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# THE SENSITIVITY OF THE THUNDERSTORM ACTIVITY IN THE CITY OF SÃO PAULO TO TEMPERATURE CHANGES: PREDICTING THE FUTURE ACTIVITY FOR DIFFERENT SCENARIOS

O. Pinto Jr.*

Atmospheric Electricity Group (ELAT), National Institute of Space Research
S. J. Campos, São Paulo, 12227-010, Brazil

## 1. INTRODUCTION

Thunderstorms are part of the complex and interactive processes that form the climate. Its variability can arise from a number of factors, some internal others external to the climate system. In consequence, our ability to predict future climate changes in the thunderstorm activity depends on a better understanding of the climate system as a whole and the external factors that could be involved such as volcanic eruptions and solar variations, as well as human-induced changes in atmospheric composition. Such an understanding can only be achieved through a greater ability to document and explain observed past variations. The study of thunderstorm changes offered the opportunity to gain a better understanding of atmospheric electricity. Also, the possibility that, as the global warming continues to evolve, increasing evidence of thunderstorm changes are found, will help to understanding the climate system, since thunderstorms as ice factories play a key role in the vertical redistributors of the most important greenhouse substance, the water vapor (Williams and Sátori, 2004).

At the present time, no direct or even indirect evidences of global increase in the thunderstorm activity exist in response to the mean global temperature increase, although positive trends are observed in specific areas where larger temperature increases than the global increase are observed (Pinto and Pinto, 2008; Williams, 2009, Pinto, 2009). In the tropics the current trend in global warming is less by a factor of four (0.1 ºC per decade) than at higher latitudes (0.4 ºC per decade), particularly in the Northern Hemisphere (Trenberth et al., 2007). This aspect tends to minimize any kind of response of global thunderstorm activity to global warming, since most thunderstorms on Earth occur in the tropical region (Pinto, 2009).

In this paper the variation of the thunderstorm activity in the city of São Paulo, Southeast Brazil, are further investigated with respect to changes in the surface air temperature in the last 60 years (since 1951) at the 30-year and monthly time scales. While the 30-year period was chosen following the period adopted by the World Meteorological Organization (WMO) to estimate long term climate variations, the monthly variation can be used to predict the future activity with more confidence than the simple annual variation,

## 2. DATA

Monthly observations of thunderstorm days in the city of São Paulo, located in the Southeast Brazil, since January 1951 were studied. The city is known to be a significant lightning spot, as evident from lightning observations in the last decade. Figure 1 shows the lightning activity observed in the last decade in the Southeast region of Brazil for a spatial resolution of 10 km x 10 km, as observed by the Brazilian lightning detection network (RINDAT). It can be seen that in most of the region the lightning activity is very high. Average value for São Paulo, for this spatial

* Corresponding author address: Osmar Pinto Jr., Brazilian Institute of Space Research, Atmospheric Electricity Group, S.J. Campos, SP, Brazil 12227-010; e-mail: osmar@dge.inpe.br.

resolution, is 8 flashes.km$^{-2}$.year$^{-1}$. The largest peak in the lightning activity is over São Paulo, reaching 17 flashes.km$^{-2}$.year$^{-1}$. A secondary peak is observed in the state of Rio de Janeiro related to the local mountains configuration.

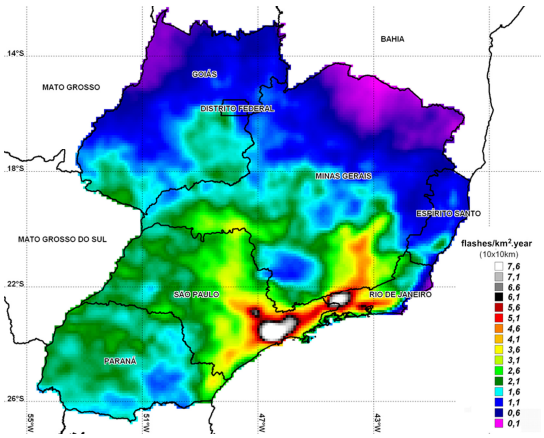


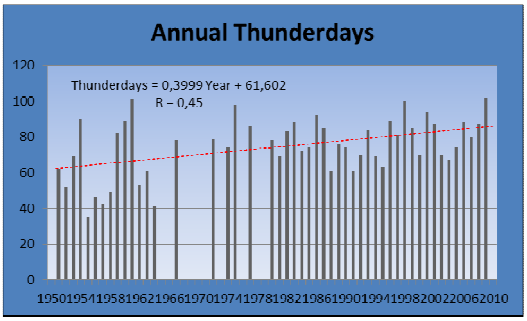

Figure 1. Annual average lightning flash density for 10 km spatial resolution observed by the RINDAT network in the Southeast region of Brazil in the last decade.

The thunderstorm activity in the city of São Paulo has increased significantly along the last century, in closer relation to the growth of the city (Pinto et al., 2012).

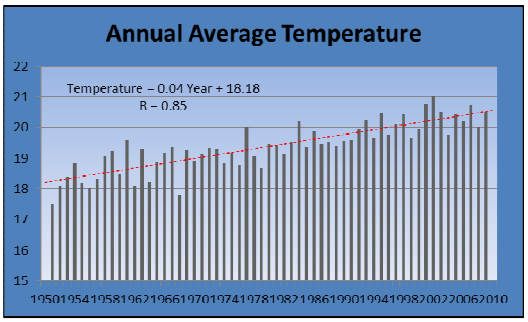
The thunderstorm data were compared with simultaneous monthly average data of the surface temperature.

## 3. DISCUSSION

Figure 2 shows annual values of thunderstorm days and average annual temperature values in the city of São Paulo since January 1951.




(a)

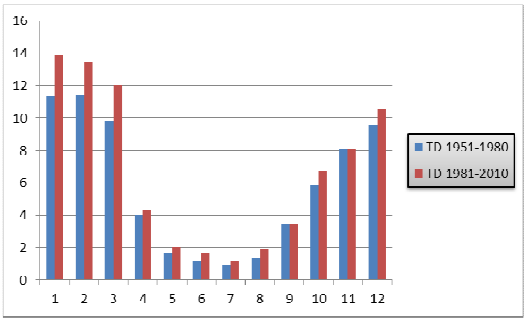



(b)

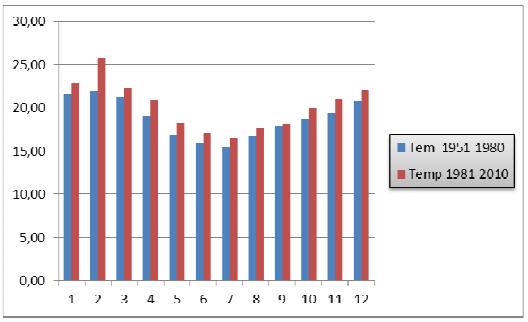
Figure 2. Annual values of: (a) thunderstorm days and (b) average temperature in the city of São Paulo since January 1951.

Figure 2 shows that although a large variability in both data sets related to intrinsic observational limitations is evident, a clear climate positive trend in the thunderstorm activity is observed. One important observational limitation is the increase in the background noise level at the observational site, related to the growing of the city, which causes a reduction in the distance in which an observer heard thunder and, in consequence, tends to underestimate the actual increase in the thunderstorm activity. Another observational limitation is the lack of information about the exact time of the thunderstorm activity along the day, since temperature changes at different hours of the day may produce different impact on thunderstorm activity.

The relationship between thunderstorm days and temperature can be observed by the changes in these parameters at the 30-year time scale. Figure 3 shows the average monthly values of thunderstorm days and temperature for the periods from 1951-1980 and 1981-2010. There is a clear increase in both parameters in the second period compared to the first in almost all months, although the enhancements are larger in the summer season. As a whole, the thunderstorm days increased by 15% and the temperature by 1.35C from the first to the second period.




(a)




(b)

Figure 3. Average monthly values of (a) thunderstorm days (TD) and (b) temperature for the periods from 1951-1980 and 1981-2010.

Also at the monthly time scale the above relationship is evident, although in this case the variability is large, indicating that other aspects are relevant as well. Figure 5 shows a scatter plot between thunderstorm days and temperature for January suggesting a linear correlation. Similar analyses were done for every month and the linear equations obtained were used to estimate the future thunderstorm activity in São Paulo for different scenarios of increasing in temperature.

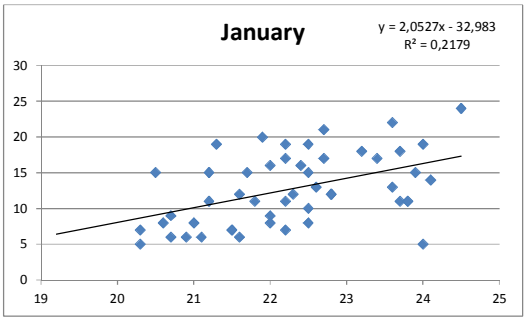



Figure 5. Scatter plot of thunderstorms days versus temperature in the city of São Paulo for January.

The positive trend observed in Figure 2 allows predicting future thunderstorm activity for different climate scenarios. However, to do so it is necessary to have projections of the future changes in the temperature in the city of São Paulo, which implies to know what are the physical process responsible for the positive trend observed in Figure 2b. Two possible candidates to explain the positive trend in the past data of temperature are the intensification of the urban heat island in consequence of the growth of the city and the global warming. Figure 4 shows the surface temperature in the city of São Paulo since 1880. The variation in the temperature follows two different regimes: below and after 1950s. Below 1950s, a slight positive trend of 0.1C per decade is observed, while after 1950s the trend increase to 0.4C per decade. The change in the trend observed in the 1950s is probably related to urban aspects. The 1950s decade is characterized by the beginning of the rapid growth of the city of São Paulo. At that time, the population is lower than 2 million people (now is over 10 millions). The industrialization was beginning and changing the city; the first vehicles were running on the streets of São Paulo (now they are 7 millions). At the same time, the global warming was not evident yet, becoming evident only in the 1980s with a positive trend after that of 0.15C per decade. It is interesting to note that after the 1980s the trend did no change suggesting that the effect of global warming is being compensated by a decrease in the urban effect, what seems very reasonable considering that the growth of the city had decreased in the last decades.

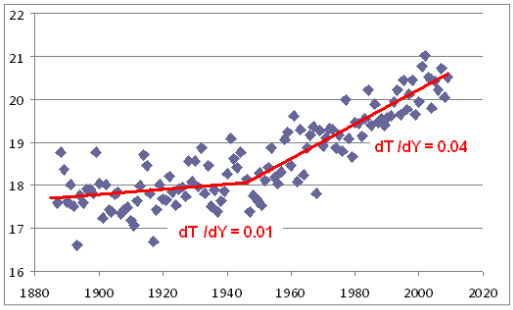



Figure 4. Annual surface temperature in the city of São Paulo since 1880.

The projections for the future thunderstorm activity in São Paulo are, in consequence, strongly dependent on the evolution of the physical mechanisms responsible for the temperature variations. If, by one hand, the rate of increase of temperature due to the urban heat island tends to decrease, on the other hand it tends to increase due to global warming, making difficult to have the rate of increase. Table 1 shows the percentage of increase in the thunderstorm activity in São Paulo for the next 30-year period for two different scenarios of increasing in temperature: the same rate of increase of 0.4C per decade observed in the last 60 years (in the last 30 years, it corresponds to 0.25C per decade to urban effects and 0.15C per decade to global warming) and a worst scenario based on the A2 IPCC projection (Trenberth et al., 2007) extrapolated for the tropics (0.8C per decade instead of the present value of 0.15C per decade) and considering the same rate due to urban effects observed in the last 30-year period (0.25C per decade).

| Same present rates | Worst case |
|---|---|
| 15 % | 90% |

Table 1. Estimates for the percentage of increase in the thunderstorm activity in the city of São Paulo in the next 30-year period (2011-2040) for two different scenarios based on temperature projections.

Of course, such predictions do not taking into account the effects of changes in the atmospheric circulation due to global warming, which in principle may produce changes in the thunderstorm activity much larger than that presented in Table 1 (see a discussion about this subject in Pinto et al. (2012)).

## 4. CONCLUSION

The relationship between thunderstorm activity and surface temperature for the city of São Paulo is further investigated. The new results confirmed previous investigation showing a clear positive trend that is very probably caused by the growth of the city and the related increase in the urban heat island effects. The available data are used to predict the future thunderstorm activity for two different scenarios using the last IPCC projections.

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