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Heat waves and Possible Air Quality Impacts over Greater Cairo, Egypt

Amira N. Mostafa[1,3], Stéphane C. Alfaro[2], S. M. Robaa[3], Ashraf S. Zakey[1] and M. M. Abdel Wahab[3]

[1]Egyptian Meteorological Authority, Cairo, Egypt, [2]Univ. Paris Est Creteil and Université Paris Cité, CNRS, LISA, F-94010 Créteil, France,
[3]Astronomy, Space Science and Meteorology Department, Faculty of Science, Cairo University, Giza, Egypt

Abstract

Several heatwaves (HWs) were recorded in Egypt in the recent years. Some of these HWs were mild while others were severe and resulted in mortalities and morbidities. On the other hand, air pollution is considered a health issue in Egypt's megacities, especially the capital city and its surroundings, the Greater Cairo (GC) region. In this study, we examine a number of HWs that hit Egypt in the recent years, along with the state of air quality, in terms of PM10, NO_2, and O_3, during the period of HWs incidence, with a focus on the GC region. During the period of study, the frequency, intensity, and duration of HWs have been observed to increase. The total number of recorded HWs events was 190 cases, with 376 HW days. The time series of daily mean NO_2 showed no correlation with temperature during the months that witnessed HWs cases. Conversely, PM10 and O_3 concentrations exhibited a similar pattern as that of daily maximum temperature. This increase of the two pollutants concentrations led to a degradation of the air quality, as demonstrated by the fact that the Air Quality Health Index went from 'moderate risk' on normal days to 'high risk' during the HWs.

Introduction

Heatwaves (HWs) are caused by very hot, stagnant air masses. They form when high pressure aloft (3,000-7,600 meters) strengthens and remains over a region for several days up to several weeks, while dew points are high and wind speeds are often low. Moreover, clear or partly cloudy skies allow intense solar energy to further heat the ground and the air mass. This situation is common in summer as summertime weather patterns are generally slower to change than in winter, which results in slow-er movement of this upper-level high pressure system [1].

There is no formal, standardized definition of a heatwave (HW). An HW can be defined as "an extended period of hot weather relative to the expected conditions of the area at that time of year, which may be accompanied by high humidity" [1]. Recently, the World Meteorological Organization (WMO) defined the HW as "a marked unusual period of hot weather over a region persisting for at least two consecutive days during the hot period of the year based on local climatological conditions, with thermal conditions recorded above given thresholds" [2].

Severe HWs can cause several adverse effects, such as health, psychological, sociological, and economic effects. They cause catastrophic crop failures and thousands of deaths from hyperthermia, which is also known as heat stroke.

Recent works suggest that HWs could have a direct impact on the concentration of some air pollutants, thus aggravating their adverse health effects. Extremely warm weather exacerbates the negative health effects of both heat and air pollution, and the deteriorated air quality status may add up to the mortality and morbidity toll of an extreme heat event. This can worsen chronic respiratory and cardiovascular conditions as well as cause heat exhaustion, cramps, heat stroke, and in certain cases, heat-related mortality. Those with chronic conditions, the elderly, women, and children are among the most vulnerable groups [3,4].

This study aims at investigating some of the most pronounced HWs that hit Egypt in the past years, along with examining the air quality state, in terms of PM10, NO_2, and O_3 concentrations, during the period, with a focus on the GC region. Special attention will be paid to the quantification of the potential correlation between extreme heat events and episodes of high air pollution.

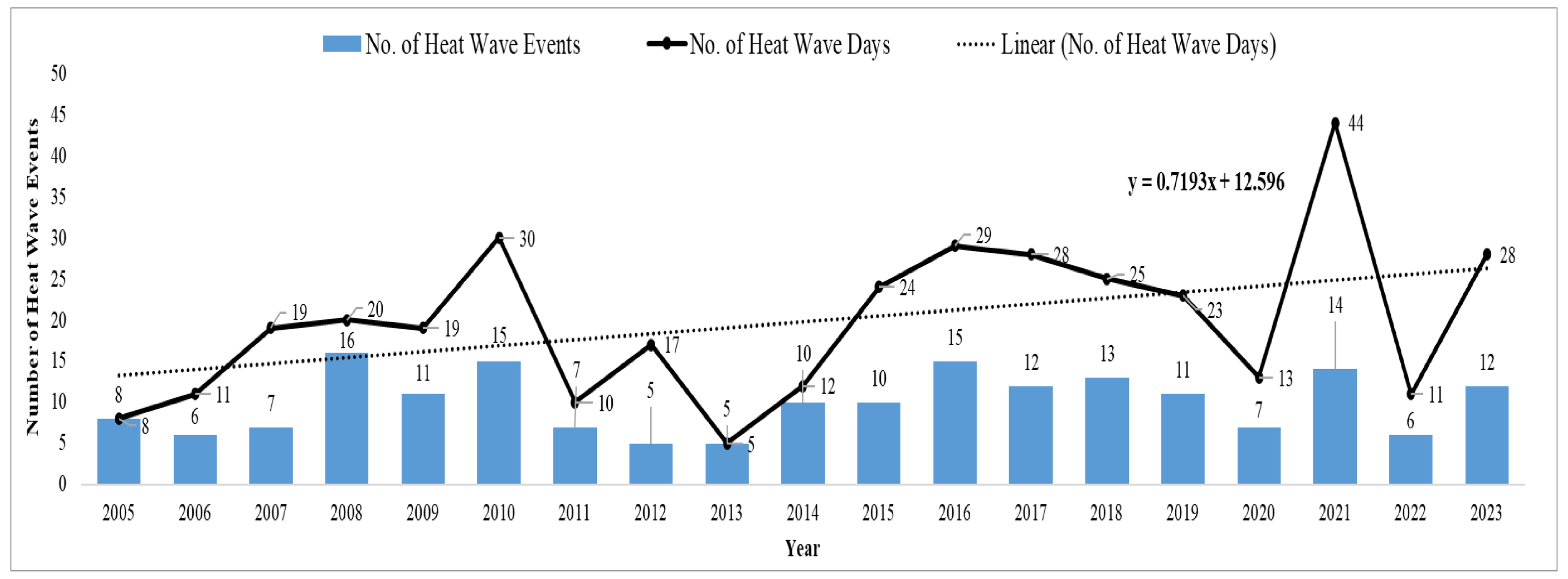

Figure 1. Number of identified HW events (bars) and HW days (solid line) during the period 2005-2023. Dashed line: linear fit.

Table 1. Details of the most severe HW periods identified between 2005 and 2023. For the concentrations, Nil corresponds to missing data.

Year	Month	Period	N (%)	Tmax (°C)	PM10 (µg/m³)	NO_2 (µg/m³)	O_3 (µg/m³)
2007	June	24-29th	6 (31.6)	39.8	134.1	Nil	Nil
	July	24-28th	5 (26.3)	39.2	146.2	Nil	Nil
2010	June	17-23rd	7 (23.3)	39.9	186.0	14.7	13.1
	August	15-20th	6 (20.0)	38.3	108.7	16.2	12.5
2012	August	7-13th	7 (41.2)	37.6	49.4	22.9	39.6
2015	August	3-11th	9 (37.5)	38.3	312.1	18.8	37.0
2021	July	15-21st	7 (15.9)	38.0	Nil	Nil	Nil
	July-August	29-8th	11 (25.0)	39.9	Nil	Nil	Nil
2023	July	22-28th	7 (25.0)	38.4	Nil	Nil	Nil

Methods and Materials

The GC is the name given to the metropolitan region, which spans three governorates (Cairo, Giza, and Qalyubia) and covers a total area of 2670 km², with estimated population as high as 26.02 million.

The meteorological dataset comprised hourly temperature data, measured by the Egyptian Meteorological Authority (EMA) at Cairo Airport station, for the period from January 2005 till October 2023. The air quality dataset comprised daily concentrations of PM10, NO_2, and O_3 measured by the Egyptian Environmental Affairs Agency (EEAA) for El-Abbasseya station (a station not far from Cairo Airport station, around 17 km away), for the period from 2005 till 2018, with some gaps in 2010 and 2012, covered by the EMA's air quality dataset.

The HW definition proposed by Metaxas and Kallos [5] was adopted, which is based on two temperature criteria: the daily maximum and the daily average temperature value should be at least 37°C and 31°C, respectively [6].

Characteristics of the recent HWs were determined based on the analysis of the HW intensity (number of HW days and maximum temperature recorded during H), and the HW frequency (number of HW events).

The relationship between daily mean temperature and air pollution levels during HW periods were assessed based on [7] the analysis of time series of daily mean temperature and air pollutant concentration during the months that recorded severe HW events, and the analysis of correlation between temperature and each of the air pollutants, using simple linear regression model.

Results

Characteristics of Recent HWs

The total number of recorded HW events was 190 cases, with 376 HW days, with no year that did not record an HW. It is shown that peak temperatures higher than 41°C were observed starting from the year 2006. Similarly, the average and maximum durations of the HW events observed each year tended to increase (*p*-values of 0.32 and 0.13, resp.). HWs did not only occur during summer seasons (June-August), but also in March, April, May, September, and October. However, the frequency of their occurrence in summer is much larger.

2. Assessment of the relationship between temperature and the pollutants concentrations during HWs

Only severe HWs was considered for this assessment, i.e., the HWs with consecutive HW days a duration above the general average (5 days). The most severe HWs were found to have occurred in 2007, 2010, 2012, 2015, 2021, and 2023 (Table 1).

In 2007 and 2010, there is a clear tendency for the concentration to increase with the temperature ($p \leq 0.05$). In 2012, there was also a positive correlation but the fact that the PM10 concentration remained relatively moderate for GC (around 50 µg/m³) masks in great part its variations. Conversely, in 2015 an isolated huge peak of PM10 (at 1288 µg/m³) occurred on 3 August due to the advection of mineral dust from the deserts surrounding GC.

The very large value of the coefficient of determination (R^2=0.84) confirms the strength of the influence of Tmax on PM10, and the slope of the linear best fit indicates that for each 1°C-increase of Tmax, the average increase of PM10 is 4.7 µg/m³ (Fig. 6).

For NO_2 and ozone, the visual examination of the time series does not reveal any obvious covariation with the temperature. An absence of influence of Tmax on the concentrations of NO_2 (R^2=0.001) was noted, while O_3 showed a significant positive correlation (R^2=0.24) with the temperature, but the slope is so modest that the average increase of the O_3 concentration is only 5.9 µg/m³ between 30 and 40°C.

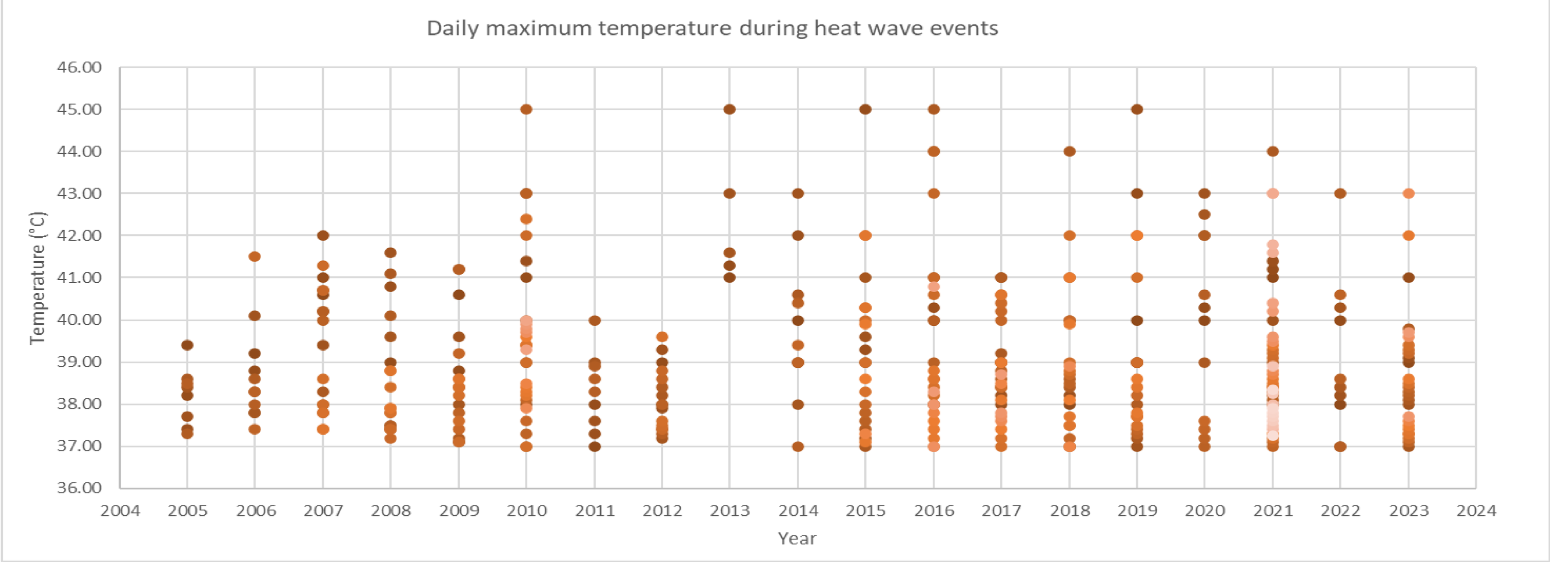

Figure 2. Maximum temperature of the observed HW days.

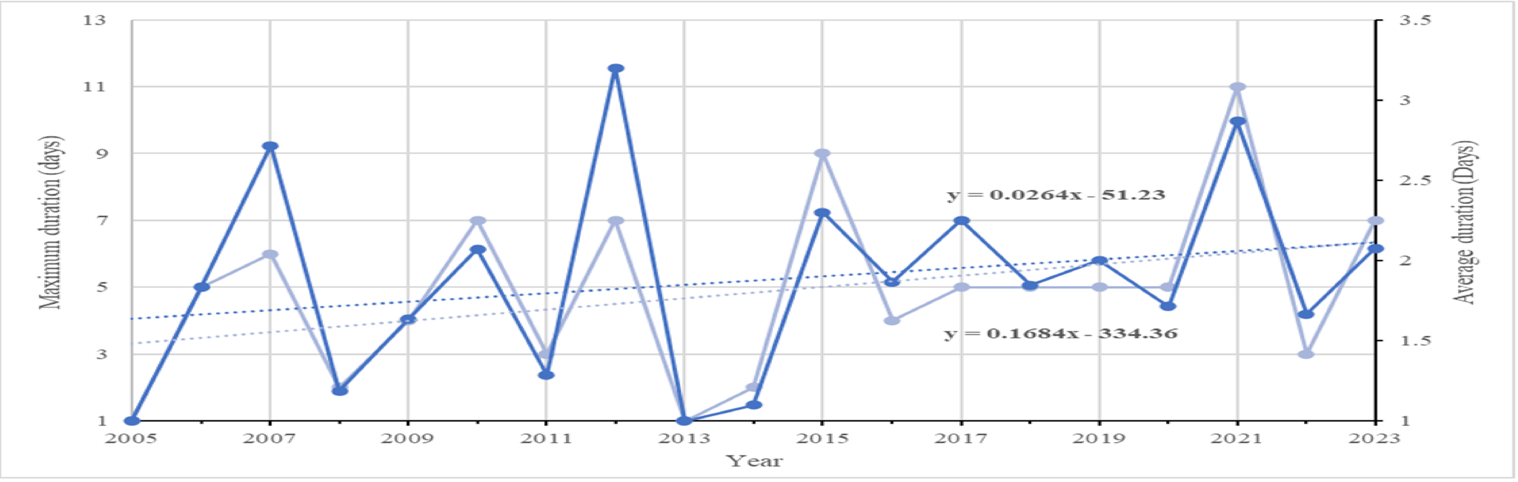

Figure 3. Average (dark blue) and maximum (light blue) durations of the HWs recorded in GC each year.

Discussion

Summer is not a season during which advection of desert dust or biomass burning is usually observed in GC, which means that we have mostly looked at the effect of temperature on the concentration of PM10, NO_2, and ozone produced locally.

The positive correlation between PM10 and temperature may be attributed in part to the fact that clear skies and active photochemistry during HWs facilitate the transformation of anthropogenic or natural volatile precursors into secondary fine particles [7]. Moreover, air pollution levels generally tend to increase during HWs due to low winds that prevail, leading to stagnancy of air and poor dispersion conditions; however, this is not consistent with NO_2. A possible explanation for this inconsistency could be that our analysis focused mostly on summer months (June to August), when the NO_2 concentration is the lowest and there are complex photochemical interactions with ozone triggered by sunlight and NOx [8].

For ozone, the "modest" increase could be explained by the fact that HWs coincide with clear summer skies, which are obviously favorable for ozone formation. The relationship between ozone and temperature depends on the availability of local resources (sunshine, ozone precursors…) and large-scale atmospheric circulations and usually does not follow a simple linear positive relationship [9].

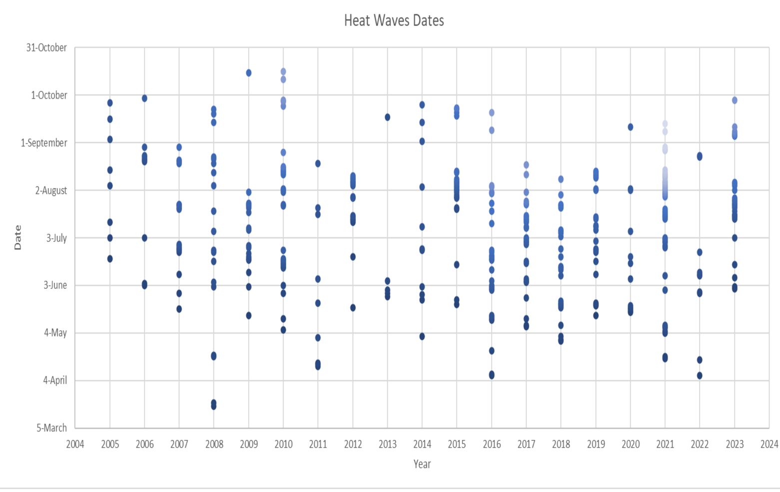

Figure 4. Dates of HW occurrence.

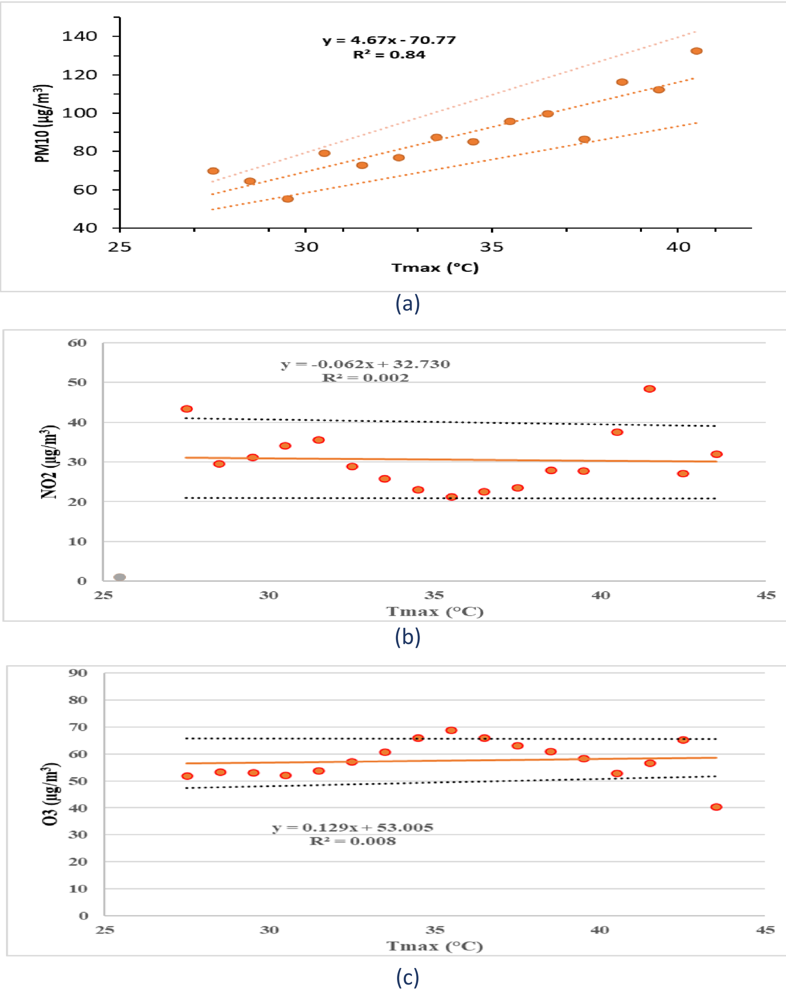

Figure 6. Influence of the increase of temperature on the average of (a) PM10, (b)NO_2, and (c) O_3 (points). Line: best fit; the distance between the dotted lines corresponds to one standard deviation.

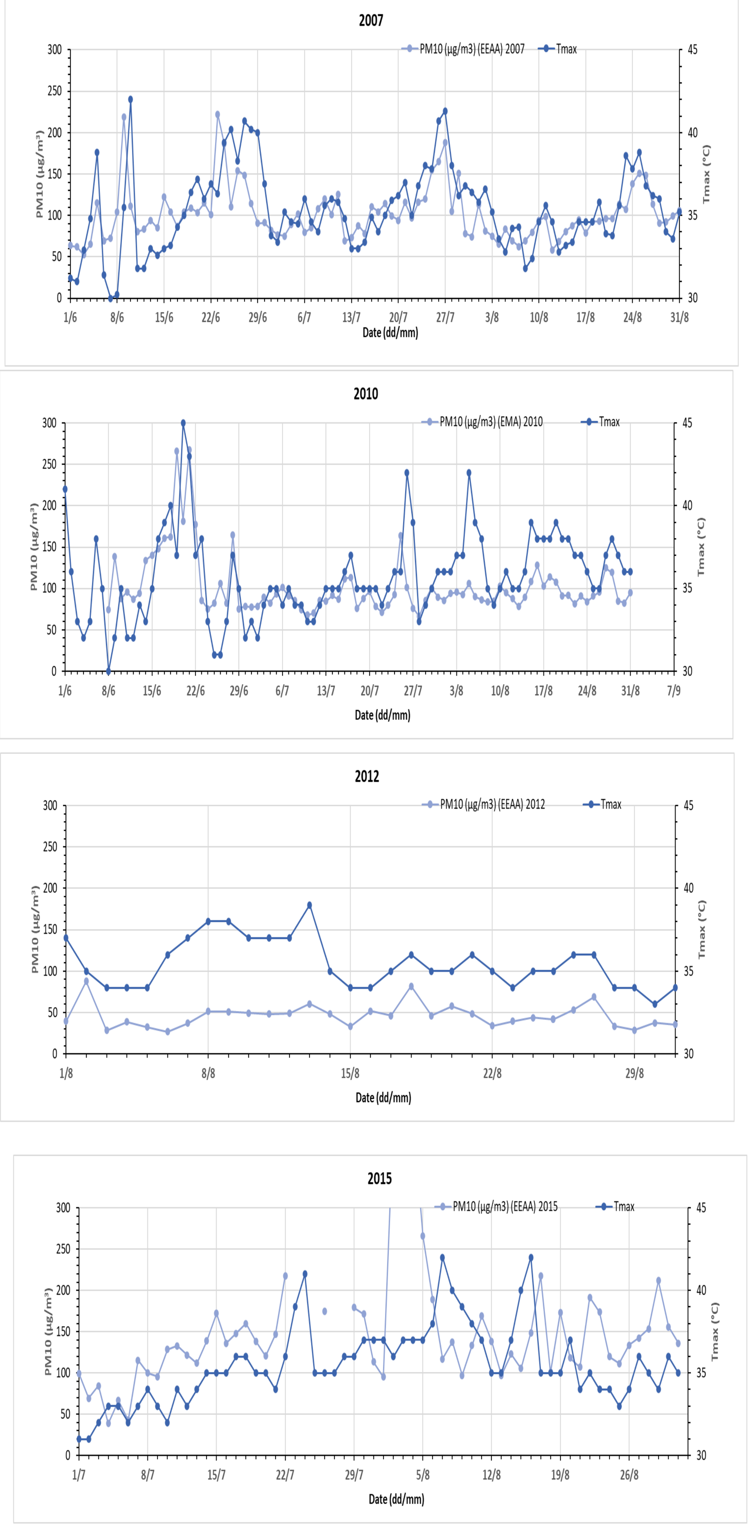

Figure 5. Co-variations of the daily Tmax and the PM10 concentrations during the summer months of the severe HWs.

Conclusion

Between 2005 and 2023, the frequency, intensity, and duration of HWs striking the GC area have increased. Although HW days could be observed occasionally as early as March or as late as October, the most severe events, i.e., those lasting at least 5 days, occurred from June to August.

Generally, low winds prevail during HWs, which favors the accumulation of air pollutants and could explain in part the higher levels of PM10 during HWs, but not the NO_2 and O_3.

These findings are a matter of concern because the frequency of severe HWs is expected to go on increasing in the future as a result of global warming of the Earth's climate. This also emphasizes the need for more research on the correlation between HWs and air pollution, specifically in examining the concurrent HWs and increased air pollution episodes. The results of such research would help in the establishment of public health early warning systems.

Contact

Amira N. Mostafa
Egyptian Meteorological Aurhority
Email: amira.nasser1988@gmail.com
Phone: +201007676001

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