Discrete Rainfall Predictability Using El Niño/Southern Oscillation Interaction.

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Abstract.
The objective of the study was to determine the probability of occurrence of wet or dry season events, based on the phase of El Niño/Southern Oscillation (ENSO) phenomenon using multinomial logit regression models. The study used monthly time series of the Pacific equatorial sea surface temperature (SST), a sea level pressure index (SOI) and rainfall anomalies over a 2.5x2.5 degrees grid along the west coast of Central and South America, for latitudes starting at 25N, through 45S, since 1951 to 2011. We defined an ENSO index (NSO) as predictor and rainfall as response. Data was categorized into terciles to construct non symmetrical three way contingency table. As results, we generated latitudinal profiles of the predictability (association), for the West Coast of Central and South America, using ENSO as predictor.

Key Words: El Niño, logit regression, rainfall, ENSO**.**

1**. Introduction**

Interest in useful climate predictions for various regions of the Americas has developed substantially over the past two decades given its enhanced recognized socio-economical as well geological impacts (Katz and Murphy,1997; Viles and Goudie, 2003). Over recent decades, efforts have increased toward improving forecast techniques for seasonal climate (Goddard et al., 2000).

In dealing with ocean/atmosphere interactions and their most commonly studied, the El Niño-Southern Oscillation (ENSO) phenomenon, most statistical forecasting studies focus on time series modeling and/or spatial fields for predicting the time of arrival and strength of an event. In the first case, it is done by fitting univariate or multivariate ARMA (Box et al., 2008; Alfaro and Cid, 1999) models in time domain, Fourier-derived methods for the frequency domain, as well as neural networks (Goddard et el., 2000). In the second case, it is generally done by using multivariate techniques such as principal components or derivations thereof (Maldonado et al. 2013; Zwiers and Von Storch, 2003). However, common practice has shown that in many cases the primary interest is not to measure the exact magnitude of an ENSO associated event, but just to assess the "chances of occurrence" of events such as the El Niño or La Niña. In that case, the main interest is to determine if a given year will or will be not an El Niño (or La Niña) year instead of predicting its strength or timing, consequently, one could be interested, for example, in the assessment of the chances that, given an El Niño/La Niña condition of ENSO, a season will be dry o wet.

At present we have some deterministic prediction ability, although the spring barrier effect (significant prediction failures between lead times of 6 to 12 months) limits the predictability of warm/cool anomalous temperatures in the equatorial Pacific ("ENSO") (Latif et al., 1998). We know from statistical analysis, that ENSO is related to these "warm/cool events" and that they are also associated with climate anomalies around the globe (e.g. Ropelewski and Halpert 1987; 1989), allowing us to make qualitative statements about expected climate effects, given a warming (or cooling) event. But this is not nearly good enough. The economic and social sectors (agriculture, fisheries, health, etc.) need more concrete information (Katz and Murphy,1997): A farmer needs specifically to know if a given year will be “dry” or a “wet” year to plan their crops and fishermen need to know if warm or cool event will affect the fisheries. However, the occurrence of an ENSO event is no guarantee of a given impact because these “teleconnected” consequences – good or bad -- do not always materialize. The deleterious effect of a false positive, normally called false alarm, result when the expected teleconnection does not occur may be worse than the direct effects when it does occur. Because observations and models usually warn us when an ENSO event is beginning or imminent, one strategy is to assume the El Niño or La Niña event to be a given, and to project probabilities, <u>one or two seasons in advance</u>, for far-field climatic and societal impacts around the globe based on the observed history (“hits” or “misses”) of such impacts. When an educated public or economic sector is apprised of the relative likelihood of a consequence, contingency plans can be made for either possibility (García-Solera & Ramírez, 2012).

1.1 The ocean-atmosphere interaction prospective

Many studies have been conducted over the last two decades linking climatic variability and ENSO, focusing on the tropical Pacific and its interactions with the atmosphere (e.g, Philander, 1990; McCreary and Anderson, 1991; Weisberg and Wang, 1997; Neely 1998; Goddard et al., 2001, Neeling et al., 2003, Lee et al., 2010, 2013). According to Rassmusson (1985) these large-scale interactions between ocean and atmosphere over the Tropical Pacific could greatly influence the weather patterns around the world.

Many of these investigations have been undertaken through the study of ocean-atmosphere indices, such as the Southern Oscillation Index (SOI) (Enfield 1989, Enfield and Mayer 1997), the difference in atmospheric pressure between Tahiti and Darwin, or the El Niño indexes based on sea surface temperature (SST). One of the frustrating problems with such schemes, however, has been the subjective nature of predictor identification, both in terms of variable selection and the identification of suitable (geographic) predictor domains. The statistical modeling of ocean-atmosphere interaction from a perspective of discrete possibilities, implies a completely different approach vis-à-vis the traditional models based on a time domain approach, in which only continuous time series are modeled according to their auto-correlative structure, in the simpler case, or using cross-covariance arrays in the case of multivariate analyses.

There are only few cases in which such an approach has been attempted, or where this type of analysis seems to be an obvious need. For example, Mason and Mimmack (2002) compared different statistical techniques, including logit models, for predicting ENSO, but did not investigate the strength of the method for associating ENSO events and their worldwide climatic impact. Along with the idea of the present paper, and therefore precursor of the present paper, interestingly, Enfield et al. (1999) used contingency tables to establish the relationships between extreme events in the Atlantic ocean and dipole configurations of the tropical Atlantic SST, using the areas north (NA) and south (SA) of the ITCZ for a 136-year period, recording the occurrence frequencies for which these indexes fall into their respective quartile extremes ranges, and then compared them against what the expected frequencies would be by chance. This analysis concluded that such dipole configurations are due only to chance, the two classes being stochastically independent.

The main purpose of this study, is therefore to introduce a rather simple methodology associated with the analysis of contingency tables, into the study of the relationships between some of the variables most commonly used to evaluate the ocean-atmosphere interaction, such as the Southern oscillation index (SOI) or equatorial SST- related time series indices (e.g., Niño 3 or Niño 3.4) and the distribution of rainfall along the west coast of South America, using data from the 22.5ºN southward to 45ºS. We expect to confirm most of the well-known relationships between cool and warm events associated with ENSO and the rainfall regimes along the west coast of South America, such as those described by Rutllant and Fuenzalida (1991), establishing the usefulness and practical need of this analytic tool.

2. Data and Methods

In lieu of such a simple binary alternative, a logical methodological approach to the problem is, instead of determining the exact magnitude of the sea surface temperature (SST) or the sea level pressure (SLP) anomalies for a given period, associated with an event, to translate the data into frequencies corresponding to a given discrete classification of the data, of which the simplest could be a binary classification of the type El Niño/La Niña. This binary approach includes, however, those periods which could be classified as transition seasons (neither El Niño nor La Niña or vice versa) so that we should consider at least three classes or categories in which any given period (month, trimester or year) could be classified. This classification will then be translated into two-way nonsymmetric contingency tables, including a predictor and a response variable (Lauro and Balbi, 1999). Using predictive generalized linear models (Agresti, 2002), we can estimate the odds of classifying a single event in each of the three predefined categories of the classification, based on the marginal probability distribution of a number of “predictive” processes.

To construct the contingency tables to evaluate the relationship between rainfall and the warm/neutral/cool events, we consider monthly time series from 1951 through 2011, for the Southern Oscillation Index (SOI) and equatorial SST represented by the series Niño 3.4 (N34, monthly mean SST along the equator between 5ºN and 5ºS and between 150ºW and 160 W). We summarize the two series into an index that considers both the atmospheric and oceanic contributions of the coupled phenomena. For this reason, throughout this paper, an El Niño-Southern Oscillation index (NSO), corresponding to the standardized difference NSO = N34 – SOI at monthly lag zero. The relationships between ENSO events and the NSO index is clear, since during the warm phase of ENSO, SST has positive (negative) anomalies and SOI has negative (positive) anomalies, so that the NSO has its maximum (minima) for El Niño (La Nina) events. As such, the NSO index has the advantage of summarizing in a straightforward manner the information given by both indices. When NSO is compared, for example with Wolter´s MEI index (Wolter, 1987, Wolter and Timlin, 1993), clearly, as seen in Figure 1, a good correspondence was found. The NSO index emphasizes the extreme events, which, for this analysis helps in the differentiation of the terciles.

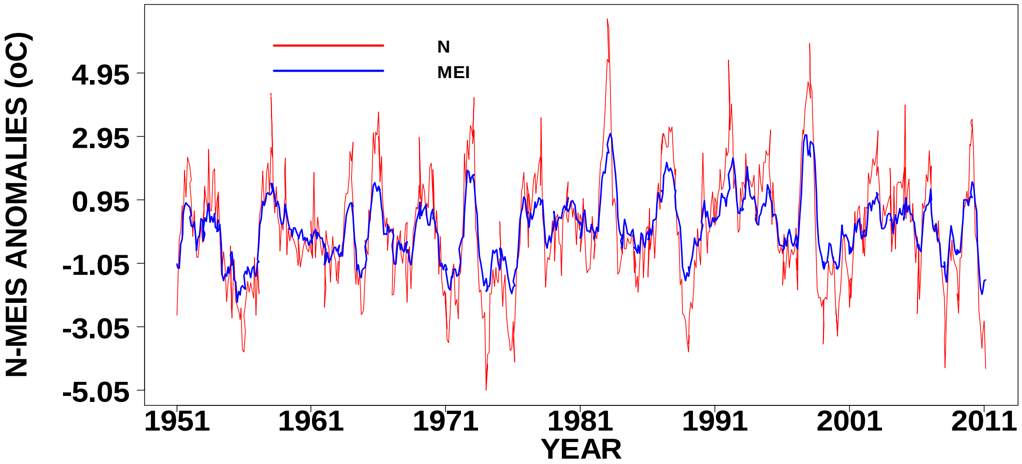

Figure 1. NSO (N) and MEI series.

The NSO time series is then summarized into seasons taking the standard average of three months DJF, MAM, JJA and SON, as a way to reduce the noise and the autocorrelation of contiguous observations and associated with boreal (austral) winter (summer), spring (autumn or fall), summer (winter) and autumn (spring). All the analyses were performed independently for each season.

Monthly rainfall (R) data were obtained from the National Centers for Environmental Prediction (NCEP) of the National Oceanic and Atmospheric Administration (NOAA), and correspond to the anomalies of worldwide rainfall measures over a 2.5° x 2.5° latitude-longitude grid from 1951 to 2011 (Chen et al., 2003). From the database we selected 28 grid points located along the west coast of South America from 25° N through 45° S. Rainfall data were also summarized into seasons as indicated above, so we obtained 61 data points for each season along the 28 different grid point latitudes for the west coast of South America. However, due to the scarce rainfall over the Atacama Desert in Chile, the corresponding two grid points, there were not included in the analysis.

2.1 Contingency Tables.

Consider two categorical variables X and Y, with I and J categories respectively, where Y is the dependent variable and X the predictive variable. These variables generate a two-way contingency table of order IxJ

For the purpose of this study, we define a two-way (RxNSO) contingency table of order 3x3. The column and row marginals of the table are divided into three classes, each of them defined by the corresponding tercile of their distribution. Data in the upper tercile of R correspond then to wet periods and those in the first tercile to dry periods. For NSO, the first tercile defines the cool events for SST (La Niña) and the third defines the warm events (El Niño). The cell (i,j) corresponds then to the i-th tercile of the NSO and the j-th tercile of the response R. Normally the categories in the second tercile are called neutral or “normal”.

For the statistical analysis of the contingency tables we used generalized linear models, which is a common statistical methodology to study how the cell counts are related to the levels of the categorical variables (Agresti 2002), analyzing the association and interaction patterns between the variables and the response is multinomial for variables categorized into ordinal classes. We also fit multinomial response logit regression models, when the predictors were used in their original continuous expression.

2.2 Interpretation of response probabilities.

Table 1 shows the probabilities P_{ij} associated with each cell, to be estimated through the logit model. In this table, the probability P_{ij} corresponds to the probability of any given trimester to be classified into the (i,j) cell of the contingency table. In the absence of any expectation for ENSO,

	RAINFALL TERCILES		
NSO TERCILES	PP_1	PP_2	PP_3
NSO_1	P_{11}	P_{12}	P_{13}
NSO_2	P_{21}	P_{22}	P_{23}
NSO_3	P_{31}	P_{32}	P_{33}

Table 1. 3x3 Contingency table for the rainfall (PPj) as response and the NSO index as predictor,. Rows and columns correspond to the terciles of the series, P_{ij} is the probability that a given observation, being classified in the row i of the predictor, is classified into the column j of the response.

The P_{ij} probabilities can be interpreted as follows:

P_{11} is the probability that the first tercile of NSO induces rainfall in the first tercile of the rainfall
distribution, so in measures the association of cool events and dry years.

P_{13} is the probability that the first tercile of NSO induces rainfall in the third tercile of the rainfall distribution, so in measures the association of cool events and wet years.

P_{31} is the probability that the third tercile of NSO induces rainfall in the first tercile of the rainfall distribution, so in measures the association of warm events and dry years.

P_{33} is the probability that the third tercile of NSO induces rainfall in the third tercile of the rainfall distribution, so in measures the association of warm events and wet years. We expect this probability as well as P_{11} , to be higher than 1/3.

P_{21}, P_{22}, P_{23}, P_{12} and P_{32} are the probabilities for the central terciles that are supposed to be determined by the climatology, i.e. be always close to 1/3.

Logit models were fitted to estimate the expected values for the cells of the contingency tables, when one of the classifications was used as causal and the other as dependent. In this study, we used the NSO index as causal and rainfall as response variable.

3. Results.

3.1 Logit Models.

In the following we will analyze the results of the response to logit models, which will associate a kind of a event (cool, neutral, warm) with a rainfall situation (dry, neutral, wet), in hope that this will give us further insight. The association between warm and cool events and the dry and wet phases will be emphasized, not the association between or with neutral phases which is less pertinent. Therefore we will investigate mostly the direct relationships, Cool-Dry, Cool-Wet, Warm-Dry, Warm-Wet, respectively the P11, P13, P31 and P33 probabilities, i.e., the corners of the contingence tables.

We will first investigate the yearly average response before moving into the seasonal analysis. According with Figure 4, the relationship El Niño = more rain and La Niña = less rain (Warm-Wet and Cool-Dry, respectively P33 and P11) are particularly intense and meaningful from 15 degrees south to southern Chile, as well as north of 6 degrees. Instead the other relation, Cool? Wet and Warm-Dry is particularly intense between 6 and 15 degrees.

The analysis by season, are shown in Figures 3 to 10 and correspond respectively to DJF, MAM, JJA and SON. For the analysis of these figures, we consider that the events with probabilities along the 0.333 line are non predictable, the events associated with values much below the 0.333 line corresponds to the less probable events, whereas values well above are associated with the most likely events.

DJF.

Results for the boreal winter (austral summer) are in Figure 2, and Figure 3.

Figure 2 below, shows that from 22.5 to 13 °N, the most likely association during La Niña is R1|N1 which corresponds to cool-dry events, While from Costa Rica through South Chile, predominates the cool-wet situation, which is particularly strong for the Panama, Colombia region and less significant for North/Central Chile and Ecuador. While for El Niño, Warm-Dry and Cool-Wet situations dominate the associations along most of the latitudes (Figure 3), except for coast of Mexico, Guatemala and Salvador, dominated by a warm-wet situation.

However, note that over the northern Chile (16°S –30°S) the difference between the Cool-Wet and Warm-Wet situations is not very meaningful. Therefore abnormal, drier summers over most of Peru and Chile, have been associated over most of the last 60 years with warmer situations in the ENSO index. Abnormal wetter summers in central Chile have been associated with cool situations in the ENSO index.

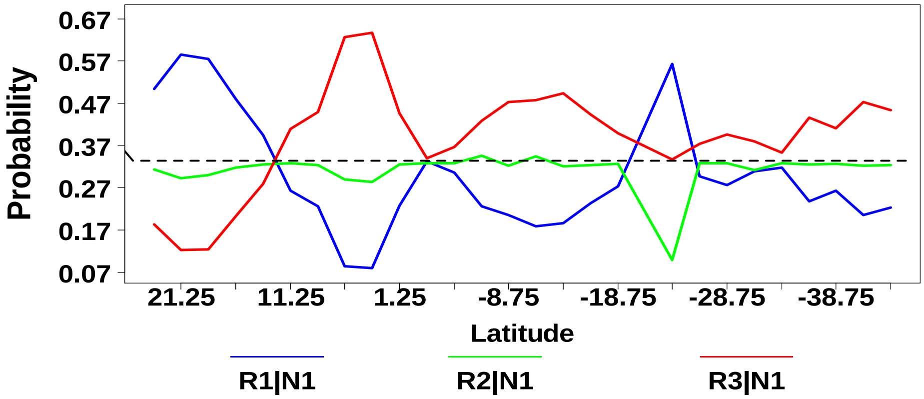

Figure 2. Latitudinal profile of conditional probabilities for each tercile of rain, given the first tercile of NSO (cool phase of El Niño).

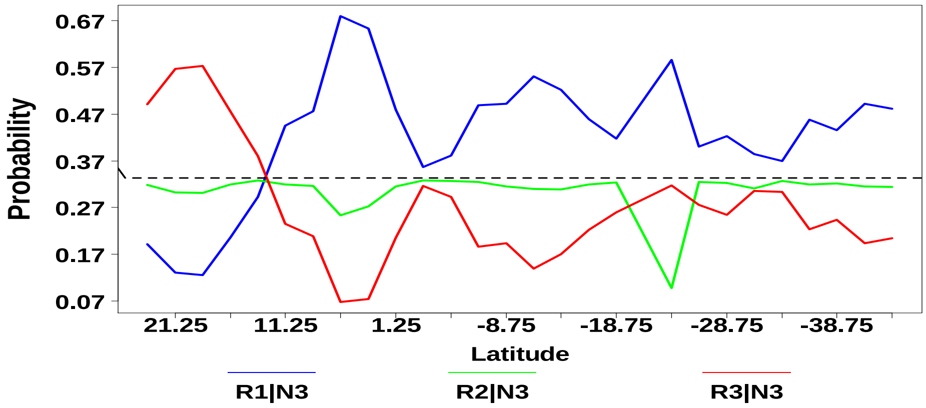

Figure 3. Latitudinal profile of conditional probabilities for each tercile of rain, given the third tercile of NSO (warm phase of El Niño).

MAM.

Results for the austral fall (boreal spring) are shown in Figures 4 and 5, show the predicted probabilities for rain terciles given the cool and warm phases of El Niño. Note that for this season, the patterns are non regular, and only few regions show a noticeable association except for Central-South Chile showing a strong wet-cool and wet/warm association. For the case of the north coast of Mexico, this season could replicate the same explanations given by Magaña et al. (1999a) and Gershunov & Barnett (1998), meaning that during the warm (cool) phases of ENSO, an increase in the occurrences of cold outbreaks or cold fronts is observed in the north coast of Mexico, associated with more (less) precipitation in that region. For Central America, this is the season associated with the beginning and the first peak of the rainy season (Taylor & Alfaro, 2005). Rainfall in this region is mainly dominated by deep cumuluinmbus formation and the northward migration of the InterTropical Converge Zone (ITCZ). Philander (1990) describes that this migration is delayed (favored) during warm (cool) ENSO phases.

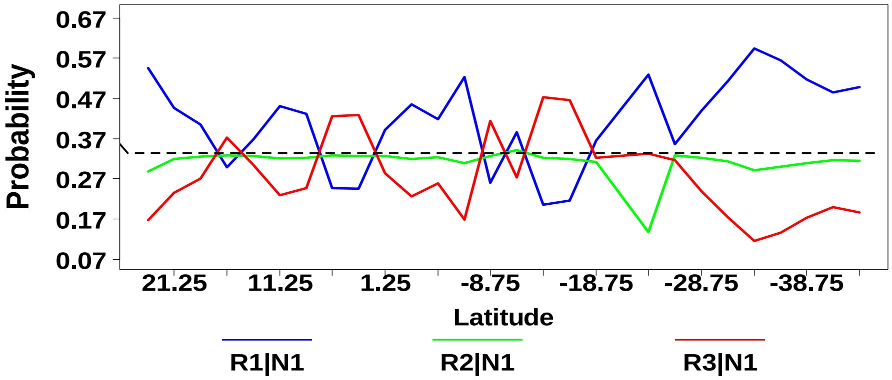

Figure 4. Latitudinal profile of conditional probabilities for each tercile of rain, given the first tercile of NSO (cool phase of El Niño).

This situation could inhibit (potentiate) the deep convection, observing drier (wetter) conditions in the Central American Pacific slope. From here it can be inferred that during the MAM trimester cannot clearly discriminate the effect of the warm and cool phases of ENSO over rainfall, except in the zones above described. In addition, it could reflect the influence of other climate variability sources that obscures or potentiate the ENSO signal, depending on their phase. For example, Gouirand et al. (2013), Taylor et al. (2002), Giannini et al. (2000) and Enfield & Alfaro (1999), observed that during this season the region of the Caribbean and Central America is highly influenced also by the tropical north Atlantic variability.

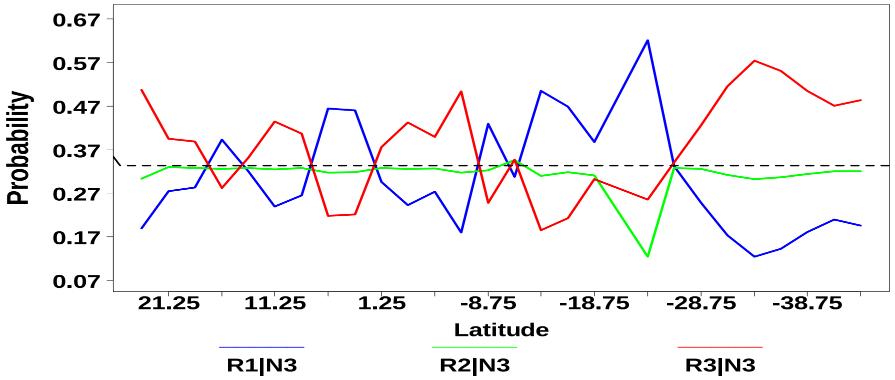

Figure 5. Latitudinal profile of conditional probabilities for each tercile of rain, given the first tercile of NSO (warm phase of El Niño).

JJA.

Results for the austral winter (boreal summer) are shown in Figure 6 and Figure 7, show the predicted probabilities for rain terciles given the cool and warm phases of El Niño. For this season, except for the (2 ºN – 14ºS), there exist a very clear pattern of association. In fact. Figure 7 shows that for the (22.5 ºN-5ºN) region, there exists a clear wet-cool association, while, from 15ºS through 45ºS, the association dry-cool. The opposite association i.e. dry-warm and wet-warm is evident for the same regions respectively, as shown in Figure 8. This result agrees with the work of Magaña et al. (1999), that shows drier (wetter) conditions along the Pacific coast of Mexico and Central America during the warm (cool) ENSO phases. That relationship is very important because the Mid Summer Drought, (Karnauskas et al., 2013; Magaña et al., 1999b) is observed in Meso America during July-August as a diminishing of rains in the Eastern Tropical Pacific. As for the previous season, Magaña et al. (1999a) explained that this could be because a southern (northern) more position of the ITCZ during the warm (cool) ENSO phases. In addition, Amador (2008) explained that contrary to what happens in winter, the CLLJ core is stronger (weaker) than normal during warm (cold) ENSO phases in summer, meaning that zonal easterlies increase (decrease) over Meso America, decreasing (increasing) the precipitations over the pacific slope by the two mechanisms mentioned also in winter previously.

Much of the rainfall in Central Chile (as worldwide) happens during the winter season. Therefore must of the agricultural economy is based in the weather conditions during this season. A particular interest in weather forecasting is related to know when the winter will be drier than normal. As shown in Figures 6 and 7, the season association with the ENSO index increases with latitude, with particular emphasis in central Chile, where it reaches its highest value at roughly 38 degrees South. The analysis of Figure 7 gives us a further clue. In fact for most of central Chile, wetter than normal situations are associated with warm situations in ENSO. The opposite can be concluded for some of the latitudes in the northern hemisphere, (Figure 6) where the wetter situations are found for the cool phase of El Niño.

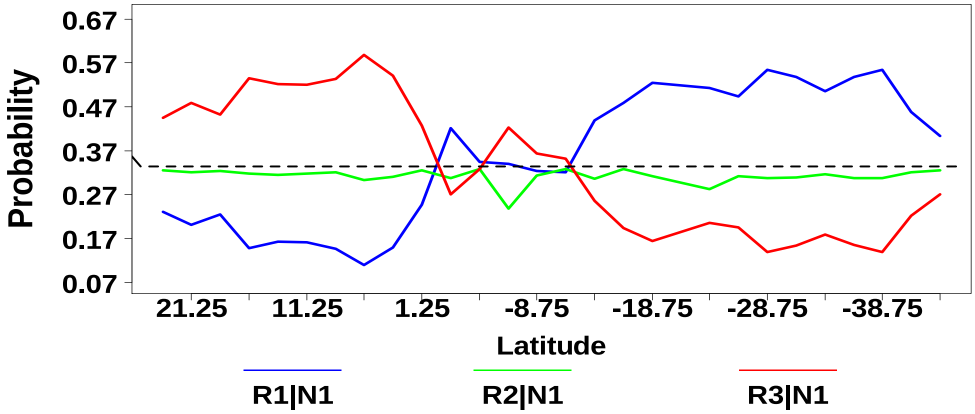

Figure 6. Latitudinal profile of conditional probabilities for each tercile of rain, given the first tercile of NSO (cool phase of El Niño).

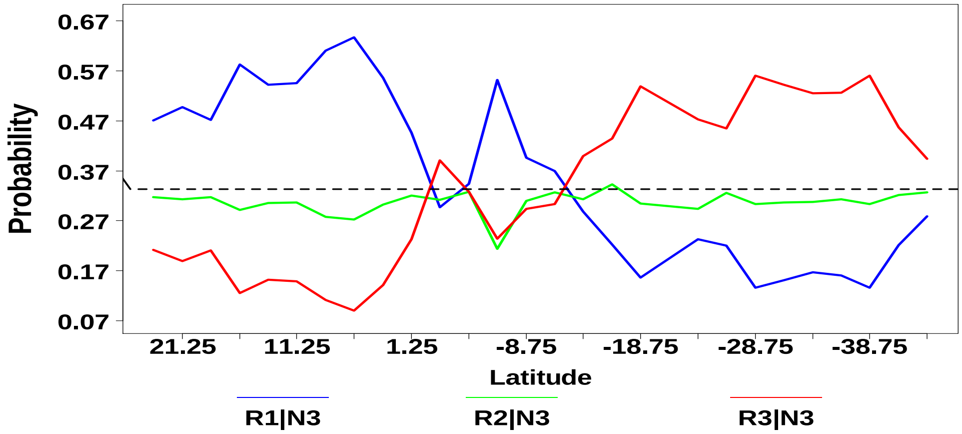

Figure 7. Latitudinal profile of conditional probabilities for each tercile of rain, given the first tercile of NSO (warm phase of El Niño).

Although drier situations are associated with cool events (upper than 1/3), and if a cool event take place there's significant probabilities that a dry situation may takes place in most of Central Chile, the analysis performed here not preclude a Warm-Dry association too at particular latitudes. Elsewhere, from Ecuador to most of Peru (1 to 10S), wetter/drier than normal winters are associated particularly to cool/warm events in ENSO. Instead for most of southern Peru and northern Chile the Warm-Wet and Cool-Dry association as for central Chile, although less strong, dominates.

SON.

Results for the austral spring (boreal autumm) are shown in Figure 8 and Figure 8, show the predicted probabilities for rain terciles given the cool and warm phases of El Niño. Here we can observe the same patterns than for the JJA term, except that for narrower regions. In fact, Figures 8 and 9, show two regions, one for (22.5oN-10oN) plus a wider region, (5oN-30oS), in with no clear predominance of an association between NSO and rainfall, while for Ecuador there is a clear wet-cool association and for Central-South

Chile the association is wet-cool (Figure 8). For the same regions, Figure 8 show strong dry-warm and wet-warm, for the same regions respectively.

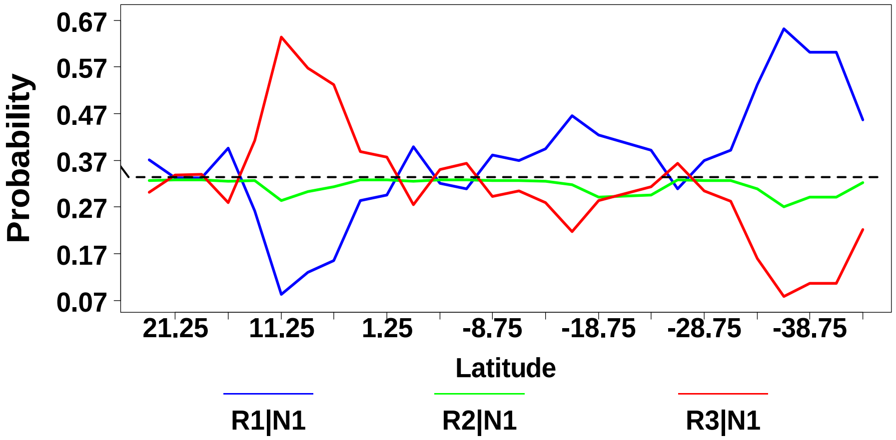

Figure 8. Latitudinal profile of conditional probabilities for each tercile of rain, given the first tercile of NSO (cool phase of El Niño).

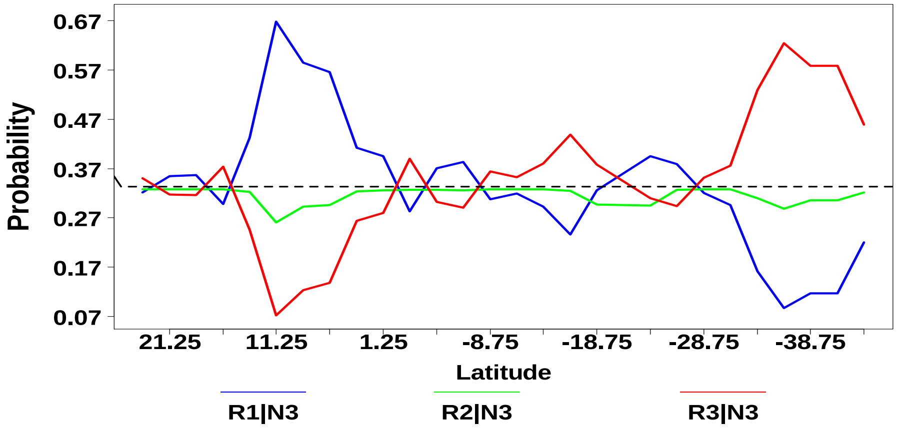

Figure 9. Latitudinal profile of conditional probabilities for each tercile of rain, given the first tercile of NSO (warm phase of El Niño).

The analysis of austral spring on Figures 8 and 9, show the latitudes for which the probabilities of association Cool-Dry followed and Wet-Dry reach their maximum i.e. Costa Rica through Colombia, and those for which the Cool-Wet and Warm-Wet associations are maximum, which corresponds to Central-South Chile.

From the analysis presented here, it can be inferred that the austral spring discriminates clearly the warm and cool phases of ENSO in the zones above described. Instead, over much of northern Chile and part of southern Peru (16ºS – 30ºS) non linear association behavior is shown. Therefore, for most of the latitudes analyzed here (from Mexico to Chile) were drier and wetter than normal spring seasons were associated with cooler and warmer situations in ENSO variability. In central Peru, spring season wetter than normal situations were associated with cooler situation, related to ENSO.

3.2 Logit regression models.

Similar results were found when applying regression models with multinomial response, and using the NSO index as independent variable in its continuos form. For this purpose, we used five different values of NSO, namely -3, -1.5, 0. 1.5 and 3.0. Some of the results, confirming the results of the analysis of contingency table analysis are shown in Figures 10 and 11. Figure 10 shows the latitudinal probability of dry season profiles , for the austral summer season, given five different values of the NSO index. This figure shows the results for the extreme values of NSO (N1 and N3) summarizesn with Figure. Figure 11 shows the latitudinal probability of dry season profiles, for the austral spring season, given five different values of the NSO index.

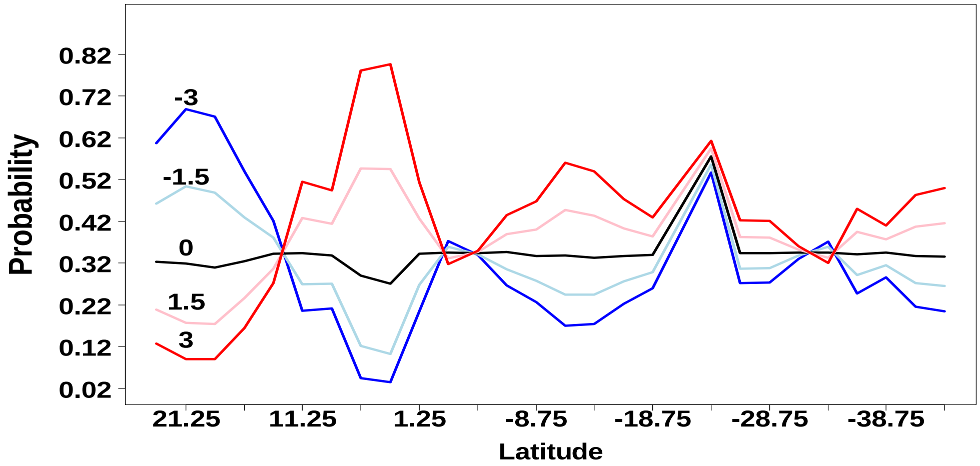

Figure 10. Latitudinal profiles of conditional probabilities of a wet season, given the five different values of NSO, from cool to dry phase of El Niño for the austral spring season.

Interestingly the highest correlation found between the ENSO index and rainfall in central Chile is related with the spring season roughly between 35°S and 40°S (figure 3). There, the seasonal Warm-Wet and Cool-Dry association is particularly clear and meaningful. Therefore if a Warm/Cool ENSO related variability takes place, most probably during the following autumn, rainfall must experience a wetter/drier than normal situation. Ecuador experiences also the same situation, whereas central Peru appears to be slightly dominated by a Cool-Wet association.

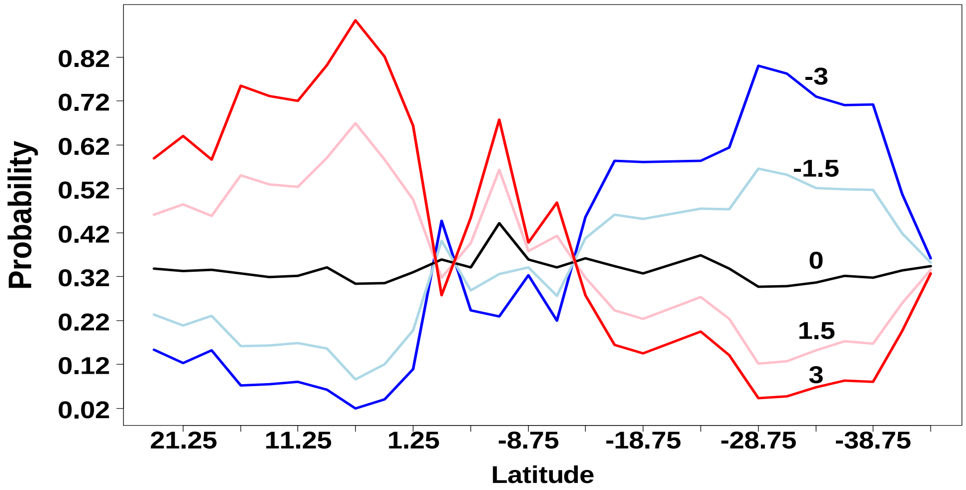

Figure 11. Latitudinal profiles of conditional probabilities of a dry season, given the five different values of NSO, from cool to dry phase of El Niño for the austral spring season.

Elsewhere, from southern Peru to most of northern Chile the association is irregular which is probably meaningful for local or other remote influences. Figure 9, shows that for SON, which corresponds to the austral spring, the highest probabilities are for P_{11}, P_{33}, for the region of Arica through Valdivia in Chile, indicating a strong association between the warm/cool events and rainfall in the region.

4. Conclusions and Discusion

Results for DJF and MAM shown are consistent with Magaña et al. (1999a) describing that during the warm (cool) phases of ENSO, an increase in the occurrences of cold outbreaks or cold fronts is observed in the north coast of Mexico, associated with more (less) precipitation in that region. Gershunov & Barnett (1998) observed that typical El Niño and La Niña patterns are strong and consistent only during the high and low phase of the North Pacific oscillation (NPO), affecting mainly the storm track.

Warm (cool) ENSO phases were associated with drier (wetter) conditions during the Meso America Pacific slope rainy season (results for MAM, JJA, SON). It means that zonal easterlies increase (decrease) over the isthmus, decreasing (increasing) the precipitations over the pacific slope by at least two mechanisms, increasing (decreasing) the Foehn or Föhn effect (Oliver 2005) and reducing (enhancing) the mesoscale system formation over that slope.

Based in the analysis of the last 60 years, considering the probabilities of association as given by a particular logit model between warm/cool events in an ENSO index , and dry and wet situations, as given by monthly rainfall data over most of the western side of South America, from southern Ecuador to southern Chile, discretized into seasonal values, we can conclude that there are high probabilities that Warm and Cool event in ENSO variability may give rise to Drier and Wetter than normal situations in Chile, particularly along Central Chile. Interestingly the best probabilities of association (in Central Chile) are given equally for both cause-effect relationship in the autumnal season. The spring season appears to be dominated by a Cool-Dry situation and winter season by a Warm-Wet situation, even if in both seasons the other direct association (respectively Warm-Wet and Cool-Dry) is also meaningful, although less intense. It is of particular interest for the agriculture that the probabilities that a cool event in ENSO may be followed or accompanied by a dry season are much higher, than it is followed by a neutral or wet season. For the epidemiological sector, the wetter than normal season are most probably related to warm situations in ENSO variability. Concerning the summer season, which present interesting differences with the other three seasons, and which are of particular interest for the economic sector related to tourism (and for normal persons interested in sunny summers), wetter than normal summer seasons will be most probably associated to cool events in ENSO events. Instead Drier than normal summer season are associated to warm events along the tropical pacific.

The relationship along northern Chile and the desert are most probably polluted by noise due to scarce pluviometry therein, although a Warm-Wet association in winter is meaningful of the rare rainfall occurrences after a very strong El Niño event. However, results for latitudes associated with desert regions need to be more carefully analyzed, since there are so few rain episodes, and even then the rainfall is so little, that anomalies could be rather large, i.e. the distribution is highly skewed and rainfall accumulation over the period could be not very different from the accuracy of the observations

The probabilities of association found for Ecuador and Peru are also very interesting. For Ecuador, represented here only by mostly and solely two points however, the yearly average association interestingly resembles that along central Chile. Warm conditions in ENSO will be most probably associated with wetter than normal rainfall, instead Cool conditions with drier ones. It appears from our analysis that all the seasons show the same figure favoring the strong association Cool-Dry, Warm-Wet, but excluding the winter season, when no association is favored. For Central Peru the relationship Cool-Wet and Warm-Dry appears to dominate the yearly around average association. Concerning the Cool-Wet association, this is supported by all seasons, particularly during winter and spring. Whereas the Warm-Dry situation in central Peru is confirmed mostly for summer and winter, particularly the former.

Although most criticisms, for this type of analysis, focus in the fact that there is an obvious loss of information, since we locate a continuous variable into only few classes, it needs to be noticed that this loss of information allows to center the analysis on the occurrence of the events, in a way which make more evident the specific categories of the event in which we are interested. In a first stage, this means that we are not really interested into how strong a strong event is going to be but in whether we are going to have an event or not. Such information can not be lost using the categorization procedure, but to be emphasized instead. Only in the second stage of the study, we will be focusing in the intensity of the events, try to determine how strong (or weak) an event will be if occurs.

Although the probabilities of the corners of the contingency table (P11, P13, P31, P33), respectively CoolCool-Dry, Cool-Wet, Warm-Dry and Warm-Wet, seem to be more interesting and having a more straightforward interpretation, there is also some interest in the center row and column, since they represent the fact that we do not have any basis to expect any extreme condition (warm or cool event), which then correspond to a probability close to 1/3. However, the results herein presented are viewed as a preliminary study on cause effect relationships, by introducing the logit models. We did not, for example, discriminate association between strong, moderate and weak events to rainfall statistics, neither had we studied a particular event impact as for example Curtis et al., (2001) for the 1997-98 event. It will be necessary to extend this research to a higher density estimations for rainfall along west coast. For example analysis of an high density Ecuadorian rainfall data (more than 210 rain gauges) by Rossel et al., (1998) revealed that although coastal rainfall is highly associated to ENSO events, it is less the case for near Andean regions like Puyo or Cuenca. Therefore, our analysis based in 2.5 degrees latitude x longitude grids (roughly over 250 kilometers) does not discriminate between coastal and near Andean regions, therefore mixing or most probably diluting ENSO influence. Also, our investigation by constructing an ocean-atmosphere ENSO index, through mixing of Nino3 and SOI index, although practical, did not take into account the reality of the tropical pacific sea surface temperature evolution through the longitudes.

We must, as well, concentrate the research to some particular time scales. For example, in this study we neither separate the different modes that participate in ENSO, say interannual from the decadal time scales (Zhou and Lau, 2001), nor we separate ENSO from non-ENSO variability (Mestas-Nunez and Enfield, 2001). All this modes can be focused on the type of relationship found here and will need a different study, particularly the effect of the decadal time scales, or even lower frequencies, like global warming effect in rainfall. Finally we might also to extend our results to rainfall prediction given precedent season variability (see Montecinos et al., 2000). Coming years will be fruitful in this regard given the practical benefit this kind of models may have for agriculture, epidemiology, and generally the economy associated with climate.

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