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Simultaneous occurrence of the North Atlantic Seesaw and El Niño

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RESUMEN

Se aplican modelos de regresión logística dicotómica y politómica en series de registros históricos de siglo y medio (1840-1990) del *seesaw* del Atlántico Norte y El Niño, buscando probabilidades de ocurrencia simultánea de ambos fenómenos en los meses invernales boreales y clasificando el *seesaw* en cuatro modalidades y El Niño en tres intensidades. El *seesaw* se refiere a las anomalías de temperatura en Groenlandia y Noruega; sus modalidades son: ambas positivas (AP), ambas negativas (AN), Groenlandia positiva con Noruega negativa (GP) y Groenlandia negativa con Noruega positiva (GN). Se encuentra una incidencia mayor del *seesaw* conforme avanza el invierno, así como una simultaneidad de ocurrencia del 61% del *seesaw* y El Niño. Las modalidades heterogéneas del *seesaw* (GP y GN) coinciden en 71% con El Niño, mientras que las homogéneas (AP y AN) lo hacen en 29%. Las modalidades heterogéneas tienen una coincidencia mayor con El Niño de intensidad más elevada (3). Al aplicar una prueba de bondad de ajuste para las probabilidades estimadas por el modelo logístico politómico, en comparación con las frecuencias observadas, se obtuvo un ajuste muy bueno al analizar las temporadas invernales completas.

ABSTRACT

Models of dichotomic and polytomic logistic regression are applied to series of historical records spanning one and a half centuries (1840-1990) of the North Atlantic Seesaw (NAS) and El Niño (EN), looking for simultaneous occurrence of both phenomena during the northern winter months and classifying NAS in four modalities and EN in three intensities. NAS refers to the temperature anomalies in Greenland and Norway; its modalities are: both positive (BA), both negative (BB), Greenland positive with Norway negative (GA) and Greenland negative with Norway positive (GB). A bigger incidence of NAS is found as winter progresses, as well as simultaneity of occurrence of 61% between the NAS and EN. NAS heterogeneous modalities (GA and GB) coincide in 71% with EN events, while homogeneous modalities (BA and BB) do so in 29%. Heterogeneous modalities have a higher coincidence with EN greatest intensity (3). When the frequencies computed through the logistic polytomic model were compared to the observed frequencies, a very close goodness of fit was found, when the whole winter season was considered.

Keywords: North Atlantic Seesaw, El Niño, logistic regression.

1. Introduction

The North Atlantic Oscillation (NAO) is a large-scale phenomenon which consists in a swinging atmospheric mean sea level pressure gradient between the subtropical high (Azores, approximate latitude 30° N) and the Arctic low (Iceland, approximate latitude 60° N). This oscillation occurs mainly during the winter season and has two phases. The positive phase shows a stronger than usual subtropical high pressure center and a deeper than normal polar low. This enhanced pressure difference strengthens the westerly winds between 50 and 60° N, producing storms crossing the Atlantic Ocean northeastward and carrying heat from the ocean to northeast Europe, which causes a milder and moister weather there, whilst in the Mediterranean region the draught predominates. Simultaneously, in northwest America the weather is rather wet, whilst in Labrador Peninsula and in Greenland it is cold and dry. The reason of this is that the strong northwesterly winds blow over the Labrador Sea, causing a cooling that forms new deep waters, and cold and dry winters in northern Canada and Greenland. This wind does not pass over the Greenland Sea, and because of this the region does not cool too much, and the formation of cold and deep water at this region is reduced (Hurrell *et al.,* 2001; Wanner *et al.,* 2001; Rodríguez-Fonseca *et al.,* 2004). During the negative phase, pressure difference between Azores and Iceland is less than normal. The subtropical high and the Arctic low are weak; both shift southward and, consequently, westerly winds also weaken and carry less humidity and heat over northern Europe. The southward shifting of those pressure cells causes that the Mediterranean region takes advantage of a less dry weather. In northeast America milder and drier winters occur (Hurrell *et al.,* 2001; Wanner *et al.,* 2001).

The seesaw in winter temperature between Greenland and Norway, known since the 18th Century, was studied by Loewe (1937, 1966), who reported the existence of large differences in the thermal run between Greenland and Norway. Later, it was defined by van Loon and Rogers (1978) starting from the behavior of the thermal anomaly registered between Jakobshavn (Greenland) and Oslo (Norway). Both locations, although being at the same latitude, show different thermal behavior, with significant differences in their anomalies (departures from the normal values), during winter time. This seesaw has four modalities (also called modes or types): 1) GA, consists in Greenland showing a positive temperature anomaly, while Norway shows a negative anomaly, with a difference of at least 4 °C between both anomalies; 2) GB, corresponds to the opposite situation (negative anomaly in Greenland and positive anomaly in Norway), again with a difference of 4 °C or greater between them; 3) BA, occurs when the anomalies have positive sign in Greenland as well as in Norway and their magnitudes are equal or greater than 1 °C; and 4) BB, being the opposite of the third, *i.e*. both anomalies are negative with an absolute value of 1 °C or greater. Additionally, modalities GA and GB are referred to as heterogeneous, and BA and BB as homogeneous.

NAO accounts for 31% of the variance in hemispheric winter surface air temperature north of 20° N (Hurrell, 1996). The Greenland-Norway seesaw is a robust feature of NAO (van Loon and Rogers, 1978; Greatbatch, 2000). GB mode of the seesaw is an expression of the positive NAO phase, while GA mode is associated with a negative NAO phase (Wanner *et al.*, 2001). Some authors call this seesaw as the North Atlantic Climate Seesaw; in this paper it is named North Atlantic Seesaw (NAS) (Dawson *et al.*, 2003).

NAS alterations in the geostrophic wind in the North Atlantic Ocean and a possible increase in the flows of cold air over Greenland, the Canadian Archipelago and even the Mediterranean Sea; while the warm advective streams in northern Europe increase their temperatures and drop in western North America (van Loon and Rogers, 1978). Rogers and van Loon (1979) described mid and high latitude variations in the atmosphere-ocean-cryosphere system associated to the seesaw. Likewise, Meehl and van Loon (1979) found that the seesaw has tropical teleconnections with the trade winds, the position of the intertropical convergence zone (ITCZ) in Africa, the sea temperature and the Gulf Stream intensity.

Several authors have found some statistical relations between NAO and El Niño (EN). For example, Rogers (1984) found that significant sea level pressure differences are correlated with these teleconnections over much of the Northern Hemisphere, even though for 80 winter years with data simultaneous appearance of both modes seemed to occur by chance (*e.g.* Hurrell *et al.*, 2001; Wanner *et al.*, 2001). According to Fraedrich (1994) noise level seemed to mask out atmospheric teleconnections.

The objective of this study is to estimate the probability of simultaneous occurrence between the four modalities of NAS and the three intensities of EN, during the winter months (in the Northern Hemisphere) along the period 1840-1990. It is necessary to point out that, although both NAS and EN occur during the northern winter months (explained in the next section), EN can span over a longer period, even reaching up to two years in some cases. However, and with the purpose of establishing the link between both events, each one of them was considered as a phenomenon of winter months, according to van Loon and Rogers (1978).

2. Data and method

In order to establish the probability of simultaneous occurrence of NAS and EN, records of EN were gathered from the classification proposed by Quinn *et al*. (1978). The authors categorize EN events recorded during the period 1726-1976, regarding the intensity of the event as much as its duration, in four categories: strong (4), moderate (3), weak (2), and very weak (1); based on nine indicators: 1) reports of perturbations on the anchovy fisheries and on the marine populations of birds of the Peruvian coasts; 2) scientific records reporting low phytoplankton production in the coastal regions of Perú and southern Ecuador; 3) hydrological data from the coast of Peru showing nutrient reduction; 4) records of sea surface temperature along the coasts of Peru and Southern Ecuador, where an alteration in the position of the thermocline was evidenced; 5) rainfall positive anomalies in the coastal stations of Perú and southern Ecuador; 6) alteration in the tendencies of the Southern Oscillation Index; 7) factors related to changes in the barometric pressure; 8) increment of sea surface temperature in the equatorial Pacific Ocean; and 9) anomalous negative rain records in the islands of the central and western equatorial Pacific Ocean.

In order to complete the studied period, EN records during 1977-1990 were taken from NOAA (2004). On the other hand, Quinn *et al.*'s (1978) record was cut away from 1726 to 1839, to have the same period for both phenomena (EN and NAS). For the purposes of this work, EN files from both sources were compared and transformed into three categories (intensities) according to NOAA classification (Table I).

Table I. Comparison of EN categories (from Quinn *et al.* and NOAA) to establish the intensity correspondence.

Quin *et al*. classification	NOAA classification	Comparison
Strong (4)	Intensity 3	El Niño 3 (strong)
Moderate (3) and weak (2)	Intensity 2	El Niño 2 (moderate)
Very weak (1)	Intensity 1	El Niño 1 (weak)

NAS records during the period 1840-1990 were taken from the World Weather Records (1929, 1934, 1947, 1959, 1965, 1966, 1979a, 1979b, 1987, 1989, 1995, 1996) and classified according to van Loon and Rogers' (1978) characterization as follows. First, the average monthly temperature for November, December, January and February, considered in this paper as winter months according to Labitzke and van Loon (1988) and Rodríguez-Fonseca *et al.* (2004), was calculated for Greenland (Jacobshavn) and Norway (Oslo). From this mean, the temperature anomaly was determined, separating the anomalies whose absolute value exceeded from 1 °C and have the same sign; and those having opposite signs with a difference of at least 1 °C between both. In order to compare the temperature differences that define the homogeneous and heterogeneous modalities, we lowered the van Loon and Rogers' (1978) range of the heterogeneous ones from 4 to 1 °C. Then, they were grouped in four modalities: BA, BB, GA and GB. Afterwards, the number of NAS occurred in every month was determined by a frequency chart for the period 1840-1990.

The data of EN and NAS were grouped in winters, so the same winter season consists in four months: November and December of one year, and January and February of the next one. Therefore, the 150 winter seasons of the 151 years were obtained, eliminating January and February 1840, and November and December 1990; so we have 600 winter months in total.

To determine whether the probability of NAS and EN occurrence is completely random or if the probability of EN occurrence is a function of NAS presence and modality, models of dichotomic (presence/absence) and polytomic (with more than two attributes for the dependent variable) logistic regressions were used. The fit of models was done with the program JMP, using robust variance estimates to account for clusters of months in each of the 150 winter seasons. The logistic models were analyzed according to Hosmer and Lemeshow (1989). In every case, EN intensities were considered as dependent while NAS modalities and the winter months were considered as independent.

The equation for the dichotomic logistic pattern is:

where P_i is the probability of the event I (i = 1, 2), for example EN occurrence, and $X_i, \ldots X_p$ are the independent variables. Once the β values are computed, probabilities for each category of dependent

$$\log \frac{P_i}{1-P_i} = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \ldots + \beta_p X_p \tag{1}$$

variables are estimated, according to Brant (1996) as:

$$P_i = \frac{1}{1+\exp\left(-\beta_0 - \beta_1 X_1 - \ldots - \beta_p X_p\right)} \tag{2}$$

$X_1 \ldots X_p$ are the values of the independent variables, with indicator variables for categorical independence.

The model equations for the polytomic logistic (multinomial with i = 0, 1, 2, 3) are:

$$\log \frac{P_0}{P_3} = \beta_{01} + \beta_{11} X_1 + \beta_{21} X_2 + \ldots + \beta_{P1} X_P \tag{3}$$

$$\log \frac{P_1}{P_3} = \beta_{02} + \beta_{12} X_1 + \beta_{22} X_2 + \ldots + \beta_{P2} X_P \tag{4}$$

$$\log \frac{P_2}{P_3} = \beta_{03} + \beta_{13} X_1 + \beta_{23} X_2 + \ldots + \beta_{P3} X_P \tag{5}$$

with the restriction $P_0 + P_1 + P_2 + P_3 = 1$.

The values of β coefficients are specific for each equation. P_0 is the probability of EN absent (i = 0), P_i the probability of EN intensity i (i = 1, 2, 3).

When the values of the logistic β regression coefficients are determined, the estimated probabilities for each NAS modalities are found, from the above four equations.

The goodness of fit of the predicted probabilities with the observed frequencies was computed through a χ^2 test, for $\alpha < 0.05$, where H_0: there are no statistical differences between the observed frequencies and the predicted probabilities; versus H_a: there are differences between observed and predicted. If H_0 is not rejected, then the model is acceptable.

3. Results

The statistical analyses were applied to EN and NAS records, covering the period 1840 to 1990, which amount to 151 years, 150 winter seasons and 600 winter months, as explained in the last section.

The results of the statistical analyses show that NAS frequency in its four modalities increases progressively as the northern winter advances, as it is shown in Table II; 72 events are recorded in November, representing 19%; 84 in December (23%) ; 102 in January (28%); culminating with 110 (30%) in February.

Regarding the simultaneity of occurrence of EN and NAS in their four modalities, from 368 cases of NAS observed, in 224 (60.9%) both events occurred; while in 144 cases (39.1%) only NAS occurred. These results imply that for NAS heterogeneous modalities coinciding with EN, 160 cases (43.5%) were recorded; while for homogeneous modalities, 64 cases (17.4%) occurred. The above implies that simultaneity of both events exists in 61% of the cases (Table II).

Table II. Monthly frequency of EN and NAS in their four modalities.

NAS modalities		Nov	Dec	Jan	Feb	Total (%)
GA	with EN	15	17	18	25	75
	without EN	10	11	9	16	46
GB	with EN	13	19	26	27	85
	without EN	4	16	14	17	51
Subtotal	with EN	28	36	44	52	160 (43.5)
	without EN	14	27	23	33	97 (26.3)
BA	with EN	6	5	8	10	29
	without EN	7	8	7	5	27
BB	with EN	11	5	11	8	35
	without EN	6	3	9	2	20
Subtotal	with EN	17	10	19	18	64 (17.4)
	without EN	13	11	16	7	47 (12.8)
Total	with EN	45	46	63	70	224 (60.9)
	without EN	27	38	39	40	144 (39.1)
	Global	72	84	102	110	
	%	(19.6)	(22.8)	(27.7)	(29.9)	

Regarding EN intensities and NAS occurrence, a larger number of NAS events is recorded in their modalities GA or GB, when they coincide with intensity 3 (strong), which corresponds to 86 (38.4%). Occurrence decreases for those of intensity 2 (moderate) with 43 (19.2%) and finally for those of intensity 1 (weak) amounts 31 (13.8%). It is possible to affirm that from 224 observed cases, in 160 (71%) modalities GA or GB prevail; while 64 cases (29%) were recorded for modalities BA or BB (Table III).

Table III. Monthly frequency of EN according to its three intensities and NAS in homogeneous and heterogeneous modalities.

EN + NAS combinations	Nov	Dec	Jan	Feb	Total	%
El Niño 3 + GA or GB	17	20	23	26	86	38.4
El Niño 3 + BA or BB	6	2	9	8	25	11.2
El Niño 2 + GA or GB	7	9	12	15	43	19.2
El Niño 2 + BA or BB	6	6	7	7	26	11.6
El Niño 1 + GA or GB	4	7	9	11	31	13.8
El Niño 1 + BA or BB	5	2	3	3	13	5.8
El Niño 3, 2, 1 + GA or GB	28	36	44	52	160	71.4
El Niño 3, 2, 1 + BA or BB	17	10	19	18	64	28.6

In first instance, the probability of NAS occurrence was determined (dependent variable) in its homogeneous and heterogeneous modalities, expressed as yes/no in a contingency table during the northern winter months (independent variable) (Table IV). The logistic model showed a $p = 0.0001$, corrected by the correlations within winters. This table shows that the relative frequency of a NAS event occurring during the winter months is on the average of 61% *vs* an average of 39% that it does not occur. In addition, it stands out that as the winter months progress, there is an increase in NAS relative frequency, particularly in February (73%).

Table IV. Contingency table for monthly occurrence or non-occurrence of NAS.

Month	NAS absent		NAS present		Total
	Number of cases	Relative frequency (%)	Number of cases	Relative frequency (%)	
November	78	0.52	72	0.48	150
December	66	0.44	84	0.56	150
January	48	0.32	102	0.68	150
February	40	0.27	110	0.73	150
Global	232	0.39	368	0.61	600

Next, the probability of occurrence of EN was estimated with a logistic model adjusted by winter, considering EN as dependent and NAS as independent, and categorizing NAS only as present-absent. In the model the four northern winter months were included, however, when considering NAS incidence per month, the interaction was not significant; therefore this model was discarded and another was proposed where only the main effects of month and NAS were included, that is to say, the probability of EN occurrence as a function of NAS and of the month. In this model a $\chi^2 = 27.57$ is obtained with three degrees of freedom and $p = 0.0001$, which leads to the rejection of the hypothesis of independence.

Regarding the main effects in the model, only NAS was significant ($p \leq 0.03$ in likelihood ratio test), and for month p was 0.91. The probabilities of EN occurrence according to NAS modalities adjusted by month are of 0.70 if there is no NAS and of 0.61 when NAS occurs (Table V).

Table V. Estimated probability of occurrence of each EN intensity for every NAS modality, grouped by winter. *n* is the number of cases for each modality.

NAS modalities	n	P_0	P_1	P_2	P_3	P
GA	121	0.38	0.18	0.16	0.28	0.62
GB	136	0.38	0.07	0.18	0.38	0.62
BA	56	0.48	0.20	0.14	0.18	0.52
BB	55	0.36	0.04	0.33	0.27	0.64
Total	368	0.39	0.12	0.19	0.30	0.61
no NAS	232	0.30	0.14	0.29	0.27	0.70
Global	600	0.36	0.13	0.23	0.29	0.64

Then, a new model of logistic regression was used, where EN presence/absence was considered as dependent variable, and the month and NAS with four modalities as independent. The interaction effect between type and month was not significant. Even though none of the main effects was significant, one of the indicator variables for NAS was significant with $p < 0.013$ in Wald test. With this model, the estimated probabilities (P) of EN occurrence were obtained for each NAS modality, corrected per month (last column of Table V), BB, GB and GA stand out in order of magnitude, with the lowest probability of EN occurrence of 0.52 with NAS modality BA.

A last model of polytomic logistic regression was used to estimate the probability P_i of occurrence of each EN intensity (i), with its four intensities as dependent variable, and with the month and NAS modalities as independent, grouped for every winter; it was found that there was no significant interaction. While this model was not significant for month ($p < 0.51$), it was highly significant for NAS modality ($p < 0.0004$). With this model, probabilities adjusted per month were obtained for each EN intensity (P_i, P_0 means absence of EN) and for each NAS modality (Table V).

The higher probabilities of occurrence of an EN intensity 3 event in the heterogeneous modalities of NAS stand out, amounting to 0.66 as a whole, which confirms the results obtained by the frequency chart (Table III); while, in NAS homogeneous modalities with EN intensity 3, they amount to 0.45 as a whole. The lowest intensity of EN had the low probability of 0.04 with BB NAS, and the highest intensity is more probable with the other modalities of NAS, reaching 0.38 with GB.

In order to determine the goodness of fit of the frequencies predicted by the polytomic model and the observed ones, a χ^2 test was performed for the different NAS modalities, considering each winter season as a whole. These results are presented in Table VI.

Table VI. Goodness of fit test for the data in Table III, observed frequencies vs estimated probabilities from Table V.

NAS modalities	Expected	Observed
EN3 + GA or GB	88	86
EN3 + BA or BB	24	25
EN2 + GA or GB	43	43
EN2 + BA or BB	26	26
EN1 + GA or GB	31	31
EN1 + BA or BB	13	13

$\chi^2 = 0.1092$ d.f. = 5 $p < 0.9998$ (not significant).

Thus, H_0 is not rejected, and the p value proves that there is a very close fit of the observed data to the probabilities predicted by the model, at least for the whole winter season.

4. Discussion

Although the present paper is basically probabilistic, some other correlations and physical mechanisms support our statement that the results of the model are not spurious, but are instead based on the link between both phenomena.

Van Loon and Rogers (1978) explain some processes at the northern mid and high latitudes related to the seesaw. Rogers and van Loon (1979) described the variations in atmosphere, ocean and cryosphere associated to the seesaw at those same latitudes. Meehl and van Loon (1979) find that the seesaw has tropical teleconnections, other than EN.

Many studies about the relations and teleconnections between atmosphere and ocean have been carried out, over a wide span of time and with a global scope. Some of the most classic and important are those of Bjerknes (1964, 1965, 1966, 1969). Nevertheless, an alternative hypothesis is that there is a coupling between tropospheric and stratospheric circulations; some researchers have found statistical correlations between the strength of the stratospheric winter vortex and the tropospheric circulation over the North Atlantic (Perlwitz and Graf, 1995; Kodera *et al.*, 1996; 1999), supported with the results by Wanner *et al.* (2001), who found significant correlations between geopotential height over the North Atlantic and the wintertime Index of NAO (NAOI), which were even higher for the Index of Artic Oscillation (AOI), up to the 50 hPa levels, thus revealing that the NAO/AO signal encompasses the whole troposphere and lower stratosphere of this region.

Even though the mechanisms are not well understood, some authors have found a coupling between the conditions at the tropical Pacific Ocean and those at the North Atlantic (*e.g.* Bjerknes, 1966). There are models predicting that the development of permanent El Niño conditions would increase freshwater flow from the Atlantic into other basins (Timmermann *et al.,* 1999; Latif *et al.*,

2000) and thus that the interaction involves the ocean as well as the atmosphere. On the other hand, Rogers (1984) found that, over most of the Northern Hemisphere, both ENSO and NAO associate to significant sea level pressure differences.

One important aspect of the present work is the proposal of the probabilistic estimation method by using polytomic logistic models, which are statistical tools with little use in climatic studies. The validity of this method is further increased when the record of events is quantitative, as NAS and EN, whose categorization was implemented since the late 1970s. This feature facilitates the statistical analysis in series longer than 100 years, with a confidence level higher than 95%. Other important aspect is that the analysis was performed from a series that includes more years than the series used by other researchers (1840-1990). Both of these facts resulted in a close fit between the observed data and the model results, at least for the probabilities for the whole winter season.

Nevertheless, a close look at Table V shows that, for heterogeneous modalities, the probability of having a strong EN or not having EN is almost the same (0.28 to 0.38), a fact that limits its practical applicability for prediction, at least while further causes are not found that would define the most likely outcome for a particular season. On the other hand, for BA homogeneous modality the probability of not having EN is close to 50%.

5. Conclusions

This analysis was performed using long series of historical records (one and a half centuries, or 600 winter months) for NAS and EN, which renders a probabilistic strength.The incidence of NAS events increases as the northern winter advances.

NAS heterogeneous modalities (GA and GB) coincide in 71% with EN events, while homogeneous modalities (BA and BB) do so in 29%.

NAS heterogeneous modalities (GA and GB) for EN occurrence have a higher coincidence with EN intensity 3.

The simultaneity of the NAS and EN occurs in 61% of cases.

For heterogeneous NAS modalities, the expected relative frequency of having EN is close to 50%.

There is a close fit between the probabilities predicted by the logistic polytomic model and the observed frequencies.

There is a close fit between the observed frequencies and the model predicted probability for the NAS modalities, at least for the whole winter season.

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