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Long-Term Forecasting of the Extreme El-Niño Events

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ABSTRACT

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Until now the widley used predictive long-term hazard models of the most intense natural phenomena do not yield predictions other than the mean return period, which indicates only a mean recurrence time, but does not allow any time prediction of the of occurrence of the phenomena. To achieve more certain estimates an alternative model is proposed, and applied for the prediction of the most violent El-Ninos events. The model is based on the observations which show that (i) the oceanic thermal reservoir generating the El-Ninos events continuously accumulate thermal energy, but releases it both through small and intense El-Ninos events, and that (ii) such an oceanic system evolves saving an almost constant average power. This means that the higher (the less) the number of small events releasing energy after the occurrence of an intense one, the later (the earlier) an intense event is expected to occur. The years of occurrence of all the very strong events estimated by the model are found to be in fair agreement with the observations.

ADDITIONAL INDEX WORDS: *Long-term forecasting, catastrophic events, El-Niños.*

INTRODUCTION

The evaluation of the anthropogenic green-house effect on recent climate changes requires the prior determination of the natural (volcanic, oceanic, solar) forcing of the climate variability. The El Niño/Southern oscillation is a large source of climate variability (QUINN, 1987) (QUINN and NEAL, 1995). For the long-term forecasting of regional and global climate changes, and for the separation of the effects of the various factors that influence, in a most linear fashion, the climate, it is required to investigate on the recurrence of the very strong El Niño events.

I will first apply the traditional long-term forecasting models; namely the exponential (GUMBEL, 1958) and the power low (TURCOTTE, 1992), and then the model I propose (PALUMBO, 1997a).

The Data

The Scientific Committee on Oceanic Research (SCOR) (1983) proposed the criteria for a quantitative evaluation of the El-Niño events that occurred over recent years, and defined El-Niño as: the appearance of anomalously warm water along the coast of Ecuador and Peru far south as Lima during which a normalized sea surface temperature anomaly exceeding one standard deviation occurs for at least four consecutive months at three or more of five coastal stations.

Following the above criteria and examining all available information QUINN and NEAL (1995), by referring strictly the regional manifestation (the El Niño) of the large scale ENSO (El Niño/Southern Oscillation) obtained the longest possible record of the ocean-atmosphere activity from the existing historical records. They provided then a list of moderate M, M+, strong S, S+, and very strong VS El Niño events that occurred between 1524 and 1987 along with their related references. In addition they also provided a second list with a lower level cut off at the M+ intensity since they found in their research some periods during which their literature sources may have not detected one of the weaker moderate events.

El Niño events are often preceded by heavy meteorological phenomena that may be considered precursors of a next occurrence of the El Niño event (QUINN, 1987). Anomalously heavy anti-El Niño precipitation over eastern and southeastern Peru and adjacent parts of Bolivia 6–15 months prior to suspected El Niño occurrence likewise often adds positive weight to the El Niño determination.

I will analyze the above series of data of the catalogue of QUINN and NEAL with the lower level cut off at M+ updated with those provided by BAUER (1998) to obtain the long-term forecasting of the very strong El Niño events.

METHODS OF ANALYSIS

The earliest reliable (exponential model) method for the prediction of the extreme events was proposed by GUMBEL (1958). Epstein and Lomnitz (1966) were the first that enlarged the probabilistic model of Gumbel, expecially for the part regarding the formulism for the estimate of the risk. Since then many authors have proposed alternative (power hazard model) statistical techniques for severe event frequency-correlation (TURCOTTE and GREEN, 1993). All the exponential and power hazard models reflect a memoryless property of extreme events occurrences based on the assump-

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tion that the occurrence of an event in a site is independent on subsequent and previous event in that site. The above assumption is not valid for the time distributions of many natural phenomena, like volcanic eruptions, earthquakes, oceanic storms, *etc.* (PALUMBO, 1997b; 1997c; 1998a; 1998b), so that further different statistical approaches have been experimented (SHIMAZAKI and NAKATA, 1980, BAK *et al.* 1988; BAK and TANG, 1989).

OUTLINES AND APPLICATION OF THE VARIOUS MODELS

Exponential Model

The events, in order of increasing intensity, have been analyzed using the method of GUMBEL (1958) who assumed that the size m (in this case intensity) of N events is a random variable with a cumulative distribution function: $N = R^{-bm}$. The parameters R and b are obtained from the least square fit to the equation $\ln N = \ln R - bm$.

Power Low Model

I have also searched for a fractal character in the data set. It is well known (TURCOTTE, 1992) that fractal distributions model processes that exhibit scale invariance or self-similar properties such as scale-invariant clustering. If the number of objects N with a characteristic linear dimension greater than r satisfies the relation $N = Cr^{-D}$ or $\log N = \log C - D \log r$ a fractal distribution is defined where C is a constant and D, denoting the fractal dimension, provides a measure of the clustering of the objects versus r. The more isolated the clusters the smaller the values of D. Scale invariance is a necessary condition for the applicability of the above equation since no natural length enters in a power law relationship.

The results of these traditional models are reported in Table 1 together with the values of the return periods computed separately assuming an uniform distribution. The mean return period computed according to these models for the very strong El Niño events were respectively 56.5 and 73 years, with large uncertainties, notably for the fractal model.

The mean difference between the mean return period of the very strong events computed by the exponential model and each observed interarrival times is equal to 24 ± 39 years. The corresponding differences for the estimates provided by the fractal model is equal to 25 ± 51 years, where the indices of incertitude are the population standard deviations.

The results of these methods have thus poor practical forecasting utility because of the large uncertainty of the computed values of the return period, and also because the return period indicates, for an event of intensity greater than a fixed threshold, only a large interval during which the event will probably occur. The main reason for the failure of these models is related to the unpredictability and to the complexity of the evolution of many natural systems that do not allow significant estimates both of their physical modeling and of the long-term forecasting of their extreme events.

OUTLINE OF THE PALUMBO'S MODEL

It is worth noting that the mean return period represents only a time interval within which the event will probably take place without, however, providing no information on the year when the event will more probably occur. To contribute to the solution of the this problem I have related the interarrival times "Δt" between all subsequent pairs of observed Very strong El-Ninos events to an index of the total energy released by all the smaller events that occurred during "Δt".

First of all, I have correlated the qualitative indices of the catalogue of QUINN and NEAL (1995) with the contemporary quantitative multivariate indices provided by BAUER (1998). The comparison allowed to assigne to the qualitative indices M+, S, S+ and VS, respectively the quantitative indices 4.5; 6: 12 and 24. The counts "E_T" of the indices relative to all the events (smaller than the most intense ones) occurred during each "Δt" including the energy released by the next VS event represent an index of the energy transferred from the ocean to the atmosphere during Δt. The years of occurrence of the VS events, the values Δt and E_T and their ratios are reported in Table 2.

Table 1. *Intensity index (a), number of El Niño events from 1525 to 1998 (b), mean return periods computed according to three different distributions: exponential (c), power law (d) uniform (e).*

a	b	c	d	e
M	108	4.3	0.1	4.4
M+	84	5.5	1.8	5.6
S	47	9.8	9.6	10.1
S+	18	26.0	29.2	26.2
Vs	10	56.5	73.0	47.3

Table 2. *(a) years of occurrence of the Very strong El Niño events; (b) observed interarrival times Δt; (c) energy E_T released from the oceanic areas generating the phenomenon to the atmosphere; ratios Δt/E; estimated interarrivals times $(\Delta t)_{comp}$; (e) differences $\Delta t_{obs.} - \Delta t_{comp}$.*

Years (a)	$(\Delta t)_{obs}$ (b)	E_T (c)	$(\Delta t/E_T)$ (d)	$(\Delta t)_{comp}$ (e)	$(\Delta t_{obs} - \Delta t_{comp})$ (f)
1578					
1720					
1728	150	205	0.73	137	+13
1720					
1728					
1791	71	107	0.66	72	−1
1728					
1791					
1828	100	138	0.72	92	+8
1791					
1828					
1877	86	127	0.68	85	+1
1828					
1877					
1891	63	102	0.62	68	−5
1877					
1891					
1925	48	94	0.51	63	−15
1891					
1925					
1982	91	126	0.72	84	+7
1925					
1982					
1998	73	106	0.69	107	−1

$(\Delta t/E_T)_{mean}$ 0.67 ± 0.07 $(\Delta t_{obs} - \Delta t_{comp})_{mean}$ 0.9 ± 7 years

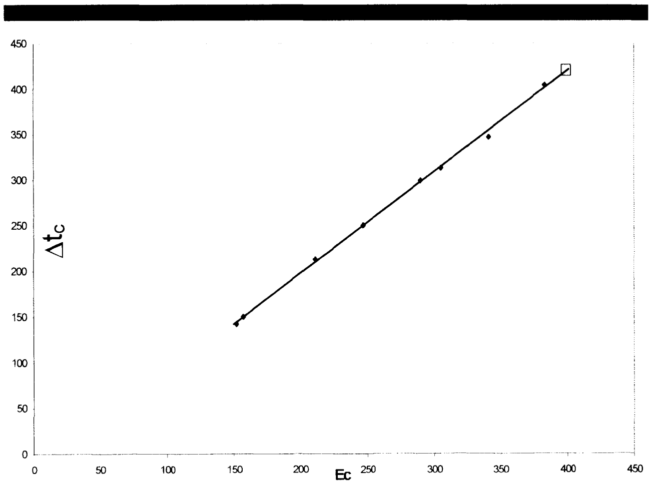

Figure 1. Interarrival times between successive very strong El Niño events versus comulate values Ec. The point * indicate the last very strong event forecasted by the model to occur in 1998 as observed.

The main results of the this analysis are: (a) the high significance level of the linear relationship (Figure 1) of the Δt_c − Ec plots (where Δt_c and Ec indicate the cumulate values of Δt and E_T) that shows a coefficient of correlation = 1, significant at 0.01 level; (b) the large scattering of the series of all Δt which does not allow any prediction ($\Delta t = 46.7 \pm 40.7$ years); (c) the significant mean value of all the ratios $\Delta t/E_T = (0.67 \pm 0.07)$, where again, the above incertitudes indicate the population standard deviations.

PREDICTION OF THE VERY STRONG EL-NINOS EVENTS ACCORDING TO PALUMBO'S MODEL

Observations show that (i) the oceanic thermal reservoir, generating the El-Ninos events, continuously accumulating energy, releases it both through small and through VS event, and that (ii) it never accumulates energy greater than that corresponding to a VS event, which is indicated, in our assumption, by E = 24.

Since $\Delta t/E_T = 0.67$ (Table 2), it follows that in the months subsequent the end of a VS event a next VS one cannot be expected earlier than $24 \times 0.67 = 16$ years.

Let us Assume to be in a year following the occurrence of a small event, when precursors indicate the possibility that a large event might occur. We may evaluate from the records the amount of energy E_T released by the system, during such time interval. From the mean value $(\Delta t/E_T)_{mean} = 0.67$, one may statistically estimate the year (following the preceding VS event) of occurrence of the next VS one, simply multiplying the observed value E_T' by 0.67. More precisely, from a phisical point of view, we should state that a nex VS event is non expected to occur earlier than the year (following the preceding VS event) given by $\Delta t = E' \times 0.67$. Similarly, since the observations show that, after a VS event, the reservoir has releases all the energy accumulated, and since we know the mean rate of discharge, we can assume that such a rate is equal to the average rate of the energy accumulation, that is, $(E_T/\Delta t)_{mean} = 1.49$.

In any year t′ counted from the year of occurrence of a VS event, we can compute the difference "D" between the energy accumulated ($1.49 \times t'$) and that released (E_T') until then. With such an information, we may compute the difference between "D" and the maximum energy capability of the system (in our case E = 24). Such a difference will indicate how much more energy the reservoir can accumulate, and thence which is the time interval separating t′ from the occurrence of the next VS event, assuming that no more small events will occur until then.

Table 2 reports the observed years of occurrence of the VS events and those predicted by the above model. For a more robust statistical computation the prediction was not performed from the last VS event, but from the occurrence of two preceding ones.

Table 2 shows moreover that the standard deviation between the observed years of occurrence of the VS El El-Ninos events and those estimated by the Palumbo's model, was equal to 0.9 ± 7 years, and thence much smaller than the corresponding estimates of the exponential and power low models.

CONCLUSIONS

The main result of the present investigation is the findings of the fairly constant value of the ratio $\Delta t/E_T$, which has allowed reliable predictions of the occurrence of the most intense El-Ninos events. According to the proposed model a next VS event, after the 1998 one, is not expected to occur before 2014. More accurate predictions can be estimated when further information on the future small events that meanwhile will take place, will be available.

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