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Recurrence of hurricanes as extreme weather events in Honduras

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Abstract

From year 1893 to 2020, seven extreme weather events have been recorded in Honduras. The event count follows a Poisson distribution with a λ value equal to 1. The arrival intervals follow a continuous Exponential distribution with mean equal to 1, equivalent to a 21.17-years period. The occurrence of hurricanes as extreme weather events is a random discrete statistical variable; the arrival intervals have a modal value of 20 years, a lowerbound of 20 years and an upperbound of 24 years. The cumulative occurrence probability exceeds the cumulative non-occurrence probability at the 15-year threshold. These extreme events are strongly associated with the Atlantic Multidecadal Oscillation (AMO) and El Niño Southern Oscillation (ENSO 3.4) indices. The average period of events' occurrence coincides exactly with one-fourth the estimated extension range's upper limit projecting the total AMO cycle, which is a range of 60-85 years. One extreme weather event coincides with a moderate El Niño, within a very prolonged period of predominantly neutral El Niño, as an exception; while for the remaining six events, all of them coincide with the onset or the intermediate period of a prolonged La Niña, just following after a predominantly moderate or strong El Niño.

Keywords: *Extreme weather event, climate change, Honduras, hurricanes, AMO, ENSO 3.4.*

Resumen

Desde el año 1893 al 2020, se han registrado siete eventos climáticos extremos en Honduras. El conteo de eventos sigue una distribución de Poisson con un valor λ igual a 1. Los intervalos de llegada siguen una distribución exponencial continua con media igual a 1, equivalente a un período de 21,17 años. La ocurrencia de huracanes como eventos climáticos extremos es una variable estadística aleatoria discreta; los intervalos de llegada tienen un valor modal de 20 años, un límite inferior de 20 años y un límite superior de 24 años. La probabilidad acumulada de ocurrencia excede la probabilidad acumulada de no ocurrencia en el umbral de 15 años. Estos eventos extremos están fuertemente asociados con los índices de Oscilación Multidecadal Atlántica (AMO) y El Niño Oscilación del Sur (ENSO 3.4). El período promedio de ocurrencia de los eventos coincide exactamente con una cuarta parte del límite superior del rango de extensión estimado que proyecta el ciclo total de AMO, que es un rango de 60-85 años. Un evento meteorológico extremo coincide con un El Niño moderado, dentro de un período muy prolongado de El Niño predominantemente neutral, como excepción; mientras que los seis eventos restantes, todos ellos coinciden con el inicio o el período intermedio de un La Niña prolongado, inmediatamente después de un El Niño predominantemente moderado o fuerte.

Palabras claves: *Cambio climático, fenómeno meteorológico extremo, Honduras, huracanes, AMO, ENSO 3.4.*

1 Introduction

Climate change phenomenon is basically a natural process, that has been occurring since millions of years ago. We can say that it is not a human-being created event, but it is important to understand that it is a natural process that has been altered by the life, economic and industrial activity of human people. In the last 273 years, human civilization has greatly contributed to accelerate this natural-phenomenon behavior, in the currently sustained climate variation (Vicuña, 2011; Regmi, 2013). The average periodicity of carbon dioxide concentration change in the atmosphere, fluctuating from 180 ppm to 280 ppm, is a total of 100 thousand years, lasting 50 thousand years in accumulation (temperature rising and declining) and 50 thousand years in deaccumulation (cooling and cooling down). Since the beginning of the Industrial Revolution in year 1750, the Earth's atmosphere had already exceeded the maximum average threshold of 280 ppm. It could be assumed that the climate would move into the new cycle of cooling and cooling down, i.e., the concentration of carbon dioxide in the atmosphere would begin to decrease naturally, until it reaches the cycle's lowest average 180 ppm, coinciding with a natural glacial period. In September 2016, carbon dioxide values in the Earth's atmosphere crossed the 400-ppm threshold (Krzaczek and Yates, 2017). Since year 2000, the concentration of carbon dioxide has acquired a slightly exponential accelerated growth; during the 20th century such growth was of linear character, increasing the same annual proportional rate during periods of approximately two decades (Meza, 2023). In this 21st-century third decade, we are rapidly approaching the next 500 ppm predicted threshold. Final thresholds are 700 ppm and 900 ppm. In the few periods that the planet has reached these last two thresholds, living things on the planet have completely disappeared and life has re-emerged after 100 million years.

In year 2019, atmospheric CO2 concentrations were higher than any other concentration that has occurred during the last two million years (high confidence) (IPCC, 2021). Intergovernmental Panel on Climate Change (IPCC) latest report gives greater prominence to the study and scientific research of extreme weather events caused by extraordinary accumulation of heat energy in the natural environment, due to their expected and demonstrated increase in intensity, frequency and destructive power. New topics in climate change science are now attracting attention, such as regional adverse climate effects, extreme events determination, the attribution of these events and the study of their behavior and predictability (IPCC, 2021). For regions such as Central America, the sixth IPCC report states the lack of elaborated and published data, the lack of regional climate evidence, the absence of regional climate studies, and in general, the weakness of scientific research related to climate change. The sixth report states that since 1980, with a medium level of confidence, it can be affirmed that a redirection of the course of mid-latitude tropical storms towards the two polar zones is very probable. This would mean that the trajectories of storms, cyclones and hurricanes would move away from the Central American territory; this, being only one of the possible consequences. Another possible consequence is that the time elapsed between these consecutive atmospheric phenomena, in the category of regional extreme events, would be lengthening.

However, there is another unexpected change that contrasts with the effect we are considering. That noticeable change is the behavior of greater interaction between the Atlantic and Pacific Oceans, throughout, around and over Central American territory. Now, the extreme atmospheric events in the southern Caribbean Sea have a greater tendency to head towards the Pacific Ocean, crossing the Central American territory. Even the same is happening the other way around, extreme weather events in the Pacific Ocean have a greater tendency to cross the territory to reach the Gulf of Mexico, or simply advance to the interior of the Central American and Mexican continental zone. Within this panorama, it is notorious the increasing activity of heat energy continental passage between the two oceans in the Panamanian territory, between the Gulf of Chiriquí and Bocas del Toro area, and in the Honduran territory, between the Gulf of Fonseca, and the corridors towards the Sula Valley and the Aguán Valley. In Honduras, society has detected during the last several decades a periodicity in extreme weather events that have caused serious damage to population, housing, infrastructure and extensive economic losses, since 1893. This paper attempts to determine some scientific basis for the behavior of extreme weather events that have periodically destroyed the economy of Honduras, as a general objective. The specific objectives include: 1) to define the most concrete categorization for extreme weather events determination in Honduras; 2) to establish in detail the objective characteristics that clearly allow these events' attribution as extreme weather events; 3) to make a detailed analysis of the individual associations between extreme events and the most relevant climatic indexes; 4) to establish a mathematical statistical model that clarifies these extreme events' periodic behavior.

2 Methodology

The research methods and procedures used here to meet the objectives included qualitative research application to establish the criteria in defining the particular type of extreme weather event covered by this work. To achieve this, I used the experience of the IPCC science team, exposed in the 2021 sixth report, on regional climatology, attribution of extreme events and updated conclusions on regional extreme weather phenomena behavior. I also used the advances that climate change and climatology scientists have made on the issues of using standardized indices about the most important climate variations or oscillations, such as the El Niño Southern Oscillation (ENSO 3.4) and the Atlantic Multidecadal Oscillation (AMO).

In this research, I have proposed a very basic mathematical model, integrated between the discrete Poisson statistical distribution and the continuous Exponential statistical distribution, to explain the periodicity and the probabilities of occurrence and non-occurrence of extreme events in Honduras.

IPCC defines extreme precipitation events as the daily amount of precipitation on the ground that was exceeded on average once in a decade in the reference period 1850-1900.

For IPCC, the main phenomena of internal variability in climate change are the El Niño Southern Oscillation (ENSO), the Pacific Ocean Decadal Variability and the Atlantic Ocean Decadal Variability (AMV), through their respective regional influences. It also projects that multiple climate impact drivers (CIDs) will change in all regions of the world. Climate impact drivers (CIDs) are climate system physical conditions (e.g., means, events, extremes) that affect an element of society or ecosystems. Categories are analytical logical units developed by qualitative researchers to conceptualize in an organized manner the intellectual findings related to a phenomenon or human experience that is subject to research (Given, 2008).

Hurricanes reaching Honduran territory are climatic phenomena with a strong anomaly in the usual hurricane trajectory in the northern hemisphere. This is the first element in hurricanes as extreme weather events categorization, as related to climate change impact on Honduran territory.

The classic qualitative study is one in which the conclusions are ”grounded” in the data. Rather than descending into the field of study armed with an aprioristic theoretical construct, and allowing theory to color the data, a grounded theory approach would suggest that the researcher begin his or her study with an open mind to the possibilities offered by the data and the perspectives of the research topics (Hyde, 2000).

Qualitative methods allow the researcher to study topics in greater depth; the collection and selection of data does not remain limited to predetermined categories. Qualitative methods produce a wealth of detailed data from a small or limited amount of individual data or information (Hyde, 2000).

Even with a single isolated case, if it is studied in sufficient depth and fine-tuned insight is applied, it can provide the basis for a theoretical explanation of a more general phenomenon (Hyde, 2000).

Inside the observed historical climate records there are 4 substantial increases in global temperature. The first is in 1878. The second is in 1914, at the beginning of World War I. The third is between 1940 and 1945, the World War II years. The fourth is in 1998, the Hurricane Mitch's year. In addition, two not so obvious increases could be considered, the year 1954, the tropical storm Gilda's year, and the years 1970-1974, the hurricane Fifi's year, in 1974.

As environmental degradation induced by natural disasters has become more frequent in recent decades, the impact of environmental changes on migration has created unprecedented new challenges. Compared to other natural disasters such as earthquakes and tsunamis, climate-related events caused most of people's displacement in 2010, forcing 38 million people to move away from their usual place of living (Delavelle, 2014).

Although climate change is a global phenomenon, its impacts can be locally differentiated. Mesoamerica's greenhouse gas emissions will most likely continue for a long time to be a very small fraction of global emissions, but its geographic characteristics make it one of the most vulnerable regions, related to the impacts of climate change (Barcena, Prado et al., cited by Delavelle, 2014). Latin America and the Caribbean is surrounded by the Pacific and Atlantic oceans, and the climate in the region is strongly influenced by prevailing ocean surface temperatures (SSTs) and associated coupled phenomena, such as El Niño-Southern Oscillation (ENSO). Both El Niño and La Niña influence weather patterns and the occurrence of extreme events (WMO, 2023).

La Niña ENSO phenomenon has occurred three times during the last 50 years, with a three- consecutive-years duration. The first one occurred in 1973-1976, the second in 1998-2001, and the third began in September 2020, continued most of 2021, with a slight pause in the summer of 2021, and evolved into an event of moderate intensity during 2022, passing to a neutral ENSO by March 2023. In these three presentations of a very strong and prolonged La Niña, in September 1974 there was the destructive hurricane Fifi, which destroyed the economy of Honduras; in October and November 1998 there was the destructive hurricane Mitch, which wreaked havoc throughout the Honduran territory; and in November 2020 there were two tropical storms in a row, just one week apart, after having a hurricane category, Eta and Iota (WMO, 2023).

Since last century to present time, the entire northern tropical region has warmed. The broader Caribbean (5º N - 35º N and 100º W - 55º W) has seen an increase in ocean surface temperature (SST) of 1.08 $\pm$ 0.32 ℃ per century and the West Indies (defined as the region covering the island countries in the Caribbean Sea) has seen a slightly higher increase of 1.32 $\pm$ 0.41 ℃ per century (Taylor and Stephenson, 2017).

The Atlantic Multidecadal Oscillation (AMO) is a natural cycle of basin-wide variation within the North Atlantic Ocean basin, in ocean surface water temperature data, with a cyclical period of 60 to 80 years in duration. It is based on the average of ocean surface water anomalies (SST) within the North Atlantic basin, typically between latitudes 0-80N (Trenberth et al., 2023). AMO index is defined as an average over a geographic area, of SST anomalies without mathematical trends, to reflect low-frequency heat variability in the Atlantic Ocean, on time scales longer than a decade (Enfield et al., 2001; Sutton and Hodson, 2005; Knight et al 2005; Ruiz-Barradas et al., 2013; cited by Trenberth et al., 2023).

Historically, alternating periods of warming and cooling of Atlantic Ocean surface waters occur, with a variable duration between 30 and 40 years (Taylor and Stephenson, 2017). Sometimes, the upper limit extends up to more than 40 years (Mann, 2016). This coincides statistically with extreme cyclonic events data behavior, that have affected Honduran economy since the year 1893 to the year 2020 (127 years).

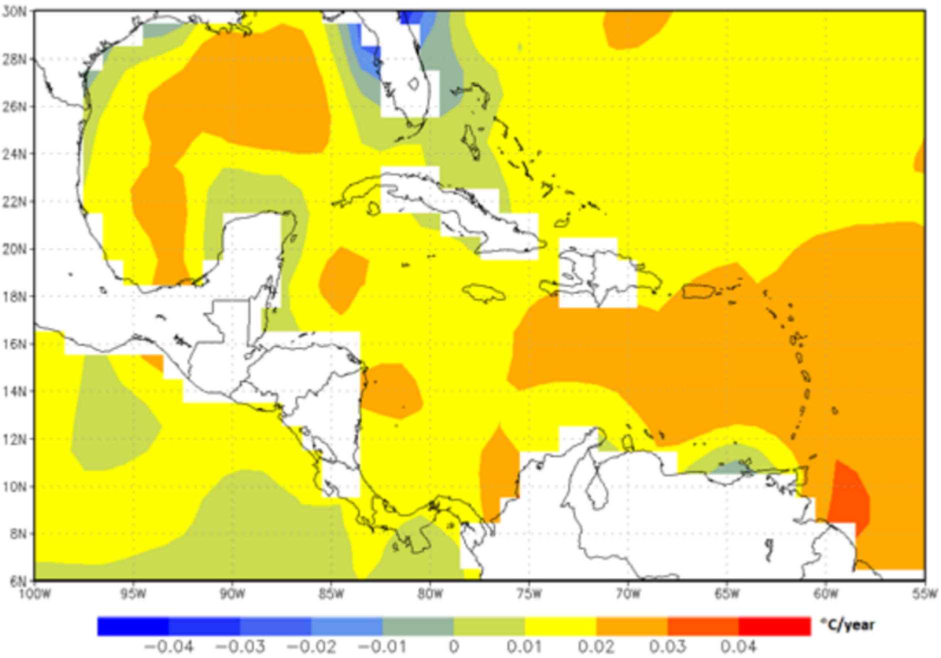

Figure 1: Detected SST trends (°C/yr), 1982-2016.

A second variability mode present in ocean surface water temperature data is linked to El Niño Southern Oscillation (ENSO). ENSO oscillation manifests as a warming in SST values in the central and eastern equatorial Pacific Ocean, which generally peaks in December after its onset and occurs on an irregular time scale shown every 3 to 7 years (Taylor and Stephenson, 2017).

Increased rainfall due to warmer ocean surface temperatures (SSTs) is a direct result of the convection barrier (usually taken at 26.5 °C) when it is being exceeded early in the year. Waliser et al. (1993) and Zhang (1993), cited by Taylor and Stephenson (2017), showed that the amount of rainfall precipitation in the tropics is a function of the SST magnitude, with non or little variability due to SSTs below 26.5 °C, but with an association of rapid changes between 26.5 °C and 29.5 °C, before falling again with higher temperature values.

It has been observed that, during AMO warm phases, a greater number of tropical storms (at least twice as many) mature into severe hurricanes than when AMO is in its cool phase (Taylor and Stephenson, 2017).

I have considered some hurricanes as extreme weather events, given that they meet the following objective criteria: a) They have shown a strong anomaly in the normal path following the established track of tropical storms, cyclones and hurricanes, in the Caribbean Sea, with a straight east-west direction or with a southerly direction.

b) Their geographical point of origin is from the north of Lake Maracaibo, up to a distance of 400 km to the north, and up to the Gulf of Honduras, including the Gulf of Darien.

c) At some point along their route, they touch or cross Honduran territory, or their route are parallel and very close to the Atlantic coast of Honduras.

d) The phenomenon's intensity, with the strength of its winds and the volume of its precipitation, had cause severe damage in Honduras.

Hurricanes that fall into the category of extreme weather events in Honduras have a singular statistical behavior, with a modal value of 20 years, with frequency 3 among 7 individual events, as the waiting time between successive arrivals. This behavior suggests a discrete random variable, with a count of 1 unit as a representative value in each occurrence interval, which is typical in a Poisson distribution.

Conditions for a Poisson model (Crawshaw and Chambers, 2001; Lavine, 2013; Ramachandran and Chris, 2009; Tsitsiklis, 2011): • Events occur individually and randomly within a given interval in time or space.

• Defined individual events are all statistically mutually independent. This means that the occurrence of an individual event at one location in the domain does not influence, affect, presuppose, or limit, under any circumstances, the occurrence of any other individual event at another location in the domain.

• In each unit interval, location of a unit or individual time period or subperiod, only one individual statistical event can occur. It is not feasible to superimpose two or more events in the same unit interval or individual time period.

• The domain of the study, that is, the domain of space, or time, or of the acting variable, as a platform for the presentation of events, is a defined block of that type of variable, strictly determined for its use within the Poisson model, and limited to the characteristics specifically defined in the study.

• In the statistical process, the presence of a rate of occurrence of statistical events that is invariant within the same space of the domain is clearly observed. The behavior of the statistical variable is consistent throughout the domain, and there are no substantial changes in this behavior due to transitory periods.

• λ, lambda, the average number of occurrences in the given interval, is known and is finite.

• The random variable X is the statistical variable on which the Poisson distribution is theoretically constructed.

• The random variable X is the statistical event's discrete number of occurrences within the given interval.

• The variable "x" is a sample variable, observed or experimental, of the user's choice, to test or recognize its occurrence probability within the model.

• Poisson process is closely related to the continuous Exponential statistical distribution, whose random variable is the time variable, defined to the measurement of time in a given time unit. The mean of the Exponential distribution is the inverse of the lambda parameter λ that determines the Poisson distribution. In the Exponential distribution, the probability density decreases as the value of the continuous random variable W moves away from the value 0; this means that when the waiting times between arrivals or arrivals are very long, their specific individual probabilities, to occur within a very short interval, decrease significantly, although their cumulative probabilities from zero increase (i.e., the probability that the event does occur is closer to 1).

Given the above conditions, we can state that X variable behaves according to the model of a Poisson distribution, which is represented as:

$$X \sim \text{Po}(\lambda) \text{ or } \text{X} \sim \text{Poisson}(\lambda) \tag{1}$$

$$P(X = x) = \frac{e^{-\lambda} \cdot \lambda^x}{x!} \quad \text{for x} = 0, 1, 2, 3, \ldots + \infty; \lambda > 0 \tag{2}$$

The lambda parameter, λ, is the only statistical parameter in the Poisson distribution. The natural number e is an irrational constant, equal to ≈ 2.71828.

The distribution is defined entirely on the basis of the parameter λ. This parameter is determined from the number of expected occurrences at the mean value of the distribution, within the temporal or spatial interval.

The mean or expected value of the distribution, E(X), is equal to the parameter λ value, by definition.

The variance of the distribution, Var(X), is also equal to the parameter λ value.

The mode in the Poisson distribution is the numerical value of the random variable X that has the highest occurrence probability. In practice, it is noted among the observed values of the corresponding variable x, which is assumed to have the same theoretical behavior as the variable X, that the relative frequency of values is concentrated in one value, in two values and in very rare cases in three or more values.

In the Poisson distribution, the modal values are very consistent. For example, when λ=1, the mode falls on the observed value 0 and also on the observed value 1; when λ=2, they are always two modes, value 1 and value 2; when λ=3, the modes are value 2 and value 3. This property holds on, and when λ=n, the two modes are n-1 and n.

Modal values 0 and 1 have the highest probability value, 0.36; modal value 2 has about half that probability, 0.18; modal value 3 has a much smaller probability, 0.5; the next successive modal values drop rapidly in their probabilities and get closer and closer to 0.0. The first three possible positive modal values accumulate most of the probabilities, although the possible modal values extend to infinity; but the highest possible modal values have very low probabilities. This is why the Poisson distribution is known as "the distribution of rare events".

In the same way, when the rate that constitutes the λ value is expressed as a ratio between integer numerical values, the mode will be the integer part of the lambda value. For example, if λ=8/5=1.6, and the mode is equal to 1; if λ=9/4=2.25, the mode will be 2; if λ=18/4=4.5, the mode will be 4.

The cumulative probability for an experimental random value x, or what is the same, the probability that the theoretical variable X takes values equal to or less than the experimental value x, is calculated by means of the cumulative probabilistic mass function:

$$P(X \leq x) = \sum_{i=0}^{x} \frac{e^{-\lambda} \cdot \lambda^{i}}{i!} \quad \text{for i} = 0, 1, 2, 3, \ldots \text{x}; \lambda > 0 \tag{3}$$

The probability density function for the Exponential distribution is defined as follows:

$$\text{W} \sim \text{Exp}(\mu) \text{ or } \quad \text{W} \sim \text{Expon}(\mu) \tag{4}$$

$$\text{F(W = w)} = 1/\mu \cdot \text{e}^{-\text{w}/\mu} \quad \text{for w} > 0. \tag{5}$$

Because of differentiation, we use the variables W and w, indicating "waiting time".

Between two specific trials or point trials, a and b, the cumulative probability function is a definite integral that calculates the density of the probability function between the two values.

$$F(W) = \int \left(\frac{1}{\mu}\right) \cdot e^{\frac{-w}{\mu}} dw \text{ , } for \text{w} > 0 (indefinite integral) \tag{6}$$

$$F(W) \mid a, b = e^{\frac{-a}{\mu}} - e^{\frac{-b}{\mu}} (definite integral) \tag{7}$$

The expected value of the random variable W is E(W) = µ and the mean is µ = 1/λ.

The variance is Var(w) = $µ^2$.

3 Results and discussion

Temperature differentials or anomalies for the Central American territory fluctuate between 3.5 ºC and 4.0 ºC (IPCC, 2021). Although the global average temperature increase is 1.5 ºC, the real change for the interregional zones in the Central American countries is much stronger, rising to more than 8 ºC during the 12 months in the years in which a very intense El Niño phenomenon occurs. The impact on agriculture is catastrophic, and the negative impact on the inhabitants' quality of life is very drastic due to the heat wave permanent intensity during these periods.

It is virtually certain that salinity contrasts at the ocean surface have increased since 1950, and there is high confidence that marine heat waves have become more frequent during the 20th century. In the last four to six decades, it is virtually certain that the global ocean has warmed, making climate change irreversible with a duration of centuries to millennia (medium confidence) (IPCC, 2021).

Ocean warming observed intensity since 1971 is likely to increase by at least 4 to 8 times by the year 2100, according to a high global warming scenario (SSP5-8.5). The Brazil Current, originating in the discharge of the Amazon River, will intensify during the present century (IPCC, 2021).

The national-territories average temperature has now globally increased by 1.59 ºC (varying between 1.34 ºC and 1.83 ºC). But this index shows strong variations within national land regions. In Honduras, in a very marked way, certain land corridors between the Pacific Ocean and the Atlantic Ocean, suffer average increases of up to 12 degrees Celsius, varying seasonally between 6-8 degrees and 16-18 degrees.

The factors affecting the intensity and frequency of extreme weather events (prioritized in the destructive hurricanes affecting Honduras) cause a multiple intervention in the statistical distribution of destructive hurricanes. This statistical distribution has the nature of a Poisson distribution. Hurricanes are behaving as if they were bounded by a continuous cycle of very long term, and by one or more driving factors that support their inevitable creation. The continuous cycle separates them in time, uniformly, acting in a horizontal plane dimension; the separation currently observed from 1893 to the year 2023 is a statistical mode of 20 years, which also functions as a lower boundary that quite strongly delimits the individual period to an observed minimum of 20 years; however, this lower limit or lower boundary of 20 years is not absolute and deviations to values less than 20 years are to be expected. The other drivers act in at least a linear and vertical dimension. Their dimensionality could very well lose verticality and become a volumetric dimension with linearity similar to an upward or downward spiral.

For this analysis, which considers some hurricanes as extreme weather events, the following geographical zones are vital: the Amazon and Orinoco river basins, the formation zone of the Orinoco anticyclone, the Gulf of Darien, the three areas of preferential passage of the atmospheric heat flow from the Pacific Ocean to the Atlantic Ocean (and vice versa) in the Strait of Tehuantepec, the Gulf of Fonseca entry point and the small Gulf of Chiriquí, and the southernmost area of the Antillean Sea off-coast from Venezuela.

The more frequent and intense droughts in the Orinoco and Amazon river basins represent a greater risk for Honduras, due to their impact on the anticyclones -weakening around the mouth of the Orinoco River in Venezuela, the greater floods in the Amazon River discharges at the end of a prolonged dry period, and the concentration of hot or cold water in gigantic volumes in the Gulf of Darien, as a result of the Amazon River discharges; this creates the ideal conditions for hurricanes formation as Hurricane Mitch's category in that gulf. An additional element is the intensification of deforestation in the Amazon River basin and, in turn, in the Orinoco River basin (Taylor and Stephenson, 2017).

The next illustration shows projected long-term changes in the hydrological cycle considering the SSP2-4.5 scenario. According to conclusions derived from the analysis contained in the scientific publication over El Niño phenomenon forecast for years 2015-2017 (Meza, 2023), we are in a certain dual position within the climate-change current phase with respect to the possible scenarios reported by the IPCC, in its ARG6-2021 emission, in the sense that SSP2-4.5 scenario conditions partially coincide with those of SSP2-8.5, as of the current period, but the real trend in the last 23 years is going towards the SSP2-8.5 scenario situation, due to the fact that in this 23-year period the carbon dioxide concentration in the atmosphere's increasing rate went from being linear to being very slightly exponential.

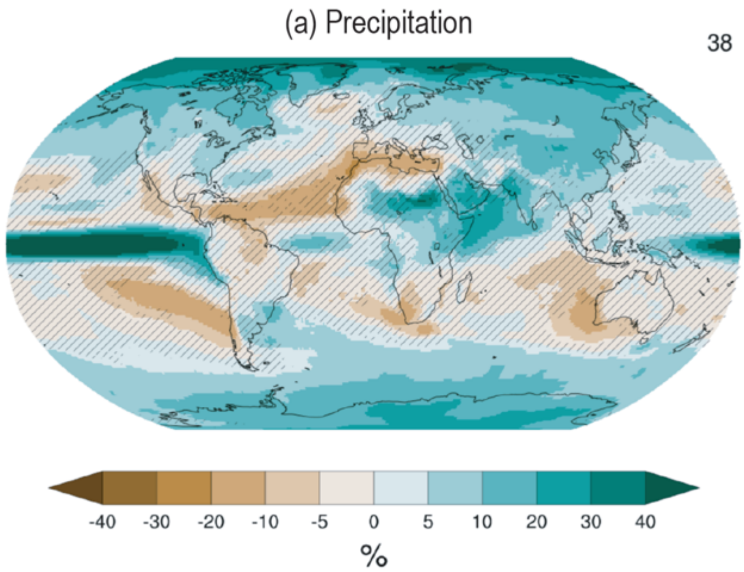

Figure 2: IPCC's 6th report precipitation projection into 2100.

We can, therefore, assume this long-term projection to be valid. The interesting thing about this projection for the Central American isthmus is that in Central American region there are two opposing processes. On the Pacific Ocean side, there is a trend towards a more intense rainfall rate, with an increase of more than 40 percent, comparing the periods 1995-2014 with 2081-2100 (projected). On the Atlantic Ocean side, there is a trend towards less rainfall, with a decreasing level varying between 10 and 20 percent. In both oceans, the geographical subregion of impact coincides with the area occupied by the planet's Global Warming Belt, which covers the equatorial zone of the Pacific Ocean from Australia to the vicinity of the coasts of Peru, Ecuador and Colombia, it crosses Central American territory towards the north, and advances through the southern part of the Caribbean Sea or the Antilles, towards the eastern coast of Africa and enters the entire area of the Mediterranean Sea, affecting the entire region of southern Europe and the northern region of the African continent.

There are two climate change indices that become relevant to associate the phenomenon of hurricane recurrence as extreme atmospheric events around the territory of Honduras. The first and most important is the Atlantic Multidecadal Oscillation (AMO) index, which in recent years is conceptualized with its transformation into the Atlantic Multidecadal Variability (AMV) index. The second index is the El Niño Southern Oscillation (ENSO 3.4).

One of the most important climatic "factors", "drivers" or climatic "drifters" (CIDs) for the Central American region is the behavior of rainfall discharge and the corresponding water discharge in the Amazon River basin in South America. This water discharge from the Amazon River is linked to Hurricane Mitch's formation in the Gulf of Darien, in 1998. The IPCC projection is that there will be a gradual reduction in the number of hurricanes, tropical cyclones and tropical storms in the Central and South American region, but correlatively there will be a sharp increase in the intensity of these atmospheric phenomena. In fact, during the last decades, the intensity of hurricanes has increased from categories 1 and 2 to categories 4 and 5.

The total mass of the atmosphere is 5.14 × 1018 kg, and is barely equivalent to about 3.7 thousandths of the total mass of the oceans, which is 1.39 × 1021 kg, and one millionth of the solid mass of the Earth, 5.98 × 1024 kg (Mathez and Smerdon, 2018). It is easy to conclude, by qualitative deduction, that the atmosphere is predominantly receptive to the effects produced in the oceans and on continental and island masses. By convection, in the equatorial warm zone of the Pacific Ocean, the atmosphere receives ascending currents of warm air, which reach above-1,000-kilometers heights, and gives off descending currents of cold air, generating a cyclic energy exchange (Mathez and Smerdon, 2018).

The high propensity towards drought or aridity zone, which affects almost the entire Caribbean Sea, and spreads towards the northern part of the African continent, also extends through the northern triangle of the Central American territory, penetrating some 600 km into the Pacific Ocean, southward the Gulf of Fonseca. The high drought-prone zone has an average rainfall of 2 mm of rain per day; the high humidity-prone zone has an average rainfall of 7 mm per day; the latter only includes the easternmost part of Gracias a Dios Department's territory (Mathez and Smerdon, 2018). The transfer and exchange of atmospheric climatic conditions between the two huge oceanic liquid masses, Atlantic and Pacific, evolves the effects of global warming around the Central American territory, which constitutes a weak and very vulnerable geographical barrier between the two oceans.

Ocean surface temperatures (SSTs), for example, can alter regional pressure patterns in the atmosphere and thereby cause changes in winds, move convection regions, and alter the direction of storm tracks and high-speed currents. Winds, in turn, feed back into the ocean by modifying the direction of ocean currents and influencing the transfer of energy between the atmosphere and the ocean (Mathez and Smerdon, 2018).

El Niño and La Niña are two linked oceanic phenomena, linked to the atmospheric phenomenon known as the Southern Oscillation, which is a recurrent, cyclical movement in atmospheric pressure that occurs between the eastern and western regions of the equatorial Pacific Ocean.

Collectively, these phenomena are referred to as ENSO (El Niño Southern Oscillation). To forecast their occurrence, the ENSO 3.4 index is used as a parameter. This index is integrated by the ocean surface temperature (SST) in a geographical box of the tropical Pacific Ocean, limited by latitudes 5º N and 5º S, and by longitudes 170º W and 120º W. Its location is exactly in the central zone of the Pacific Ocean. The associations between the ENSO 3.4 index and the AMO index and hurricanes as extreme weather events in Honduras can be described as follows:

A. Hurricane I-2.

In 1893, Hurricane 2 formed in the western Gulf of Darien, lasting from July 4-7. The hurricane headed for Cape Gracias a Dios in Honduras, crossing the Mosquitia territory in Honduras, northern Belize and the southern Yucatan Peninsula in Mexico. The average Atlantic Ocean SST anomaly for year 1893 was +0.11 °C. This was the second strongest positive anomaly in the Atlantic Multidecadal Oscillation (AMO) Index over the period 1870-1897, second only to the annual average SST AMO anomaly for 1878, at +0.22 °C.

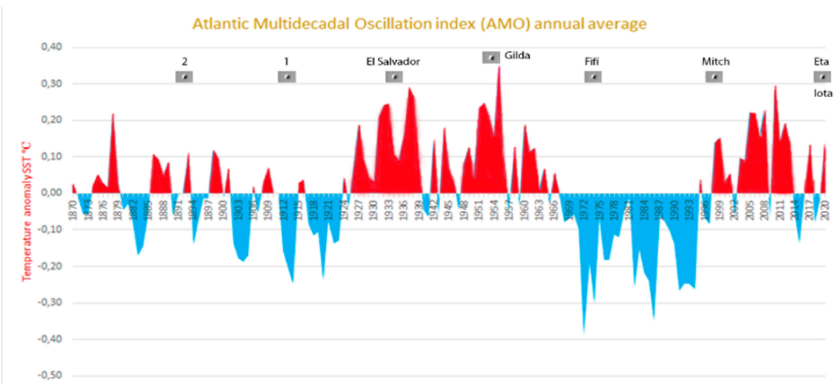

Figure 3: AMO SST index, anual average.

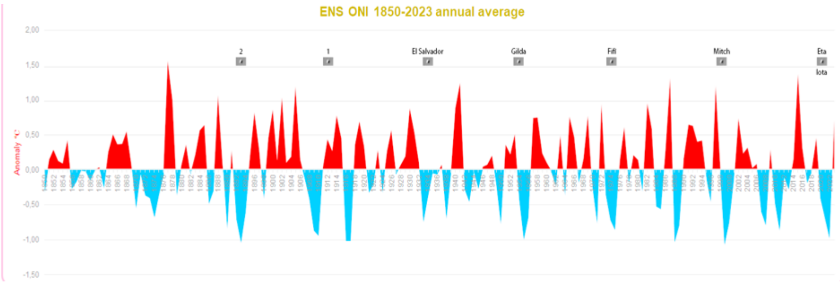

Figure 4: Ensemble ENSO 3.4 index, annual average.

On the other hand, the average ENSO 3.4 index for that year shows a maximum negative anomaly value of -1.05 ℃, the most intense value in 1850-1893 whole period. In that same year 1893, months with ensembled values as cooling indices (negative SST anomalies in the central Pacific Ocean region), whose absolute values are greater than or equal to 1 ℃, accumulated continuously from September 1892 to October 1893. Monthly values are stacked in three-month periods, with the index month in the middle, as a criterion for the endurance of the meteorological effects of the ENSO 3.4 oscillation, and an El Niño is considered if the indices continuously equal or exceed during several index months the value +0.5 ℃, or a La Niña is considered if these indices continuously equal or exceed the absolute value -0.5 ℃. La Niña SST anomalies began in June 1892, with a stacked value of -0.5 ℃, and ended in June 1894, with a stacked value of -0.6 ℃. The total duration of La Niña was 25 months, and right in the median month, the month of July 1893, Hurricane 2 occurred. The indices were equal to or greater in absolute value than -1.0 from September 1892 through October 1893. All other months in the 25-month set had indices less in absolute value than -1.0 ℃.

La Niña classification in this period corresponds to a ”moderate La Niña”, with a maximum intensity index marked by an absolute value between -1.0 ℃ and -1.5 ℃. La Niña maximum intensity was -1.4 ℃ during October and November 1892. B. Hurricane I-1.

In 1913, Hurricane 1 formed in the aftermath of a very prolonged La Niña event (October 1908 - April 1911, 31 months), with a short lead-in, towards the end of 1913, of a moderate El Niño event, which lasted 20 months, from November 1913 to June 1915. The period covered by Hurricane 1 was between June 21 and June 29, 1913. The 1908-1911 La Niña classification was ”moderate La Niña,” with a peak intensity of -1.2 ℃ in SST anomaly.

The relevance of this extreme weather phenomenon is that it occurred in the last phase of a very prolonged La Niña event of moderate intensity, the most intense and prolonged of the period 1850-2023 (173 years).

It also occurred while existing the succession of very prolonged neutral ENSO phases, from May 1906 to September 1908, then very prolonged moderate ENSO La Niña, from October 1908 to April 1911, and finally neutral ENSO, from May 1911 to October 1913, with interspersed variability of moderate and short-lived El Niño, with a peak intensity of -1.4 ℃ as the SST anomaly.

In the corresponding Atlantic Multidecadal Oscillation (AMO) Index, the average Atlantic Ocean SST anomaly for year 1913 was -0.2 ℃. This was the strongest negative anomaly in 1870-1913 period, second only to the negative anomaly for the following year 1914, in the entire sinusoidal, multidecadal cooling subcycle prior to 1925. C. Hurricane El Salvador.

During 1934, between June 4 and June 21, the Central America hurricane, El Salvador or Temporalon, formed one month after the coolest period of a dominant and very prolonged neutral ENSO event (April 1920 - December 1939). The average ENSO 3.4 SST anomaly for the year 1933 was -0.75 ℃, the lowest negative value in the 20-year period between 1920 and 1939. In that year 1933, the peak negative SST anomaly was -1.10 ℃ from August 1933 and persisted the same value until January 1934 for 6 continuous months. This was the longest dominant neutral weather event since records date back to 1850. During this period there were 4 La Niña events of very short duration and intensity, and 3 small El Niño events of mild to moderate intensity.

Immediately following the two strongest ENSO events of 1920-1939 period, moderate El Niño 1930-1931 and moderate La Niña 1933-1934, Hurricane El Salvador formed in the Gulf of Honduras, penetrated Belize, then Guatemala, moved into the border zone of Guatemala, El Salvador and Honduras, and headed north out of the Yucatan Peninsula into the Gulf of Mexico. This is the only extreme weather event being formed in the Gulf of Honduras since 1850.

Hurricane El Salvador marked the beginning of the continuation of a dominant neutral ENSO event, which resumed in May 1934 and lasted until March 1938, briefly giving way to a weak La Niña between April 1938 and February 1939, ending in neutral ENSO during December 1939.

The corresponding SST AMO anomaly for 1934 dropped to +0.11 °C, following three consecutive years of the highest Atlantic Ocean surface water warming anomaly (AMO index), with annual average values of +0.21 °C for 1931, +0.24 °C for 1932 and +0.24 °C for 1933. These are the highest warming anomaly values in that index over the entire 1870-1934 period. Also, the continuous period of positive SST AMO 1926-1939 anomalies constitutes the longest such period from year 1870 to year 2020.

This hurricane departs from all known patterns in terms of pre-established historical paths for Atlantic Ocean hurricanes. The hurricane formed in the Gulf of Honduras and penetrated southward into the territory of the Republic of Guatemala, also intensely affecting the entire territory of the Republic of El Salvador, and the western and central part of the Republic of Honduras. The intense rains lasted unceasingly for regional periods ranging from 15 to 30 days, causing in these regions the most catastrophic floods in the entire 20th century. In the city of Ocotepeque alone, it was estimated that more than half of the population died and only the Catholic church building was left standing, where the group of survivors took refuge.

D. Tropical Storm Gilda.

In 1954, on September 24, tropical storm Gilda formed at the beginning of a very intense and prolonged ENSO La Niña event, and after a lapse of ENSO SST anomalies 3.4 greater than zero, but of very low intensity. The area where the storm formed was northbound of Colombia, at the same latitude as Honduran territory. In just three days, the storm advanced from Colombia to Belize, passing through Cape Gracias a Dios. Storm Gilda crossed the Yucatán Peninsula and entered the Gulf of Mexico, disappearing in Mexican territory in the last days of September.

It affected the entire northern coast of Honduras, causing severe flooding. There were floods and landslides in San Pedro Sula's urban sector. Flood damage was extensive in the Sula valley, around the communities of San Pedro Sula, La Lima and others (Davis, 1954). Official reports mention a death toll of at least 29 people on the northern coast of Honduras.

Monthly SST ENSO 3.4 negative anomalies, characteristic of the La Niña event, began in May 1954 with a value of -0.6 °C, and ended in August 1956 also with a value of -0.6 °C. Its highest peak in the period was -1.6 °C already for the month of November 1955. This peak determines it as strong-La Niña.

Annual average value for 1953 was +0.51 °C; for 1954, it was -0.42 °C, signaling a very weak transition from El Niño to La Niña in that year; for 1955, it was -1.0 °C, the year of greatest ENSO 3.4 cooling intensity; and for 1956, it was -0.69 °C.

SST ENSO 3.4 anomalies greater than zero did not exceed +0.5 °C from April 1942 to July 1951. Then began a very brief period of monthly indices characteristic of moderate-El Niño, in August 1951, which ended in January 1952. This was followed by a neutral ENSO which ended in April 1954. The negative ENSO 3.4 SST anomalies lasted until January 1957. The annual average of the greatest cooling in SST ENSO 3.4 anomalies from 1942 to 1957 was -1.0 °C in 1955, during the La Niña phenomenon that included the formation of the Gilda storm.

Similar to what occurred during Hurricane El Salvador in 1934, a sudden decrease in the AMO index coincided with Storm Gilda, which averaged +0.23 °C in 1951, +0.25 °C in 1952, +0.21 °C in 1953, +0.16 °C in 1954, and +0.35 °C in the year 1955. Both meteorological phenomena were formed in the first half of the first sinusoidal cycle of Atlantic Ocean Multidecadal Oscillation (AMO) index, which is shown with greatest mathematical graphic evidence in the last 174 years. Hurricane El Salvador occurred while the cumulative phase of the positive AMO index, and storm Gilda in the decumulative phase of the same positive AMO index (warming of the Atlantic Ocean).

The first half of the previously described sinusoidal cycle began in 1924 and ended in 1967, with an approximate duration between 42 and 43 years. Therefore, it is so postulated that AMO cycle's maximum duration in Earth's current climatic process is between 84 and 86 years. However, the second "half" of the sinusoidal cycle, the cold or cooling phase, began in 1968 and ended in 1997, with an approximate duration of 30 years. Therefore, it is so assumed that AMO cycle's minimum duration would be 60 years. Between 1924 and 1997 a complete cycle of the Atlantic multidecadal oscillation was closed. The observed AMO oscillation demonstrates that the prevailing climatic process on planet Earth is a global warming process. Because of this predominance, in this work I assumed a total AMO cycle's duration centered on the maximum of 85 years, and an average duration of its four cumulative and decumulative phases, at 21.25 years. Due to planet's global warming advance, it is possible that next AMO cycle's observed values will show a tendency to increase the number of years.

E. Hurricane Fifí.

In 1974, between September 14 and 24, hurricane Fifi formed in the middle of the third moderate and prolonged La Niña phenomenon, which allocated in series with the ENSO La Niña of 1934 and 1954, form a triad of ENSO La Niña linked to three hurricanes as extreme weather events in Honduras. The storm formed in Caribbean Sea's eastern part, some 400 km northward the coast of Venezuela, at the same latitude as Honduras' northern coast. Its course remained westward, reaching the Honduran coast on September 17. In the first 24 hours, the hurricane dumped some 600 millimeters of rain over the territory of Honduras, causing catastrophic flooding and massive landslides. The storm continued its path to the Mexican Pacific coast.

The extensive damages of the hurricane were estimated in at least 9,000 dead people, hundreds of missing inhabitants; damaged cities: Choloma, Omoa, La Ceiba, San Pedro Sula; the Sula Valley turned into a lake that lasted two to three months, massive destruction of infrastructure, livestock and crops lost, destroyed bridges, landslides, and more than 60,000 people who lost their homes (AAP-Reuter, 1974). In La Ceiba city, Cangrejal River dragged more than 80 people into the sea, those who did not manage to survive, and whose bodies we could not rescue.

Negative SST ENSO 3.4 anomaly reached in 1973 the annual average value of -0.36 °C; in 1974, it was -0.72 °C; and in 1975, it was -0.86 °C. The most intense cooling SST anomaly corresponded to December 1973, with a value of -1.7 °C; and for September 1974, it declined through the index -0.3 °C.

This extreme weather event to Honduras occurred in AMO cycle's third phase initial period, the cooling accumulation stage in the surface waters of the Atlantic Ocean. This third and fourth phase of Atlantic Ocean cooling began in year 1967, with a neutral annual average AMO SST index of 0.0 °C.

Since 1968, the AMO SST indices have been persistently negative, signaling ocean cooling, starting with an annual average value of -0.08 °C, and ending in 1997, with the same value. This is a continuous 30-years Atlantic Ocean's surface-water-cooling period. AMO SST average annual rate in 1974 was a moderate cooling, with a -0.3 °C value. That was the second most intense cooling rate of the cumulative AMO phase, after the largest rate occurred in year 1972, with a value of -0.39 °C, which was the most intense annual Atlantic cooling rate of the last 170 years, from 1870 to 2020. F. Hurricane Mitch.

In year 1998, the most disastrous devastation in the history of Honduras occurred, with the formation of Hurricane Mitch, the most destructive hurricane in Honduras' history and one of the most powerful hurricanes in recorded meteorological phase. Hurricane Mitch, which reached category 5, formed on Gulf of Darien's northern edge, on October 22 and lasted until November 9. The phenomenon caused some 9,086 deaths, not including missing persons, of which 5,677 are attributed to human damage in Honduras. Damage to infrastructure in Honduras was very severe, with roads blocked by landslides, almost a hundred bridges destroyed by rivers, and hundreds of thousands of people affected, with many thousands of homes destroyed. Crop losses were almost total (Guiney and Miles, 1999).

Hurricane Mitch had a maximum accumulated rainfall of 897 mm in Choluteca city (southern region), 863 mm in La Ceiba city (northern region), and a minimum accumulated rainfall of 251 mm in Gracias city, department of Lempira (western region) (Guiney and Miles, 1999).

Hurricane Mitch was the transition point between a one-year ENSO Super El Niño (May 1997 - April 1998), with a maximum positive ENSO 3.4 SST anomaly of +2.7 °C in December 1997, and a moderate ENSO La Niña, lasting 25 months, starting in July 1998, with a SST anomaly of -1.0 °C, and ending in July 2000, with a SST anomaly of -0.5 °C; the beginning of 1998 started with an ENSO 3.4 SST anomaly in January 1998, with a +2.5 °C value; and at the end of 1998, in December, the ENSO 3.4 SST anomaly dropped to -1.4 °C. In October and November 1998, the corresponding SST anomalies were -1.2 °C and -1.4 °C.

Hurricane El Salvador in 1934, tropical storm Gilda in 1954, hurricane Fifi in 1974 and hurricane Mitch in 1998 share very roughly the same climatic scenario, so occurring between the beginning and middle of a transition period from a moderate to Super ENSO El Niño, immediately preceding or somewhat close to preceding, to a weak to moderate ENSO La Niña, and with an 2-to-3 years extension.

Regarding AMO SST anomalies, temperatures in Atlantic Ocean surface waters, Hurricane Mitch occurred at the beginning of a new AMO cycle, very close to the transition of AMO decumulative cooling phase that ended in 1997. No new very intense or very prolonged accumulation of heat energy in the Atlantic Ocean was needed as a prerequisite for an extreme weather event in Honduras. The annual average index of AMO SST anomalies for year 1996 was -0.07 °C; for year 1997, it was -0.08 °C; both years were mild cooling ones of Atlantic Ocean surface waters with respect to previous-30-years standard average. In year 1998, the AMO index shifted to positive or warming values, with +0.14 °C annual average, which is a moderate value. By coincidence, exactly same behavior, in terms of 2018-2020 triennium data, occurred later with the next extreme weather event for Honduras, in year 2020, with hurricanes Eta and Iota.

Comparing meteorological data between the previous AMO SST warming half-cycle from 1924 to 1967, into which Hurricane El Salvador and Tropical Storm Gilda occurred, with the new warming half-cycle in the Atlantic Multidecadal Oscillation, featuring Hurricane Mitch and Hurricanes Eta and Iota, the first two extreme weather events were characterized by a sudden decrease in the AMO SST warming index, from +0. 24 °C in 1933 to +0.11 °C in 1934, and from +0.21 °C in 1953 to +0.16 °C in 1954; two years later in the first case, and one year later in the second case, the warming level in the oscillation rebounded. In the Mitch event and in the Eta and Iota event, what occurred was a sudden rise in the warming rate in the AMO oscillation, from a mild cooling level during the previous year. G. Hurricanes Eta and Iota.

During year 2020, extreme weather events in Central America were repeated with hurricanes Eta and Iota, which penetrated Honduran territory, already downgraded to tropical-storm category. Hurricane Eta formed on October 31 in the eastern part of the Caribbean Sea, some three hundred kilometers north off the coast of Venezuela, north off the Gulf of Maracaibo, and 1,075 kilometers east of Cape Gracias a Dios. The hurricane headed exactly westward towards the territories of Nicaragua and Honduras, where it crossed and then headed northward, crossed Gulf of Honduras, Gulf of Mexico and finally advanced towards the North Sea, until November 13. It also crossed the territories of the Cuba island and the Florida peninsula. On two occasions, this hurricane headed south, then north and finally to the northeast.

On November 3, in just one day, Eta quickly reached category 4, and that same day it penetrated the territory of Nicaragua. It is considered the third most powerful hurricane in the month of November since records have been kept.

Eta caused more than 200 deaths and a hundred people disappeared. Floods, damage to infrastructure and destruction of homes were catastrophic in Honduras and Nicaragua. In Honduras, some 1.7 million people were affected.

Eta crossed Honduran territory through the departments of El Paraíso, Francisco Morazán, Comayagua, Yoro, Cortés and Atlántida. Quantification of material damage caused by Eta in Honduras amounts to US 5 billion, within a grand total of US 7.3 billion calculated for the entire path of the hurricane.

Hurricane Iota formed on November 13, only 10 days after Eta's entry into Central America. Previously, on October 30, a low-lying tropical wave moved from the west coast of Africa, across the Atlantic Ocean. On November 7, 8 and 9, the tropical wave rapidly moved along the northern coast of South America, crossing the entire southern Caribbean Sea. The hurricane strengthened in 48 hours, between November 14 and 16, to category 4, stronger than hurricane Eta. Iota benefited from the hurricane eye having passed very close to an anticyclone center in the upper levels of the atmosphere. It also benefited from the atmospheric remnants left by Hurricane Eta in the same area of the Caribbean Sea. Both atmospheric phenomena, Eta and Iota, interacted slightly to intensify weather damage along the same path and in the same area of the Atlantic Ocean.

Iota became a hurricane in the eastern Caribbean Sea, about 400 kilometers off the coast of Venezuela, north off the Gulf of Maracaibo. It descended southwestward to penetrate the Gulf of Darien and then moved westward to enter northeastern territory of Nicaragua and southern Honduras, dissipating within the Salvadoran territory on November 18.

Iota presented extraordinary weather manifestations. The hurricane sustained an explosive-deepening incredible period between November 14 and 16, during which central pressure dropped an astonishing 80 mb in 42 hours (Stewart, 2021). Coincident with the rapid deepening, the hurricane advanced to intensity levels that strengthened it in wind speed and high destructive power. It also showed hail formation on its inner walls, in the hurricane eye, which is a very rare phenomenon in these storms.

Damage caused by Hurricane Iota was substantial because its material effects accumulated over a territory that was still not recovering from the physical damage caused by Hurricane Eta. COPECO (Permanent Contingency Commission, a government entity) officially reported 366,000 people directly affected by the hurricane. In western Honduras, there were two cases of towns that were destroyed by landslides where houses were built. The infrastructure of roads, bridges and airports suffered numerous damages.

Hurricanes Eta and Iota formed at the onset of a moderate ENSO La Niña phase, which followed a weak ENSO El Niño transition and a neutral ENSO. The weak ENSO El Niño lasted 8 months, between October 2018 and May 2019. The neutral ENSO started in June 2019 and ended in July 2020. The moderate ENSO La Niña started in August 2020 and ended in April 2021. However, the weak ENSO El Niño of years 2018-2019 can be considered as a remnant effect of 2014-2017 very intense and prolonged dry period, in which one of the strongest ENSO El Niño of last 174 years occurred. The most relevant ENSO El Niño have had their intensity peaks in SST anomalies as follows: years 1877-1878 peak intensity +2.9 °C in December and January, respectively. 1888-1889 peak intensity +2.2 °C in December and January, respectively. 1972 peak SST anomaly +2.2 °C in November and December. 1982-1983 peak intensity +2.3 °C in December and January, respectively. 1997 peak intensity +2.7 °C in December. And 2015 peak intensity +2.6 °C in December. These intensity peaks have no immediate temporal relationship with extreme events in Honduras, but the last three do have an approximate relationship, in 1972, in 1997 and in 2015. In all intensity peaks, the month of December is involved. And in all cases, a continuity of anomalies above +2 °C implies a catastrophic accumulation of heat energy in the Pacific Ocean, with meteorological effects that spread to all corners of the planet.

Between 1997 and 2015 there is a difference of 18 years; a manifestation of consequence would be expected for 19 or 20 years; however, the effects occurred in two more years, in 2020, with hurricanes Eta and Iota. This suggests a shared total climate behavior between the two oceans, and in this case the Atlantic Ocean is apparently in the positive sinusoidal cycle downward phase of heat energy accumulation in surface waters.

This positive sinusoidal AMO cycle of heat energy accumulation in the Atlantic Ocean could be slightly lower than 1924-1967 previous cycle, both in intensity and duration, as opposed to the expected increase in climatic effects due to planet's global warming. If it is lower, natural explanation is that it responds to sinusoidal cyclic behavior prevalent in physical phenomena, applied to spheroidal object and in a planetary system of almost circular motions. Incremental trends do occur in the long term, but decreases in climatic indices are frequent in particular periods. The hurricane occurrences' count as extreme weather events in Honduras, between years 1893 and 2023, gives a total of 7 events.

The 2020's event includes two hurricanes and tropical storms, Eta and Iota, which, because of their location of origin, their trajectories, and even because of the incorporation by Iota of cloud remnants left by hurricane Eta, lose their random statistical independence, and should be considered as an individual event associated in a single Poisson statistical event. The lambda value λ of this statistical population is 1, at an average unit period of 21.17 years. I retain the integer value of 1 and not the fractional rate of 1 among 21.17 years, to further identify the distribution with its discrete character. Consequently, the period will be a "unitary" period of length 21.17 years.

Associating Poisson distribution with the Exponential distribution, we use λ=1, $\mu=1/\lambda=1$, and the average period in the arrival intervals is 21.17 years (see Table 1).

In the Poisson model, the probability of x = 1 is written as P(x=1), which is 0.3679. This is also the probability that x = 0, the probability that no extreme weather event occurs in the 21.17 years of the mean. The probability P(x=1) is the probability that only one extreme weather event occurs in the 21.17 years. The sum of both probabilities, P(x=0) and P(x=1), is equal to $2 \cdot 0.3679 = 0.7358$. Therefore, the probability of 2 or more extreme weather events occurring in the 21.17 years is equal to 0.2642.

The cumulative probability in the Exponential model, of an extreme weather event occurring in the 24 years following an extreme event that has already occurred, is 0.67815; then, the probability of no extreme weather event occurring in that same 24-year period is 0.32185. In very simple words, we are a little more than 2/3 of an extreme event occurring in that period, and a little less than 1/3 of it not occurring.

The cumulative probability in the Exponential model of an extreme weather event occurring in the already observed average period of 21.17 years is 0.63212, a little less than 2/3. The probability of an extreme weather event occurring in the observed modal period of 20 years is 0.61122, a little more than 6/10.

In the same model, the cumulative probabilities of an extreme event occurring in the periods between approximately 0 and 15 years are lower than the complementary cumulative probability of no extreme event occurring. The probability that the period extends to 42.34 years (upper bound equal to 2) and an extreme weather event occurring in that period increases to 0.86466; therefore, the probability that no extreme weather event occurs in that period is 0.13534.

Table 1: Exponential cumulative probability values for a mean equal to 1.

Lower limit (a)	**Upper limit (b)**	$e\string^((-a)/\mu)$	$e\string^((-b)/\mu)$	$F(W)\,\vert\, a,b$	**Years**
0	1.13368	1	0.32185	0.67815	24
0	1	1	0.36788	0.63212	21.17
0	0.944733	1	0.38878	0.61122	20
0	0.9	1	0.40657	0.59343	19.053
0	0.8	1	0.44933	0.55067	16.935
0	0.7	1	0.49659	0.50341	14.819
0	0.6	1	0.54881	0.45119	12.702
0	0.5	1	0.60653	0.39347	10.585

4 Conclusions

Since year 1893 through 2020, seven extreme weather events have been recorded in Honduras, characterized as the occurrence of hurricanes or tropical storms of great intensity; great destructive force; rare or unusual trajectories separated from the standard path of storms, cyclones and hurricanes in the northern hemisphere of the Atlantic Ocean; those whose geographical point of origin is located in the southern Caribbean Sea, up to about 400 kilometers north off Lake Maracaibo, in Venezuela, and including the Gulf of Honduras and the Gulf of Darien; generating severe flooding in the Honduran territory, destruction of cities and communities, severe damage to infrastructure, extensive losses of crops and livestock; causing substantial economic damage and loss of human lives to the country.

In year 2020, there was an extreme event with two cyclonic phenomena associated by their point of origin, their same trajectory and their close simultaneity in time of occurrence, and the sharing of remnants of Eta's wet mass with Iota.

Destructive hurricanes and tropical storms, as extreme weather events in Honduras, occurred in the following seasons: Hurricane I-2, July 4 and 7, year 1893; Hurricane I-1, June 21 and 29, 1913; Hurricane El Salvador, June 4 and 21, 1934; Tropical Storm Gilda, September 24 and 30, 1954; Hurricane Fifi, September 14 and 24, 1974; Hurricane Mitch, October 22 and November 9, 1998; Hurricanes Eta and Iota, October 31 and November 13 2020 Eta, November 13 and 18 2020 Iota. There is an evident historical trend towards a temporal shift by the end of the year, going down the end of the cyclonic season, from the initial months of June and July, to the final months of September, October and November.

Linkage of extreme events with the AMO index is denoted as follows: 5 events (71%) occurred during AMO oscillation warm phase, Hurricane I-2 1893, Hurricane El Salvador 1934, storm Gilda 1954, Hurricane Mitch 1998 and Hurricanes Eta and Iota 2020; in AMO cold phase, Hurricane I-1 1913 and Hurricane Fifi 1974 occurred (29Hurricane I-1 occurred one year before the coldest peak, SST anomalies less than -0.2 ℃, of the entire AMO oscillation cold phase from year 1870 to year 1925 (first cold phase; 55-year period). Hurricane Fifi occurred during a coldest AMO SST peak anomaly as of -0.3 ℃, two years after the coldest AMO oscillation peak anomaly by -0.4 ℃, from year 1870 to year 2020 (150-year period), in the early part of the second AMO cold phase.

The count of extreme weather events in Honduras follows a Poisson statistical distribution. The lambda λ value of this statistical population is 1, in an average unit period of 21.17 years. The arrival intervals follow an Exponential statistical distribution. Given $\lambda=1$, $\mu=1/\lambda=1$; this exponential mean value is equivalent to 21.17 years. In Poisson, the probability of x = 1, P(x=1), is 0.3679. This is the probability of a single extreme weather event occurring in the 21.17 years of the equivalent exponential mean, and is equal to the probability of no extreme event, P(x=0), occurring in that same period.

The equivalent exponential mean, 21.17 years, multiplied by 4 gives a very close value to the 85-year average estimated maximum extent of the AMO oscillation, using the warming subcycle. The 15-years threshold value, where the extreme event's probability of occurrence exceeds the probability of non-occurrence, multiplied by 4 gives a value of 60 years, equal to the AMO oscillation minimum estimated extent, using the cooling subcycle. The intervals of occurrence are random ones and do not coincide with the end of the AMO cycle subphases.

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