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Urban sensitivity to compound drought and heatwaves using climate and Earth Observation data in Beijing, China, and Athens, Greece

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Abstract

Traditional climate risk and impact assessments typically consider a single extreme event, a fact that leads to the underestimation of risks, as such events are often interdependent.
The principal aim of this study is to evaluate the current state of the climate in Beijing, China, and Athens, Greece in terms of droughts and heatwaves, focusing on their compound effects (CDHW) and examining their association with urban form and fabric factors. The term compound events describes the combined effect of multiple climate factors (processes, variables, phenomena including feedback mechanisms) or climate hazards. In urban areas, these compound events can lead to other challenges, such as increased energy demand for cooling, higher air pollution levels, and impacts on critical infrastructure which can be associated with urban morphology.
The determination of the CDHW climatology is carried out through the joint use of an Excess Heat Factor (EHF) and a Standardized Precipitation Index (SPI), according to the general definition of CDHW events (heat waves occurring during the period of drought events), using the high-resolution state-of-the-art ERA5-Land reanalysis product along with ground-based climate data, while Earth Observation (EO) imagery is used to extract land cover information from visible and near-infrared sensors.
The study addresses the challenges of CDHW in cities and a range of strategies is proposed that include climate-resilient infrastructure, nature-based solutions, and heat warning systems.

Background

In recent years, numerous severe droughts and heatwaves have taken place in various regions around the world (Hao et al., 2022; Mukherjee et al. 2023). These instances of concurrent or closely successive dry and hot events - CDHWs - are anticipated to rise with the progression of global warming (Ridder et al., 2022). Given their implications for human health, socioeconomic factors, and agriculture, these events have garnered increasing attention (Wu et al., 2020). To describe these events a plethora of indices have been developed to characterize the different properties of extremes. In parallel, spatially detailed information on urban landscapes is indispensable for informed decision-making, sustainable urban planning, and addressing the complex challenges associated with urbanization.

Excess Heat Factor - EHF

The EHF is a measure of heatwave intensity. The calculation of the EHF is based on a three-day averaged daily temperature, in relation to

- the 95th percentile of climatological average temperatures (significance index)
- to the recent past - previous 30 days (acclimatisation index)

The strengths of the EHF:
is location dependent; accounts for both short-term and climate-scale temperature anomalies.

Standardized Precipitation Index – SPI

The SPI index to characterize meteorological drought on a range of timescales. The 3-month SPI compares the precipitation over a specific 3-month period with the precipitation totals from the same 3-month period for all the years included in the period of study (short- and medium-term moisture conditions and provides a seasonal estimation of precipitation).
The strengths of the SPI:
requires only precipitation data; comparable across regions with different climates

Local Climate Zones – LCZ

The LCZ maps are constructed using the LCZ typology (Stewart and Oke, 2012), which differentiates urban surfaces based on their characteristic combinations of micro-scale land cover and related physical attributes. The LCZ system characterizes urban and rural landscapes, encompassing a total of 17 distinct classes within the LCZ framework. Among these 17 LCZ classes, 10 are related to the 'built' environment, and each LCZ type is associated with generic numerical descriptions of key urban canopy parameters critical to model atmospheric responses to urbanization.

Methodology

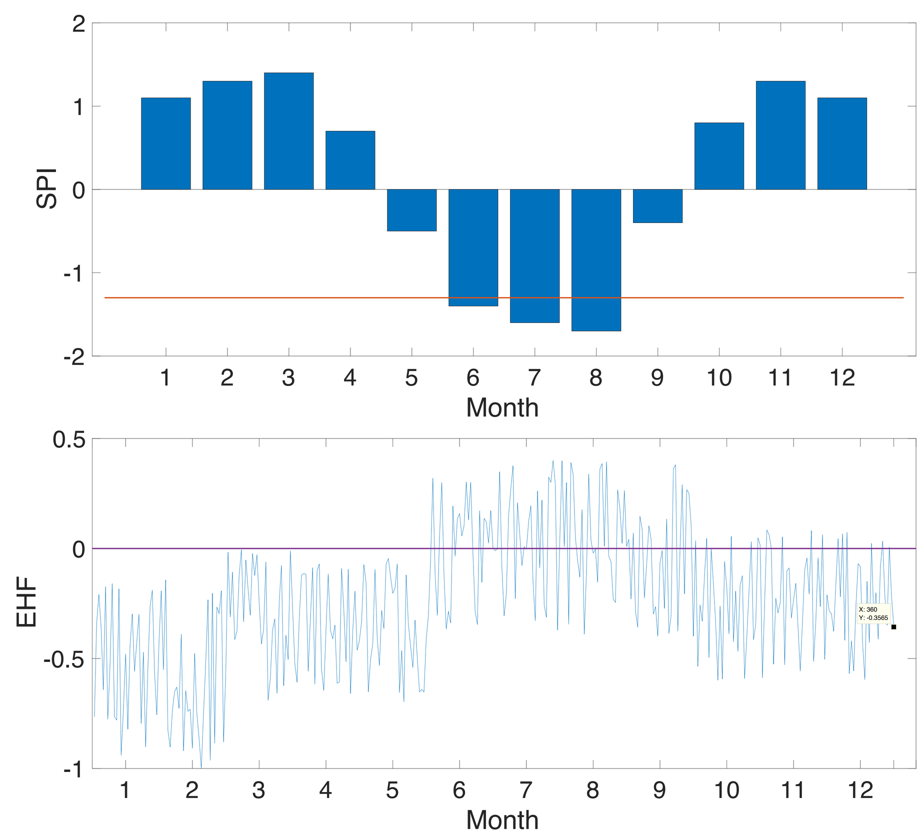
Peak-over-threshold approach: A CDHW event occurs when both contributing variables exceed a relative threshold on the same day at the same grid point.
Heatwaves and droughts are identified using extreme indices

- Excess Heat Factor (EHF) for heatwaves
- 3-month SPI for meteorological drought

Definition of events

- EHF > 0 °C and SPI ≤ −1.3 (moderate drought conditions)

Schematic representation of CDHW events identification



Climate Data

ERA-5 Land data (1991-2022):

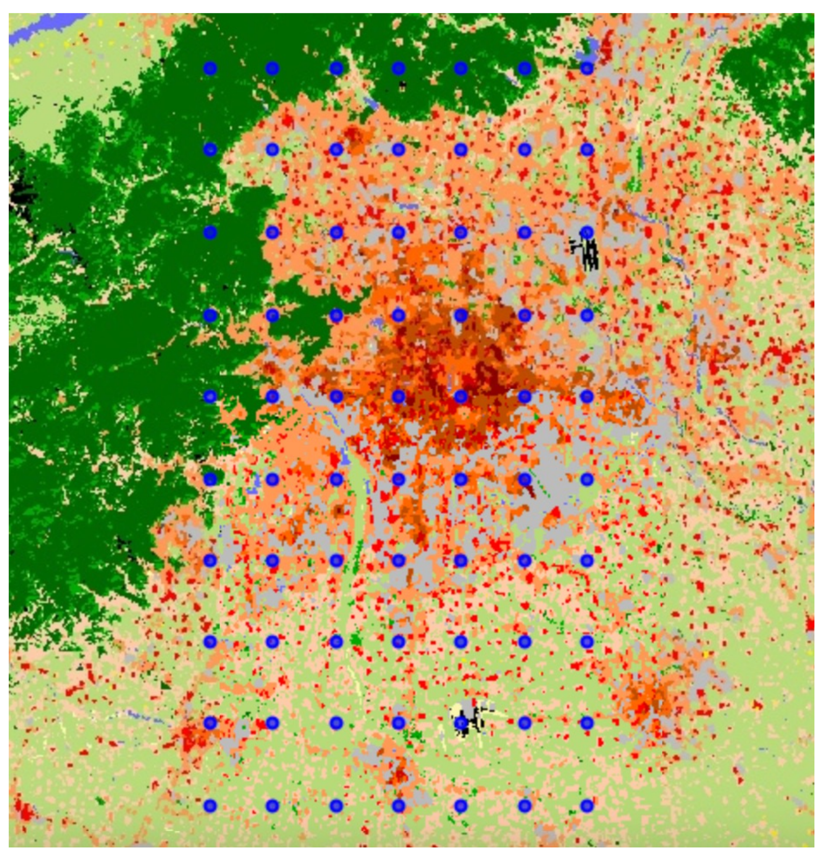
- Daily precipitation (pr),
- hourly temperature (tas)

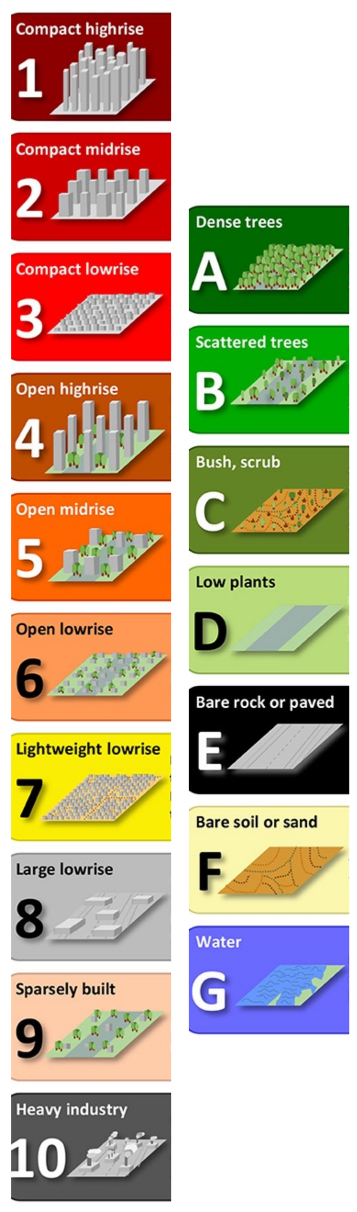
The dataset combines observations from various sources, including satellite data, ground measurements, and weather station records, with advanced numerical models to produce a consistent and high-resolution representation of the land surface at a 0.1-degree spatial resolution.

Areas of study

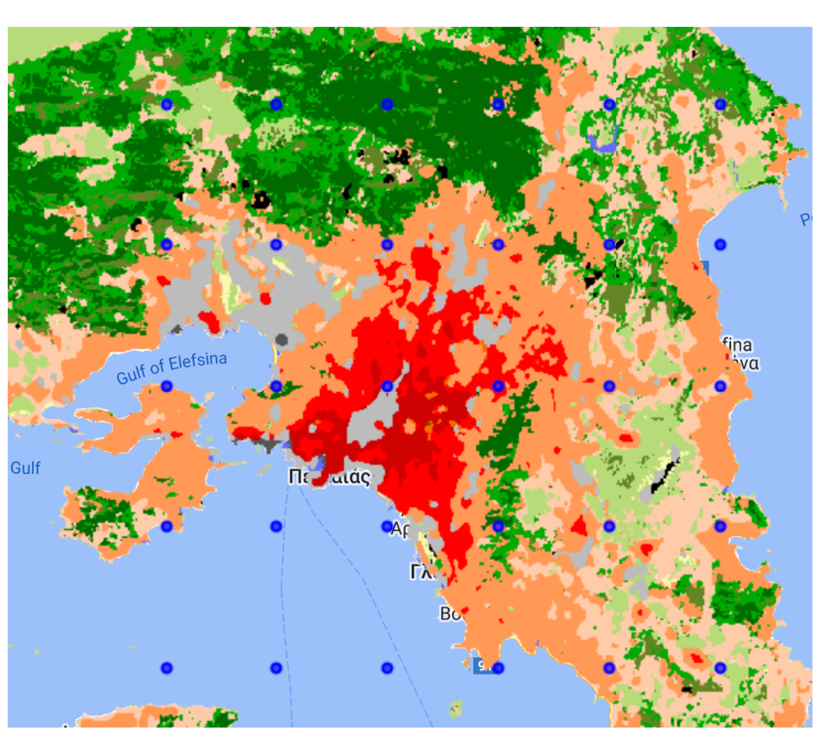
The study areas are Beijing, China, and Athens, Greece. In the following maps produced by Google Earth Engine (Gorelick et al., 2017) the LCZ of each city (Demuzere et al., 2022) at a 100m spatial resolution is presented along with the ERA-5 land grid points (blue points) that are used in the analysis.

Beijing, China



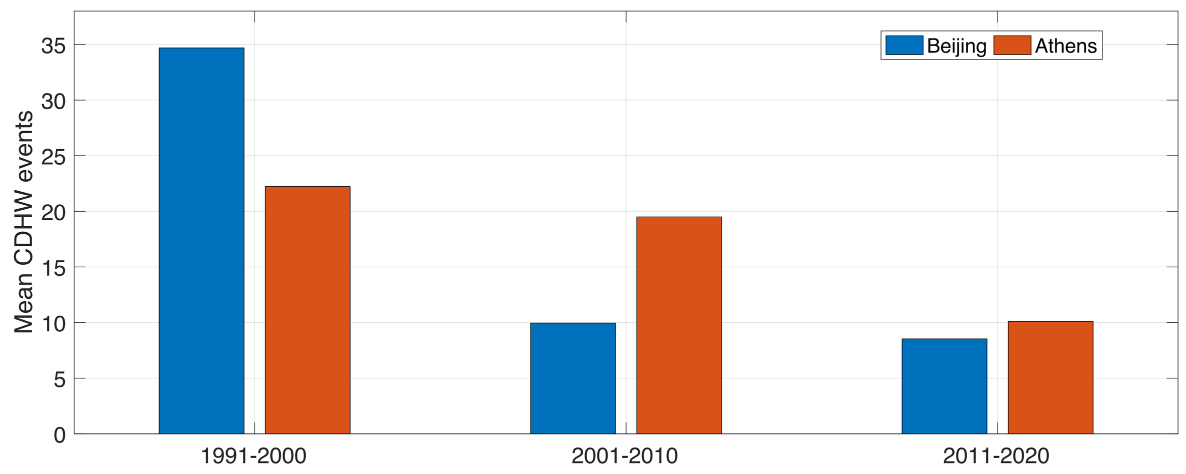


Athens, Greece



Results

Mean number of CDHW events per decade



Total mean CDHW events
Beijing: 53.2 - Athens: 51.8

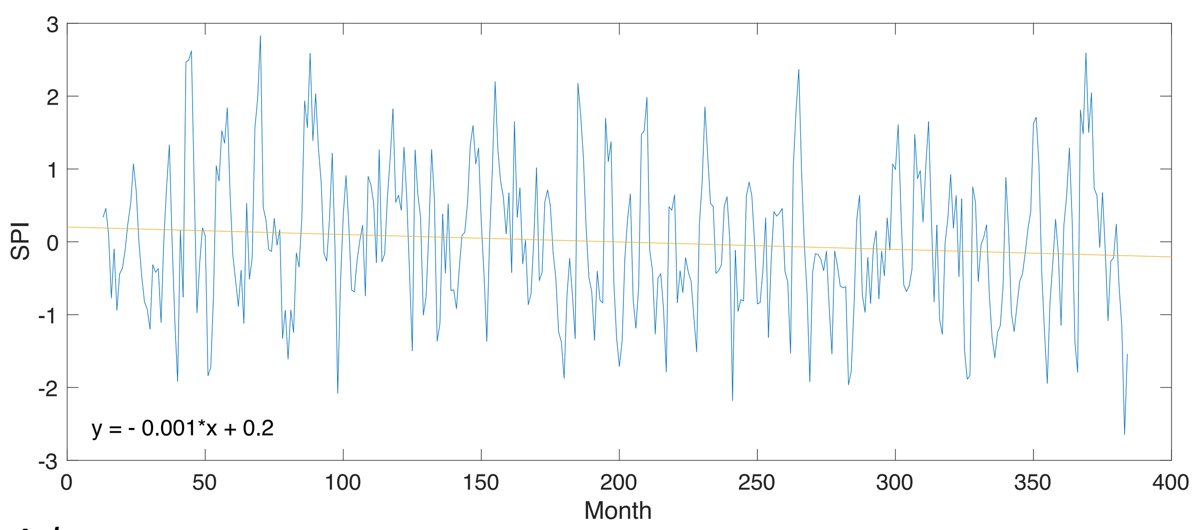
Increased sensitivity of CDHW to the urban fabric

Beijing Urban Grid point(LCZ4):66 events
Beijing Urban Grid point(LCZ4):84 events
Beijing Rural Grid Point (LCZA):45 events

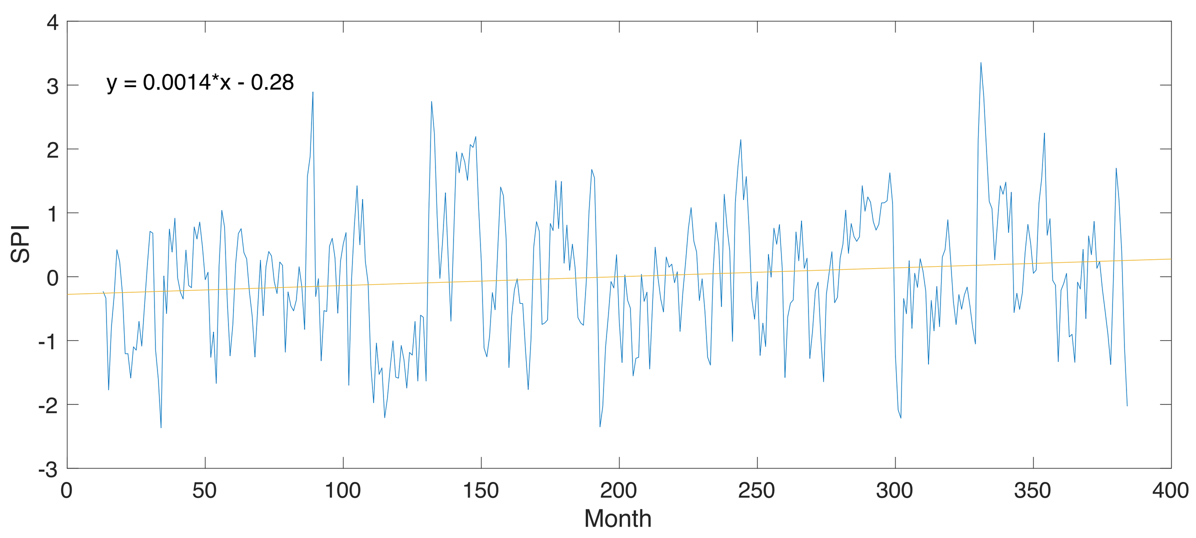
Athens Urban Grid point (LCZ6):75 events
Athens Rural Grid Point (LCZA): 44 events

Evolution of SPI at Beijing and Athens urban grid points

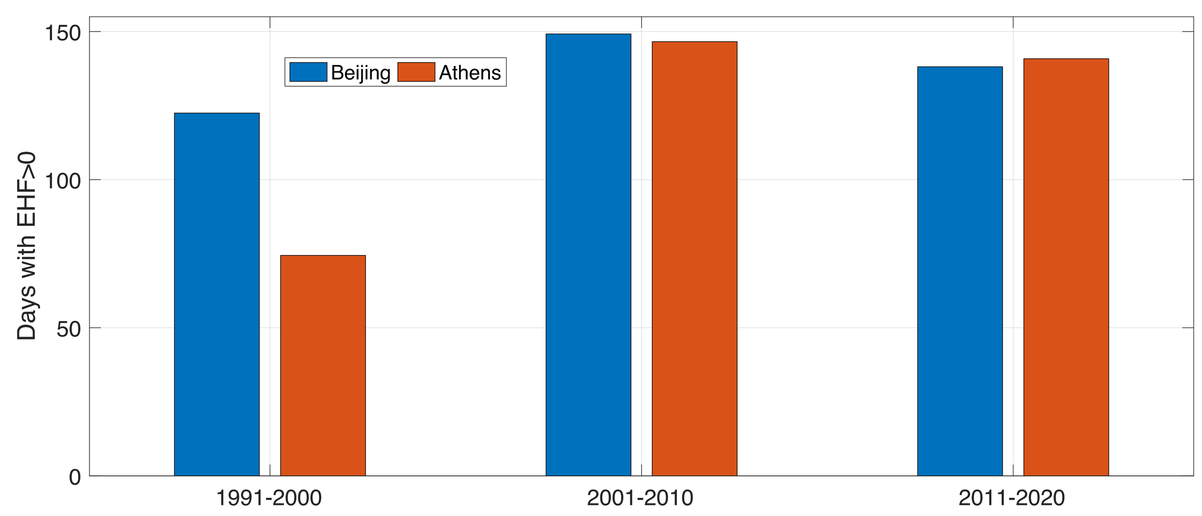
Beijing



Athens



Mean number of days with positive EHF at Beijing and Athens



Conclusions

- The complexity of the climate system poses a great challenge regarding the CDHW risk assessment and the results provide the required scientific evidence for improving the resilience and preparedness of the critical sectors affected by CDHW.
- Heatwaves are the critical factor for the frequency of CDHW events for both regions
- The CDHW events exhibit increased sensitivity to the urban fabric
- Nature-based solutions are proposed to counteract the effect of increased temperatures in both urban areas such as:
    a) Green Infrastructure (Urban parks, green spaces, and urban forests, Green roofs, Permeable pavements)
    b) Sustainable Water Management
    c) Climate Adaptation
    d) Urban Greening Policies

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