



# Compound hot extremes at an urban site based on climatic and bioclimatic indices

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## 1. BACKGROUND

Over the past decades, extreme weather phenomena like hot extremes and heat waves (HWs) stand out as a major threat for humans and ecosystems. Compound extremes are understood as simultaneous, concurrent or sequential extreme events, taking place at a single or different locations. Compound extreme events may exacerbate the risk and increase associated adverse impacts, compared to individual events.

## 2. RESEARCH SCOPE

In the study, we examined the occurrence of compound hot extremes at an urban site of the eastern Mediterranean (Athens) over a century-long period, using the historical climatic records of the National Observatory of Athens (NOA, 1904-2023). The area has been experiencing an ongoing, striking warming after the mid 1980s (Fig. 1), with 2023 being the hottest year on the record.

## 3. MATERIAL & METHODS

Compound hot extremes were defined as concurrent daytime and nighttime hot extremes based on climatic and bioclimatic indices.

### Compound hot extremes based on air temperature

- Daily maximum (**T<sub>max</sub>**) and daily minimum (**T<sub>min</sub>**) air temperatures are above a predefined threshold value.
- Threshold values for **T<sub>max</sub>** and **T<sub>min</sub>** were set equal to **36.7 °C** and **25.9 °C**, respectively, corresponding to the 90<sup>th</sup> percentile of the summer T<sub>max</sub> and T<sub>min</sub> distributions at NOA, over the reference period 1981–2010.
- Compound HWs were defined as sequences of at least 3 consecutive days when both T<sub>max</sub> and T<sub>min</sub> exceed the predefined thresholds.
- Study period 1904–2023.

### Compound hot extremes related to human thermal comfort

- The advanced bioclimatic index **UTCI** (Universal Thermal Climate Index) was employed, accounting for air temperature, air humidity, solar radiation and wind speed conditions.
- UTCI calculations were based on hourly data.
- Compound heat stress extremes based on UTCI were defined as the cases when the **daily maximum UTCI** value was above the index threshold indicating '**at least very strong heat stress**' (**UTCI > 38 °C**), and **simultaneously**, the **daily minimum UTCI** value was above the index threshold indicating '**at least moderate heat stress**' conditions (**UTCI > 26 °C**).
- Study period 1964–2023 (UTCI calculations were confined to the more recent 60-years period, dictated by the availability of continuous / reliable radiation data from 1960 onwards).

## 4. RESULTS

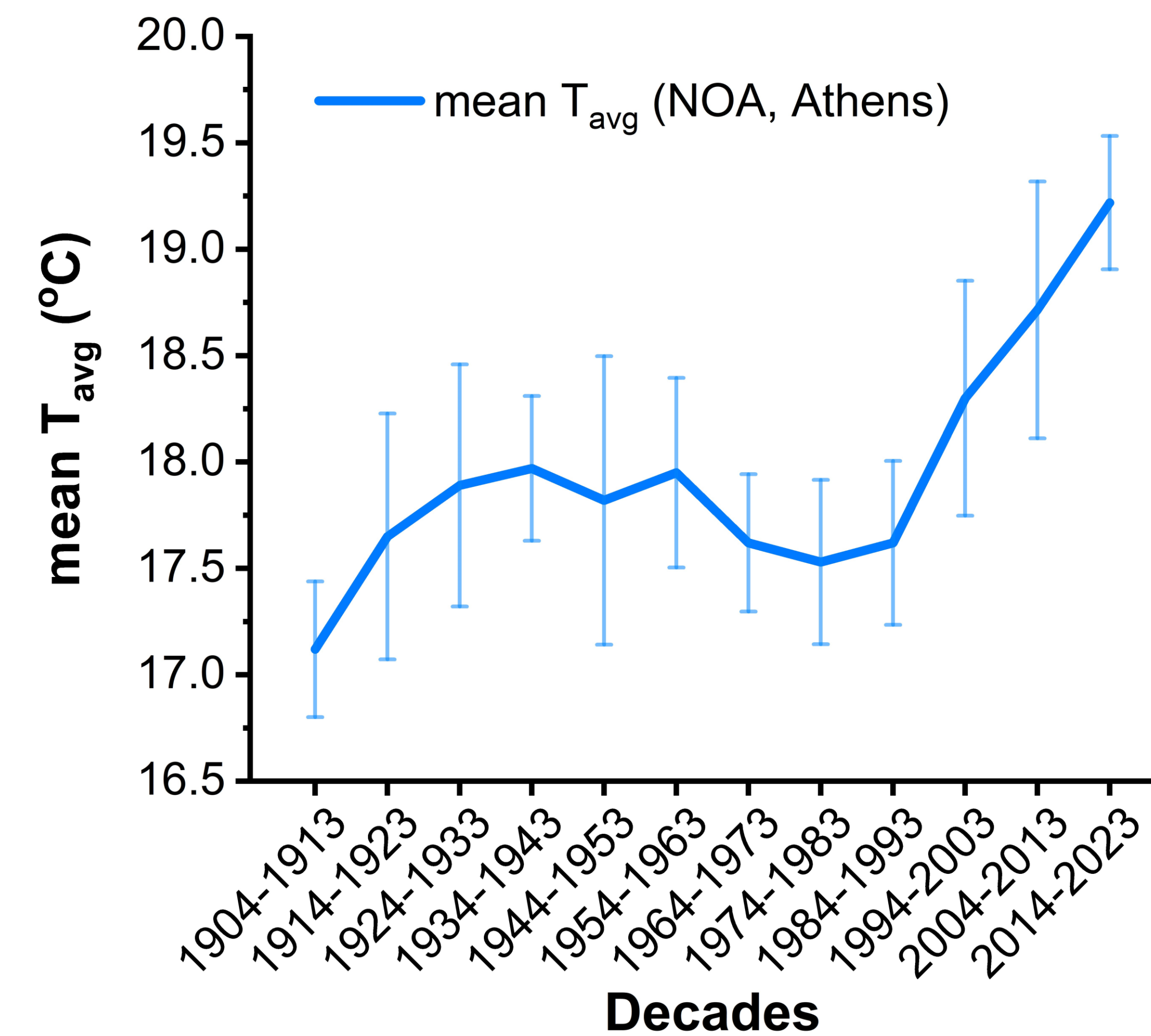


Figure 1. Mean value and standard deviation of the daily average air temperature (T<sub>avg</sub>) at NOA (Athens) per decade, over the period 1904–2023.

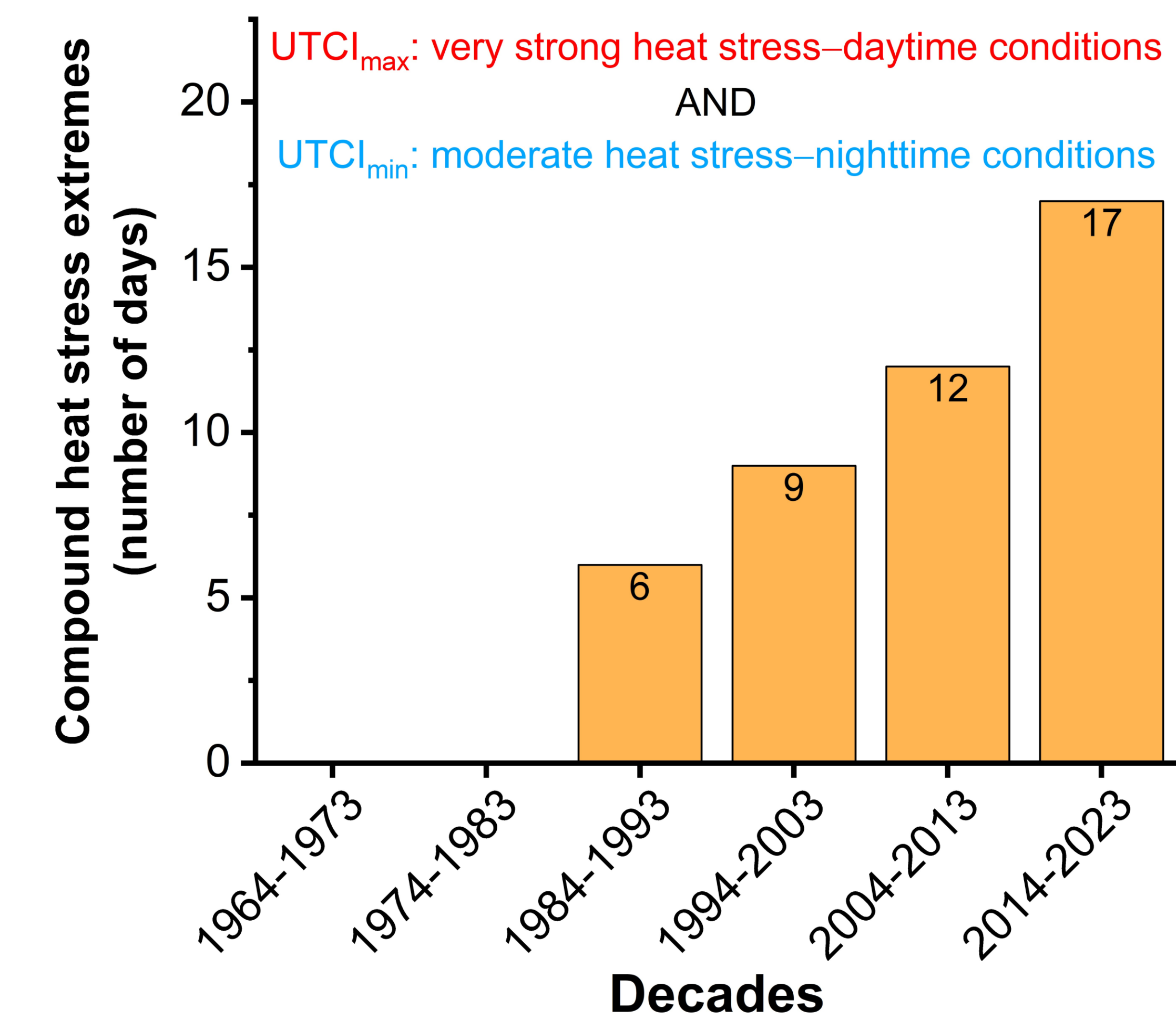


Figure 2. Number of compound heat stress extremes (days) based on UTCI index (**UTCI<sub>max</sub> > 38 °C** and **UTCI<sub>min</sub> > 26 °C**) per decade, over the period 1964–2023.

The analysis detected **44 compound heat stress extreme days**, with **34** of them occurring after the year 2000, suggesting a dramatic increase in the frequency of cases with heat-related thermal discomfort throughout the whole day and night.

The higher frequency of compound heat stress events was observed during the extreme years **2007**, **2021** and **2023**.

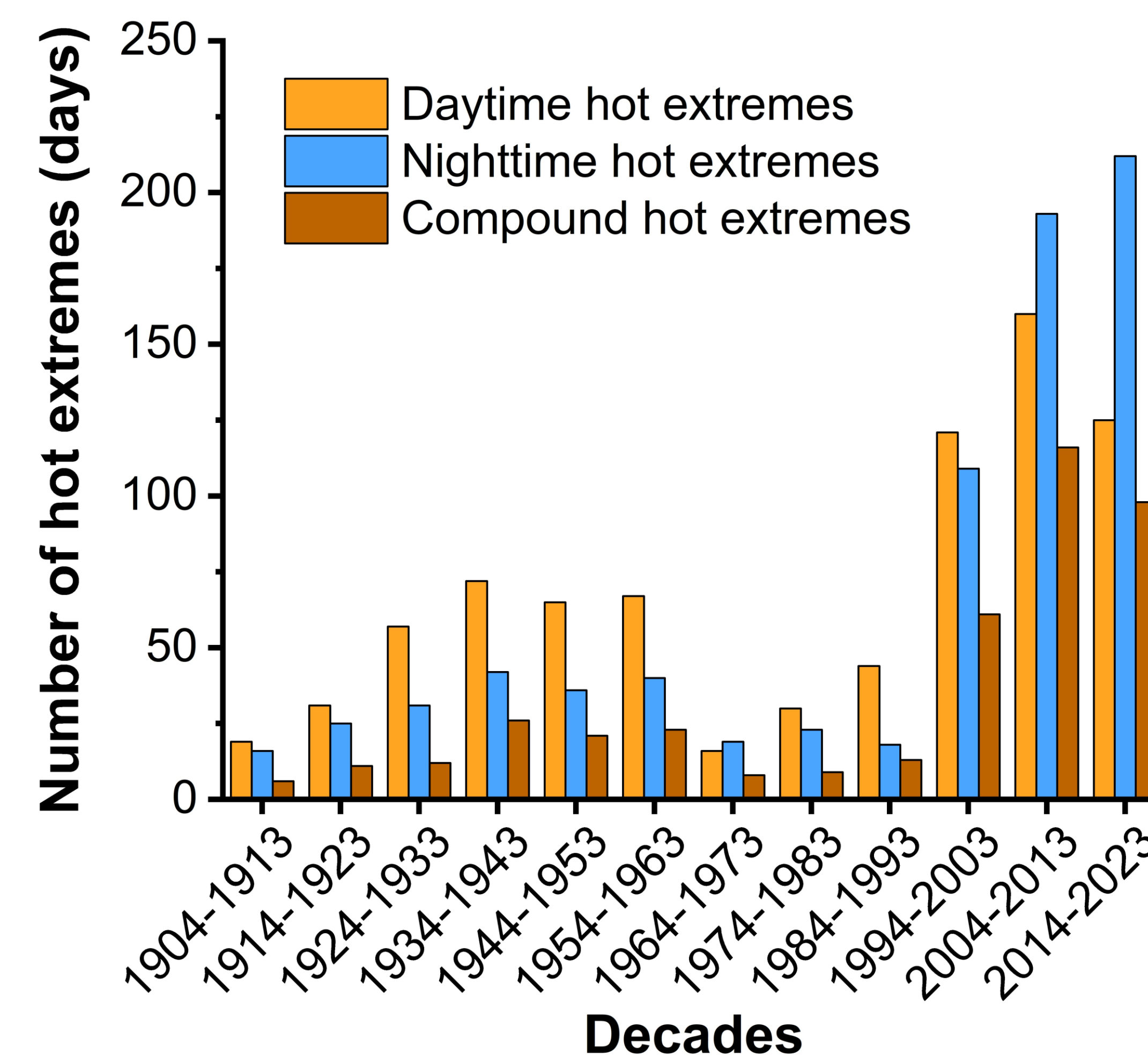


Figure 3. Number of daytime, nighttime and compound hot extremes (days) per decade, over the period 1904–2023.

About **60%** of the total number of compound hot extremes and compound heat waves in Athens (NOA) was observed from **2000 onwards**.

Besides, **57%** of the daytime HWs over the whole study period constitute also compound HWs, while this percentage increases to **72%** after the 2000s, indicating an increase in nighttime HWs, very likely related to the urban heat island effect.

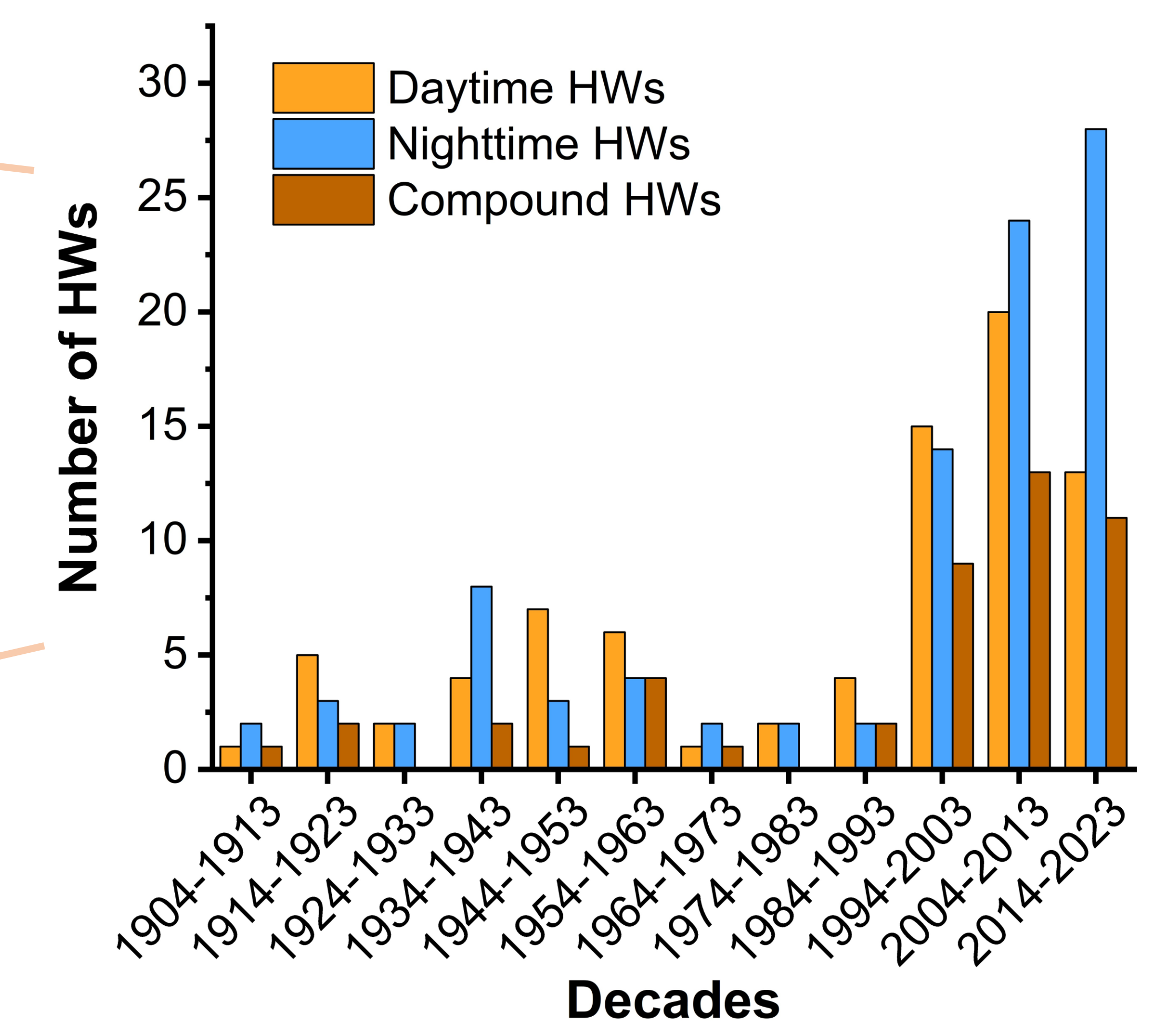


Figure 4. Number of daytime, nighttime and compound heat waves (HWs) per decade, over the period 1904–2023.