level n_{ij} will appear with a certain probability of appearance Pn_{ij}. All the earlier tasks ignore the existence of this associated probability, introducing an error in the probabilistic calculations (expected value, variance, correlation, etc), when they supose that all the grey levels have the same probability among themselves, and numerically the same as the reverse of the number of the possible digital levels.

This generates a new concept of image, in which the traditional concept of grey level per pixel is combined (in this case by associating the grey level with the espectral radiance received by a remote sensor) with the concept of probability of appearance. This idea is justified by the fact that in the particular case of a satellite image there exists a group of pixels that possess a higher probability of appearance than others, idea reflected by Qing X.(2) when he states in his article that it is possible to separate Land, Sea and Clouds in an image by means of thresholds through the visual inspection of the histogram.

We can clearly establish three groups of pixels with particular probabilities of appearance. In our case, once the image has been classified, we will focus our attention on the grey levels that correspond to sea, and over them we will calculate their associated probabilities, allocating value zero to all the rest. This will enable us to avoid the use of high frequency filterts commonly used (3) to do away with the noises present in images, because the probability associated to these (always with extremely high or low values) will be practically near zero.

The method we are going to describe is based on the calculation of the cross-correlation coefficient between different windows belonging to the image which we will call principal, and its displaced image (the one belonging to the following day). We will supose that the standards of upwelling have not been deformed but merely moved. We will also suppose that there have been no rotations, because the method is only sensitive to the translations according to the X or Y axis.

We define the cross-correlation coefficient of two random variables X and Y as (9):

$$\rho = \frac{\operatorname{cov}(x,y)}{\sqrt{\operatorname{var}(x)\operatorname{var}(y)}} \tag{1}$$

We will divide our image in size 32x32 cuadrants, and will be looking for similitudes in a window situated in the second image of 64x64. We will have 32x32 possible movements according to the two axis so that the position of the calculated peak p will indicate which the movement suffered by the upwelling is. If we note the cuadrant in the first image by f(x,y), and the moved cuadrant by $g(x+\varepsilon,y+\eta)$, the amount (ε,η), ec.1 will become,

$$\rho(\varepsilon,\eta) = \frac{\operatorname{cov}(f(x,y),g(x+\varepsilon,y+\eta))}{\sqrt{\operatorname{var}[f(x,y)]\operatorname{var}[g(x+\varepsilon,y+\eta]}} \tag{2}$$

where,

$$\operatorname{VAR}[f(x,y)] = \frac{1}{R}\iint\left(f(x,y)-\bar{f}\right)P_{f(x,y)}\,dx\,dy \tag{3}$$

$\bar{f}$, is the expected value in the window as we call it in stadistics:

$$\bar{f} = E[f(x,y)] = \frac{1}{R}\iint f(x,y)P_{f(x,y)}\,dx\,dy \tag{4}$$

$$\begin{aligned}\operatorname{var}[g(x+\varepsilon,y+\eta)] = \frac{1}{R}\iint(\,&g(x+\varepsilon,y+\eta)-\\ &-\bar{g}(\varepsilon,\eta)\,)P_{g(x+\varepsilon,y+\eta)}\,dx\,dy\end{aligned} \tag{5}$$

$$\bar{g}(\varepsilon,\eta) = \frac{1}{R}\iint g(x+\varepsilon,y+\eta)P_{g(x+\varepsilon,y+\eta)}\,dx\,dy \tag{6}$$

As we have already calculated the expected values in both windows, we use the ecuation (6) to calculate the

$$\begin{aligned}&\operatorname{cov}[f(x,y),g(x+\varepsilon,y+\eta)] =\\ &= E[f(x,y)\cdot g(x+\varepsilon,y+\eta)] -\\ &-E[f(x,y)]\cdot E[g(x+\varepsilon,y+\eta)]\end{aligned} \tag{7}$$

co-variance between both functions:

$$\begin{aligned}&E[f(x,y)\cdot g(x+\varepsilon,y+\eta)] =\\ &= \frac{1}{R}\iint f(x,y)\cdot g(x+\varepsilon,y+\eta)\cdot Pc_{f,g}\,dx\,dy\end{aligned} \tag{8}$$

The concept of *overall or conditional probability* appears here associated to the random variables, Pc_{fg} which is the probability that once the grey level f(s,y) has appeared in the first image, we will obtain the level $g(x+\varepsilon,y+\eta)$ in the second one, which is defined as:

$$Pc_{f,g} = \lim_{n\to\infty}\frac{n_{12}}{n_1+n_{12}} \tag{9}$$

where n is the number of points in the image, n_1 the number of times that the level of grey f(x,y)has appeared in the first image and n_{12} the number of occasions on which, once f(xy) has already appeared in the first image, we obtain $g(x+\varepsilon,y+\eta)$ in the second.

The maximum $\rho(\varepsilon,\eta)$ found once we have moved our window will give us the position of the upwellining in the new image. As we know the resolution (Km./pixel) of our images (1,1km.) we can know how much the event we are analyzing has increased or decreased.

4.- RESULTS

We have processed two images corresponding to the Coasts of Galicia, the Spanish region situated in the far west which we can center at 43ºN, (Fig 1 and 2). The images have been corrected geometrically and present a grid that indicates the latitude/longitud of each point, as well as an edge that encloses the part corresponding to the land. Upwellings always appear on the West Coast of the continents and Iberian upwelling in particular has its main intensity around the Finisterre Cape (10) (Cape situated further west in figures 1 and 2), so that the area of interest is completely clear of clouds and can be thoroughly processed.

These images were taken with two different satellites, figure 1 corresponding to channel 4 (10.5-11.5 microns, thermic infrared) in the polar satellite NOAA-10, while figure 2 corresponds to channel 4 in NOAA-11. As we can see in the image histograms, fig. 4, the levels of grey corresponding to the sea (second peak) are situated between different bands, figure 1 situating its peak in 400 and figure 2 around 450. This will not prove to be a problem because in the calculation of variance, ec.3 and 5, we are only interested in variations above average. As we can see in the figures 1 and 2 the thermic structures are manifested. We have preferred to work directly over the levels of grey, which present a greater variability than the temperatures associated to them, which move along a band of 3ºC. in the areas of interest.

We have also chosen this method to compute the Mcc over the first derivative, because it introduces a lot of noise in images that do not present great variations of temperature as in our case. However, we have seen that for the control of thermal fronts, which present strong thermic gradients in their proximities, it does have good results.

In the result figure 3 we have marked the centre of the window to be treated with a white point, and with a red arrow with a yellow end we have marked the movement found for that particular window, that is, the offset (ε,η) which presents the maximum cross-correlation found in the second window. As the algorythm ifinds the image covering the land and the clouds, it does not calculate the MCC in windows where the mask occupies more than its 5%, leaving only the white point over the figure. This is the case where all the window falls onto the land, or even when the centre falls onto the sea it is very close to the coast.

Figures 1 and 2 are thermic images, and following conventional notations, the darker levels represent warmer areas than the lighter levels. By following this notation we can see that as we get nearer the coast, temperatures fall owing to the phenomenon of upwelling described in the introduction, which occurs every year on the Galician coasts. The image corrresponding to August 5th (fig 2) presents noises owing to failure in the reception characterized by white points (1024 level of grey), and black ones (O level of grey) which as we have already explained do not introduce errors in the algorythm because they have a zero associated probability asigned to them. In figure 3 we can appreciate that a recession of the amplitude of upwelling has occured, because all the arrows point to the West. If we part form parallel 42, we can see the transversal movement has been of an average of seven pixels which implies 3.5 marine miles (6.4 km.) appproximately.

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DATE/ TIME	SATELLITE	SENSOR	CHANNEL	BITS/ PIXEL
4-August-92/ 18:26:17	NOAA 10	AVHRR	FOUR	10
5-August-92/ 16:03:36	NOAA 11	AVHRR	FIVE	10

Table 1

AXE \ ROW	1	2	3	4	5	6	7	8	9	10	11	12	13
X	-1.2	-1	-1	4	5	-4	1	-2.6	0	6.6	6.6	4	2.6
Y	-0.6	0	-1	-2	6	2	0	1	12	12	6.6	1.2	-15

Table II. - Averaged values of shifted waters, mesuared in pixels versus X and Y axes for each 13 raws in fig. 3