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Relation between the increment of thunderstorms, temperature and aerosols at Casablanca station

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Abstract: A World wide increment has been detected in atmospheric lightning related to the increase in surface air temperature, sea surface temperature and aerosol density. This work aims to an analysis of the relation between the annual cycles of thunderstorms occurrence, the surface air temperature and the occurrence of haze and smoke reports at Casablanca meteorological station in Havana City, which has a very reliable series of tri-hourly observations for a period of 45 years. The thunderstorms series is also related, for a shorter period, to an aerosol index series. The study yields that the frequency of thunderstorms observations has increased by 5% for the period with a highly significant growing trend. Yearly average temperatures also show a highly significant increase and the best correlation is reached for the yearly frequency of occurrence of temperatures above 30°C, where 46% of the variance of thunderstorms occurrence is explained. The haze occurrence reports have also a highly significant trend and show a correlation of 0.65 with thunderstorms. Aerosol index has a growing trend for 2005 – 2016 and explains 58% of the variance of thunderstorms frequency.

Keywords: , temperature, trend, haze, aerosols

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1. Introduction

The occurrence of thunderstorms has a huge influence upon society, death by lightning is the first cause of death by natural phenomena in Cuba and electric discharges seriously damage the power infrastructure and facilities, as well as communications and transporting. It's also the only natural cause of forest fires. On the other hand, storms are the main source of precipitation, mostly in Summer, they contribute to the creation of nitrogen compounds and also to the equilibrium of the global electric circuit.

In Cuba, it has been stated [1–3] that over the period 1989 - 2010 there has been an inter annual increase of the frequency of occurrence of observations of thunderstorms at more than 50% of all meteorological stations, according to the current weather state codes, which is the variable with most complete information available [2]. This increase has been also verified by authors elsewhere in the world [4-10] and currently the relation between electric discharges and climate change is studied [11,12]. This increase and at times punctual decrease [13,14] of the electrical activity is associated with changes of other variables such as surface temperature, at both land and sea, the amount of atmospheric aerosols as condensation nuclei and the vapor concentration in the upper troposphere [15-21].

Most of the aforementioned works use as storm related information the discharge counts between clouds or between clouds and ground detected by specialized networks [22,7,23] or from satellite borne devices [24,25]. Unfortunately this kind of information is not available in Cuba, so information on electric activity is obtained from storms observed at meteorological stations and reported in the current and past weather state code variables.

The aim of the current work is to analyze the relation between the inter-annual cycle of the frequency of occurrence of storms, the air surface temperature and the occurrence of hazes and smoke for the meteorological station of Casablanca in Havana, which has a very complete series of observations with more than 45 years of continuous tri hourly observations. An analysis is also made for a shorter series (2005 – 2016) of the relation of the annual frequency of storms and the atmospheric aerosol index and other related information supplied by a satellite borne instrument.

2. Materials and Methods

Tri hourly records of the variable current and past weather state code were used to characterize the frequency of occurrence of storms for the period 1972 - 2016 at Casablanca meteorological station in Havana, where information is quite complete with very few missing observations. Data were extracted from the data base [3]. Some parameters describing the Casablanca station are shown on Table 1 and its position shown on Figure 1.

Table 1. Position, height and maximum horizon of Casablanca meteorological station, Havana

Parameter	Value
Station number	325
Station Name	Casablanca
Latitude (°)	23.09
Longitude (°)	82.21
Height (m)	50.8
Direction of maximum horizon	S
Distance of maximum horizon (km)	15

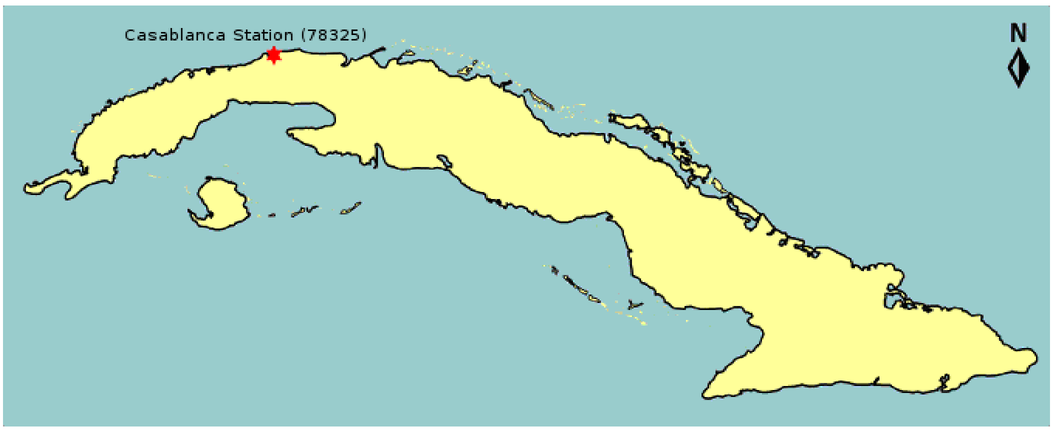

Figure 1. Location of the meteorological station of Casablanca (78325) at Havana, Cuba

In order to identify the three phenomena under study on the reported current weather state code variables, the code values were taken, according to Table 4677 "Current Weather reported from personnel operated weather stations" from the Keys Manual [26], and the selected codes are shown on Table 2. Codes not shown on table 2 are related to cases of very low or null occurrence for the region under study. The past weather state code was taken into consideration only for thunderstorms, as given by W1 - 9 [26], since smoke is not represented in this variable and hazes are counted together with fogs

Table 2. Meteorological phenomena used in this study and current weather state codes associated

Phenomenon	Current Weather state codes
Smoke	4
Haze	5
Thunderstorms	17, 29, 91, 92 , 95, 96, 97 , 99

Temperature records had two sources, for the period 1972 - 2000 data were obtained from the GRANMET base used at INSMET with data widely verified, for the period 2000 - 2016 data were taken from the Provincial Meteorological Center of Havana, Artemisa and Mayabeque, which is in charge of attending all aspects of meteorological observations at Casablanca station.

The variable chosen to account for the inter annual cycle of these phenomena was the frequency of occurrence of observations of each phenomenon, given as the ratio of observations reporting a specific event to the total number of valid observations made. In the case of temperature, three variables were derived: Annual mean temperature, the frequency of observations with values above or equal to 25 ^{o}C and the frequency of observations with values above or equal to 30 ^{o}C.

In the case of atmospheric aerosols, data were used from the OMI instrument aboard the AURA satellite, which provides daily information at places near the station of Casablanca. These series span over the period 2005 - 2016. Earlier than that, observations were made by the TOMS instrument, which bears significant differences with OMI and prevents the use of a larger homogeneous series, Tree parameters were considered:

- AI: Aerosol index (at the UV spectral zone)
- SOI: SO2 Index
- Ozone: Total ozone amount (Dobson units)

In order to achieve an annual representation of these values averages were calculated without taking the sign into account for AI and SOI, since for cloud formation it is not relevant whether particles absorb or reflect radiation. AI at the UV zone of the spectrum represent the cloud condensation nuclei between 0.1 and 1 micra

The methodology used for the analysis of homogeneity of the series was developed by Alvarez et al [27] with statistics calculated according to Sneyers [28]

Analyses were carried out with the WINSTAT software utility commonly used at INSMET and developed by one of the authors of this work.

In order to determine the relation between series, the Pearson Correlation coefficient was used, given by:

$$\mathbf{r} = \frac{\sum\left(\mathbf{x}-\bar{\mathbf{x}}\right)\left(\mathbf{y}-\bar{\mathbf{y}}\right)}{\sqrt{\sum\left(\mathbf{x}-\bar{\mathbf{x}}\right)^{2}\sum\left(\mathbf{y}-\bar{\mathbf{y}}\right)^{2}}} \quad (38)$$

In order to have an assessment of the estimation of "y" values from "x" values the typical error was calculated, given by:

$$\text{Error} = \sqrt{\frac{1}{(n-2)}\left[\sum(y-\bar{y})^2 - \frac{\left[\sum(x-\bar{x})(y-\bar{y})\right]^2}{\sum(x-\bar{x})^2}\right]}$$

Where "x" and "y" represent the series to be related and the upper bars mean average.

3. Results and discussion

A summary of the homogeneity tests applied to the series under study is shown on Table 3.

Table 3. Summary of the homogeneity tests of the inter annual cycle of variables: Frequency of occurrence of observations of thunderstorms reported on the current and past weather state codes (F-WW-W), Average Temperature (Tmean), Frequency of occurrence of temperature values above or equal to 25°C (F-T-25), Frequency of occurrence of temperature values above or equal to 30°C (F-T-30), Frequency of occurrence of observations of haze (F-Haze), Frequency of occurrence of observations of smoke (F-Smoke), UV Aerosol index (P-AI), SO2 Average Index (P-SOI), Average total column ozone (P-O3), at Casablanca station

Variable	Period	Behavior	Change Point
F-WW-W	1972 - 2016	Growing, highly significant	1989
Tmean	1972 - 2016	Growing, highly significant	Non conclusive
F-T-25	1972 - 2016	Growing, highly significant	1994
F-T-30	1972 - 2016	Growing, highly significant	1993
F-Haze	1972 - 2016	Growing, highly significant	1983
F-Smoke	1972 - 2016	Homogeneous	
P-AI	2005 - 2016	Growing, highly significant	2008
P-SOI	2005 - 2016	Homogeneous	
P-O3	2005 - 2016	Homogeneous	

The relation between the different series, given by the Pearson correlation and the typical error is shown on Table 4

Table 4: Analysis of the relation between the inter annual series under study at Casablanca station

Series 1 (y)	Series 2 (x)	Period	r	error
F-WW-W	Tmean	1972-2016	0.65	1.55
F-WW-W	F-T-25	1972-2016	0.67	2.02
F-WW-W	F-T-30	1972-2016	0.68	1.07
F-WW-W	F-Haze	1972-2016	0.65	8.72
F-WW-W	F-Haze + F-Smoke	1972-2016	0.50	6.08
F-Haze	F-Smoke	1972-2016	-0.82	6.52
F-WW-W	P-AI	2005-2016	0.77	0.60
F-WW-W	P-SOI	2005-2016	-0.18	0.95
F-WW-W	P-O3	2005-2016	0.59	0.78
P-AI	Tmean	2005-2016	0.59	-2.75

The table above shows that the fit between the frequency of occurrence of storms and the three temperature derived variables have similar correlations though it is highest with the frequency of occurrence of temperature values above or equal to 30°C, which explains about 46% of the variance, this suggests a relation between the increase of the number of storms and the rise of temperature. On Figure 2 the inter annual cycles of F-WW-W and F-T-30 are presented, showing the similarity between the series, in particular their increasing character, though the temperature growth is less pronounced and the difference is larger in the years prior to 1987.

The relation between the occurrences of storms and hazes shows similar values to that of temperatures and explains 32% of the variance. If observations of haze and smoke are taken jointly as an indication of the quality of air at the station, it turns out that the smoke does not contribute significantly to the correlation value, however, the correlation between the occurrences of haze and smoke is -0.82 and the representation of their inter annual cycles (figure 3) shows an inverse relation between the cycles of these variables, which could indicate some problem with the observation methods.

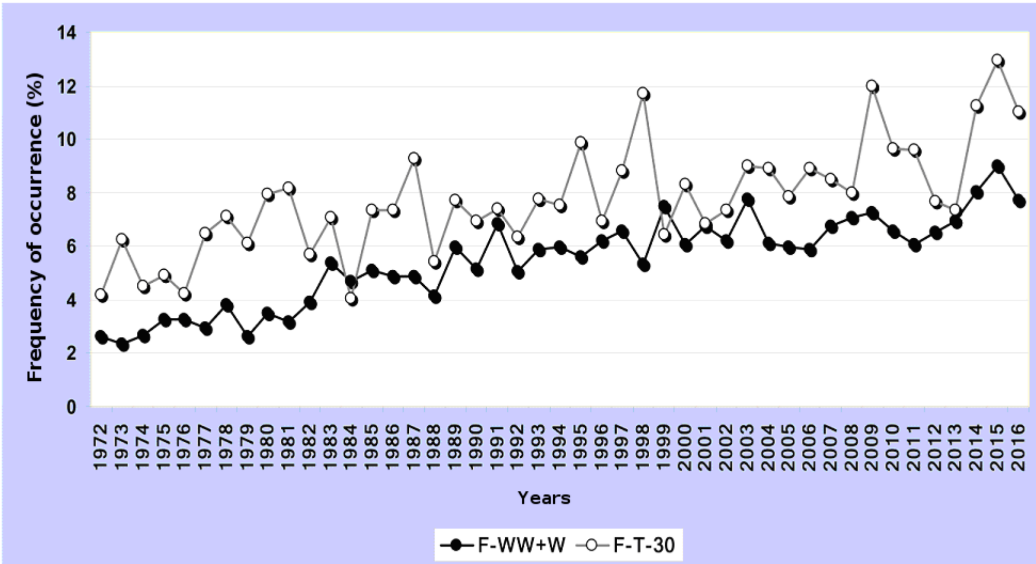

Figure 2. Inter annual cycle of variables F-WW-W and F-T-30 at Casablanca station for the period 1972 – 2016

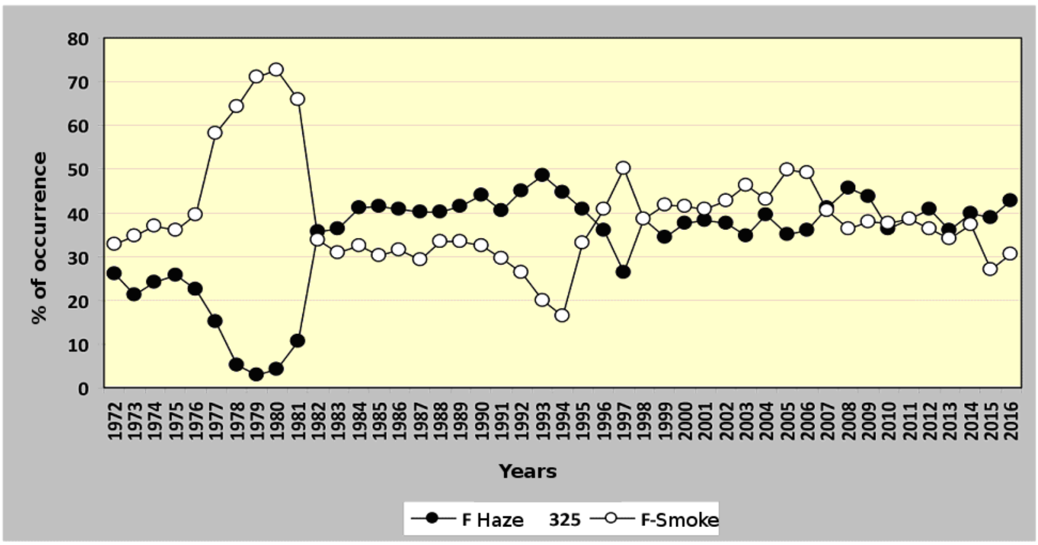

Figure 3. Inter annual cycle of the frequency of occurrence of observations with haze and with smoke at Casablanca station for 1972 - 2916.

A more objective measure of the contribution of the atmospheric composition to the occurrence of thunderstorms od given by the aerosol index (AI) which also shows an increasing trend, even for a shorter comparison series. In this case AI explains 61% of the variance, which is higher than that of temperature. However, if AI and temperature are correlated, a value of 0.59 is obtained, meaning that these two variables can not be considered as independent, and they would explain jointly about 50% of the variance. These results suggest that the increase of storm activity depends also on other variables, such as water vapor in the upper troposphere [19], the sea temperature [16], vertical flows in the atmosphere [29] and others. Correlations between the occurrence of storms and the SO2 index average (P-SOI), as well as with the total ozone (P-O3) are low.

Conclusions and Recommendations

The inter annual cycle of the variables frequency of occurrence of observations of thunderstorm, derived from the current and past weather state code records, year average temperature, frequency of occurrence of values of temperature above or equal to 25 ^{o}C, frequency of occurrence of values of temperature above or equal to 30 ^{o}C and frequency of occurrence of observations of haze show a highly significant growing trend with a change point around 1990. Among the three series related to atmospheric aerosols, only the average AI shows a growing trend with a change point around 2008.

The three variables related to temperature show quite similar correlations with the frequency of observations of thunderstorms, with the highest value corresponding to the frequency of observations with values above or equal to 30 oC, which explains 46% of the variance.

The correlation between the occurrences of storms and haze shows similar values to those of temperatures and explains 32% of the variance.

The AI annual average explains 61% of the variance with regard to the frequency of occurrence of storms, a value higher than that of temperature.

The correlation between the annual mean temperatures and annual mean AI is 0.59, so the variables are not considered as independent.

It is recommended to search other variables that could correlate with the growing records of the frequency of occurrence of storm observations.

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