Heatwaves in Rome (Italy) during summer 2022: interaction with sea breeze, urban heat island, and thermo-hygrometric comfort

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OUTLINE

- Heatwaves: alternative definitions, superimposition with local and regional atmospheric dynamics and knowledge gaps
- Extreme heat in Europe and Italy during summer 2022
- Identification of heatwaves in Rome (Italy) during summer 2022 in comparison with summer 2020
- Effect of heatwaves on:
  - Development of the sea breeze regime
  - Urban Heat Island Intensity
  - Mediterranean outdoor comfort index (MOCI)
- Conclusions

HEATWAVES: DIFFERENT DEFINITIONS

World Meteorological Organization (WMO) → "statistically unusual hot weather persisting for a number of days and nights"

↓

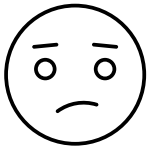
Not unique definition!!

Several alternatives based on:
(i) *intensity*: maximum temperature reached during a heatwave event

(ii) *temporal extension*: number of consecutive days that meet the chosen definition of heatwave

(iii) *frequency*: occurrence of excessive warming episodes per year/season

Some other problems related to specific geographic conditions:
- Urban Heat Island (UHI) effect
- sea/land breeze regime



Not only…
studies typically disjointedly explore the synergy between heatwaves and UHI/outdoor thermal comfort/sea breeze

Need to have an approach synergic and comprehensive!!

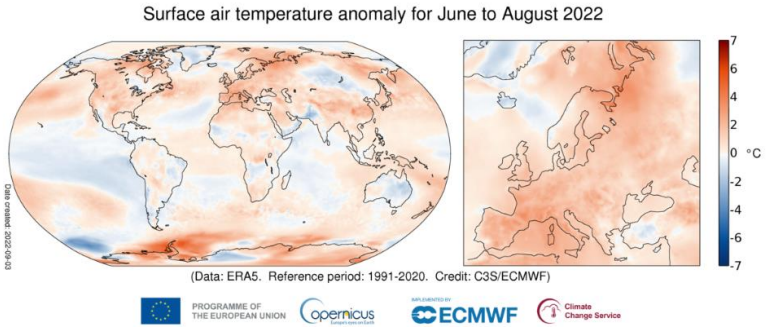
EXTREME HEAT IN EUROPE AND ITALY DURING SUMMER 2022

EUROPEAN STATE OF THE CLIMATE 2022 | NEWSFLASH

Copernicus: European State of the Climate 2022 Unprecedented extreme heat and widespread drought mark European climate in 2022

Key findings for Europe:

- Europe experienced its second warmest year ever recorded
- Europe saw its hottest summer on record
- Much of Europe suffered intense and prolonged heatwaves
- Southern Europe experienced the highest number of days with 'very strong heat stress' on record
- Low rainfall and high temperatures led to widespread drought
- Carbon emissions from summer wildfires were the highest in 15 years, with some countries seeing the highest emissions in 20 years
- The European Alps saw a record loss of ice from glaciers
- There was a record number of sunshine hours for Europe



Le Monde

With three heat waves, the summer of 2022 was the deadliest in France since 2003

France recorded more than 2,800 deaths during the heat waves, according to new data.

la Repubblica

Il caldo che uccide: a luglio 30% in più di decessi

Le temperature oltre 2 gradi sopra alla media hanno fatto aumentare la mortalità, soprattutto sopra agli 85 anni. In alcuni reparti un ricoverato su 3 ha problemi legati all'eccesso di temperatura

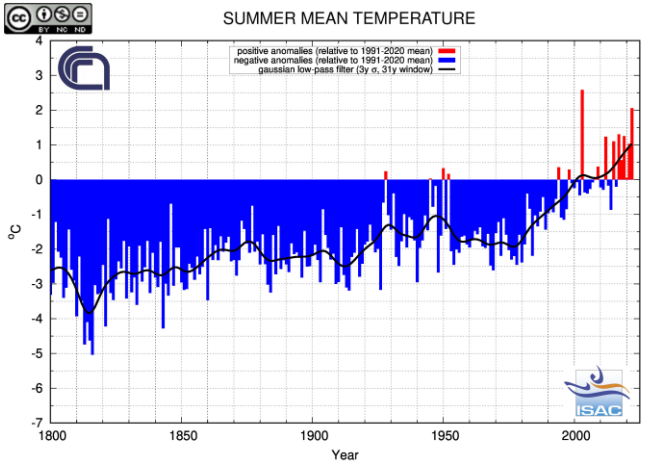
BBC

Climate change: Summer 2022 smashed dozens of UK records

EL PAÍS

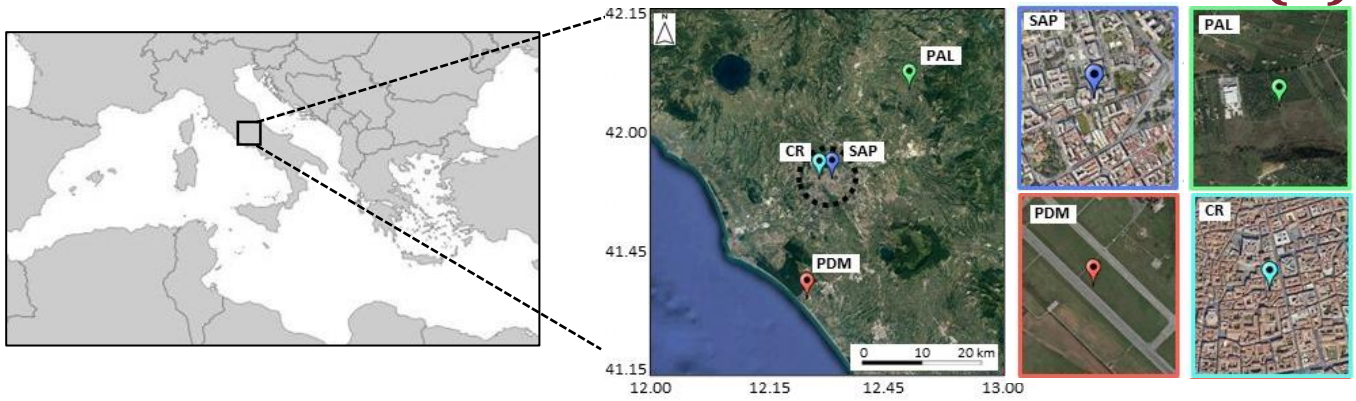
Southern Europe battles wildfires amid 'apocalypse of heat'

Deaths were reported in Spain and Portugal while France struggled with record temperatures as the heatwave began moving north, putting other countries on alert




METHODS

STUDY AREA AND DATASETS (1)



Periods

01/05/2022-31/08/2022

Vs

01/05/2020-31/08/2020

STATION #1 → SAP (Lat. 41.90 N, Lon. 12.51 E, 75 m a.s.l.)

BAQUNIN (*Boundary-layer Air Quality-analysis Using Network of Instruments*) atmospheric supersite

https://www.baqunin.eu

@BaquninProject

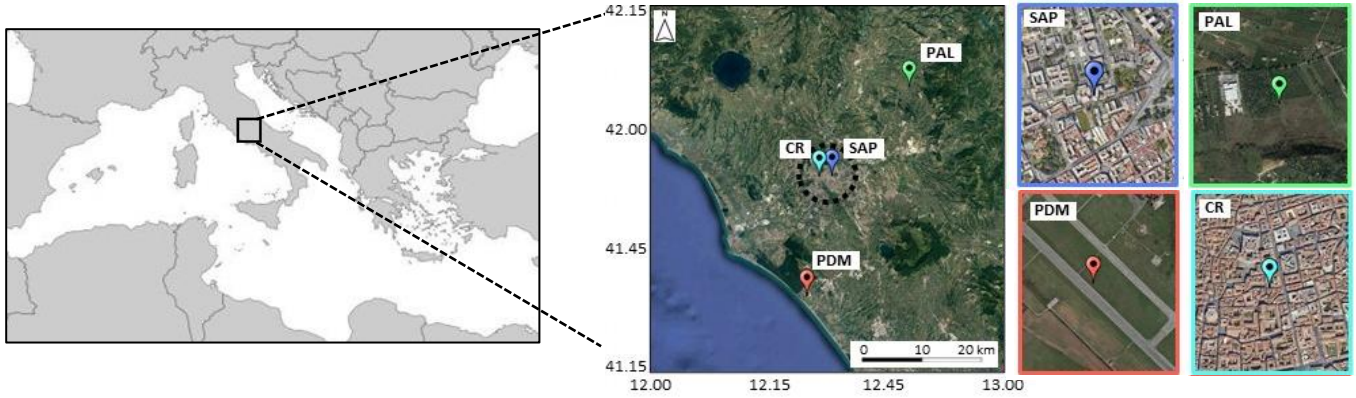
Supported by esa EUMETSAT

- **Ground-based weather station**
  Variables: air temperature, relative humidity, wind speed, wind direction.
  Temporal resolution: 10-minutes-averaged values.
- **Doppler SOund Detection And Ranging (SODAR)**
  Variables: vertical profiles of wind intensity and direction.
  Temporal resolution: 10-minutes-averaged profiles. Vertical resolution: 18.5 m.
- **Pyranometer**
  Variables: global solar radiation in the 285–3000 nm spectral range
  Temporal resolution: 5-seconds-averaged values

→ For the identification of sea breeze regime

→ For the evaluation of the thermo-hygrometric comfort index

STUDY AREA AND DATASETS (2)



Periods

01/05/2022-31/08/2022

VS

01/05/2020-31/08/2020

STATION #2 → PAL (Lat. 42.07 N, Lon. 12.74 E, 142 m a.s.l.)

Managed by Integrated Agrometeorological Service of the Lazio Region (ARSIAL)

- **Ground-based weather station**
  Variable: air temperature
  Temporal resolution: hourly-averaged values

→ For the evaluation of UHI

STATION #3 → PDM (Lat. 41.654, Lon. 12.445, 12 m a.s.l.)

Managed by Italian Air Force station (ICAO CODE: LIRE)

- **Ground-based weather station**
  Variable: air temperature
  Temporal resolution: hourly-averaged values

→ For the evaluation of spatial homogeneity of the heatwaves

STATION #4 → CR (Lat. 41.90 N, Lon. 12.48 E, 57 m a.s.l.)

Managed by Council For Agricultural Research And Economics (CREA)

- **Ground-based weather station**
  Variable: air temperature
  Temporal resolution: hourly-averaged values

→ Reference dataset
Period: 2000-2019

IDENTIFICATION OF HEATWAVES

(i) Temperature constrain

$$T_i > (\widetilde{T}_{i,ref})_{95}$$

T_i = daily temperatures of the i-th day of the year (T_{ave}, T_{max}, or T_{min})
$(\widetilde{T}_{i,ref})_{95}$ = upper 95th percentile of the probability density function related to the long-term period, chosen as a reference
Reference dataset: 2000-2019 @ CR urban station

(ii) Temporal constrain

exceeding the temperature constrain for at least 4 consecutive days.

HEATWAVE → *the average daily temperature exceeds the 95th percentile of the reference period for at least 4 consecutive days*

- **HEATWAVE DURATION (*HWD*)**: number of consecutive days meeting the heatwave criteria;
- **HEATWAVE AMPLITUDE (*HWA*)**: maximum daily-averaged temperature anomaly compared to the reference period;
- **HEATWAVE AVERAGE AMPLITUDE (*HWAA*)**: average temperature anomaly compared to the reference period;
- **HOT DAYS (*HD*)**: number of days with maximum temperature exceeding 35 °C;
- **TROPICAL NIGHTS (*TN*)**: number of days with minimum temperature exceeding 20 °C;
- **COMBINED HOT DAYS AND TROPICAL NIGHTS (*CHT*)**: number of days with concurrent HD and TN.

Adapted from Fischer and Schar (2010)

DEVELOPMENT OF THE SEA BREEZE REGIME

How to identify a *"sea-breeze day"*?

Significant increase in wind speed and a change in wind direction, which must blow perpendicularly to the coastline, are measured in conjunction with a reduction in temperature and an increase in specific humidity.

URBAN HEAT ISLAND INTENSITY

$$UHII = T_{urb} - T_{rur} \quad (1)$$

How to choose *representative* stations?

- the distance of the stations from the city center must be less than 10 km for the urban station and 35 km for the rural station;
- the altitude difference between the selected urban and rural stations, necessary to remove the impact of topography on UHI evaluation, must be less than 70 m;
- the rural station must be surrounded by natural, not densely built-up areas.

Proposed by Possega et al. (2022)

SAP and **PAL** meet these requirements.

T_{urb} → **SAP**

T_{rur} → **PAL**

MEDITERRANEAN OUTDOOR COMFORT INDEX (MOCI)

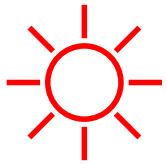
Experimentally defined and is based on an ASHRAE 7-point scale, with values in the -0.5÷0.5 range corresponding to different thermal comfort conditions.

$$MOCI = -4.257 + 0.146 \cdot T_A + 0.325 \cdot I_{CL} + 0.005 \cdot RH + 0.001 \cdot I_S - 0.235 \cdot W_S \quad (2)$$

$$I_{CL} = 1.608 - 0.038 \cdot T_A \quad (3)$$

with:
T_A = air temperature (°C)
I_{CL} = thermal resistance of the clothing (°C)
RH = relative humidity (%)
I_S = global solar irradiance (W/m^2)
W_S = wind speed intensity (m/s)

MOCI < -0.5 COLD DISCOMFORT

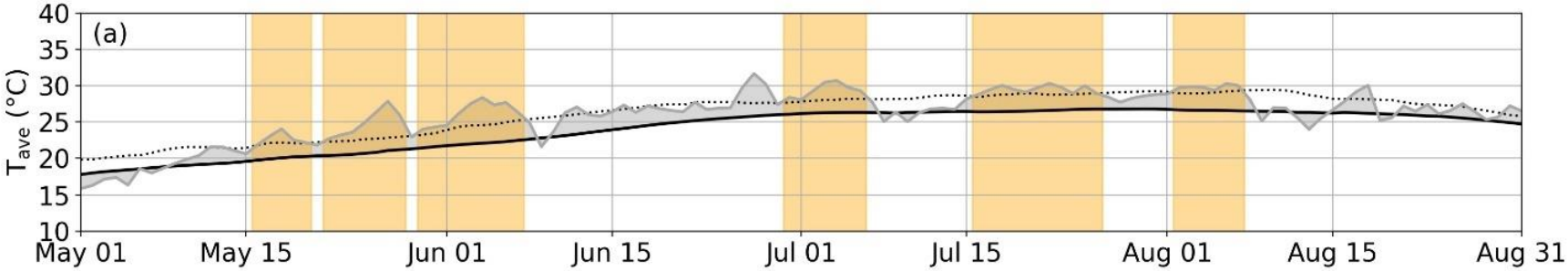


MOCI > 0.5 HOT DISCOMFORT

Proposed by Salata et al. (2016)


RESULTS

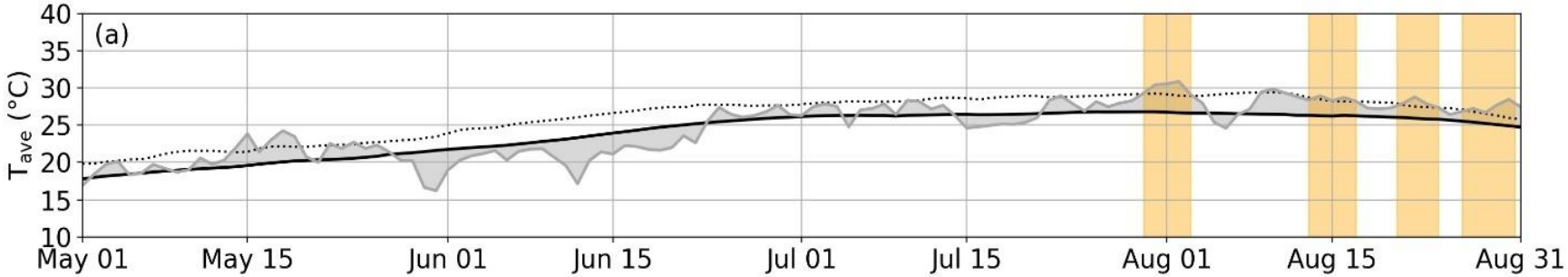
HEATWAVES DURING SUMMER 2022…



Event ID	Start	Stop	HWD (n. days)	HWA (°C)	HWAA (°C)	HD (n. days)	TN (n. days)	CHT (n. days)
HW#1	16/05/2022	20/05/2022	5	1.9	0.7	0	0	0
HW#2	22/05/2022	28/05/2022	7	5.0	2.3	0	3	0
HW#3	30/05/2022	07/06/2022	9	3.8	1.9	0	7	0
HW#4	30/06/2022	06/07/2022	7	2.6	1.5	4	7	4
HW#5	16/07/2022	26/07/2022	11	1.6	0.7	6	11	6
HW#6	02/08/2022	07/08/2022	6	1.1	0.8	3	6	3

- Heatwaves are experienced during each month (more frequent in May and June)
- Duration between 5 (HW#1) and 11 days (HW#5)
- CHT only during July and August

...AND SUMMER 2020



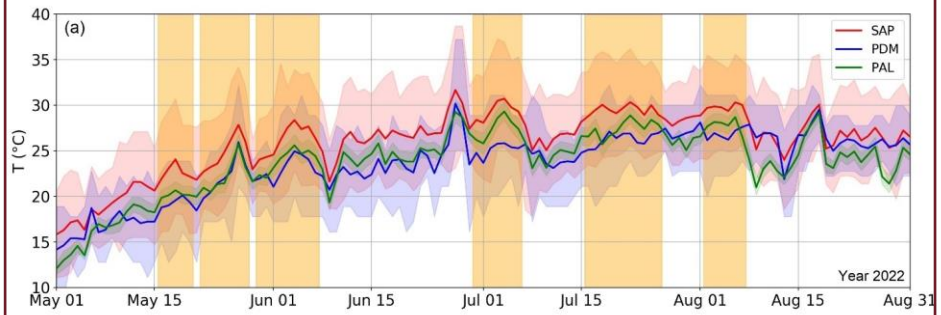
Event ID	Start	Stop	HWD (n. days)	HWA (°C)	HWAA (°C)	HD (n. days)	TN (n. days)	CHT (n. days)
HW#1	29/07/2020	02/08/2020	5	1.9	1.0	4	5	4
HW#2	13/08/2020	16/08/2020	4	0.5	0.3	0	4	0
HW#3	20/08/2020	23/08/2020	4	1.3	0.5	1	4	1
HW#4	26/08/2020	30/08/2020	5	2.5	1.3	0	4	0

- Heatwaves between the end of July and August
- Each heatwave lasts at most 5 days
- Low values of CHT

DEVELOPMENT OF THE SEA BREEZE REGIME

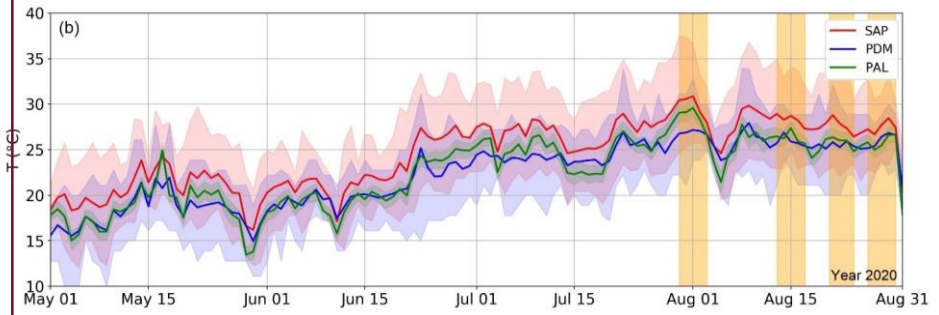
2022

Dataset	Start time UTC	Stop time UTC	ΔT (°C)	Wind speed (m/s)		
				Mean	St. Dev.	Max.
all sea breeze days	11:22	18:44	4.7	2.2	0.3	5.9
HW days	11:26	18:44	5.2	2.2	0.3	6.0
no-HW days	11:19	18:43	4.4	2.2	0.3	5.9



2020

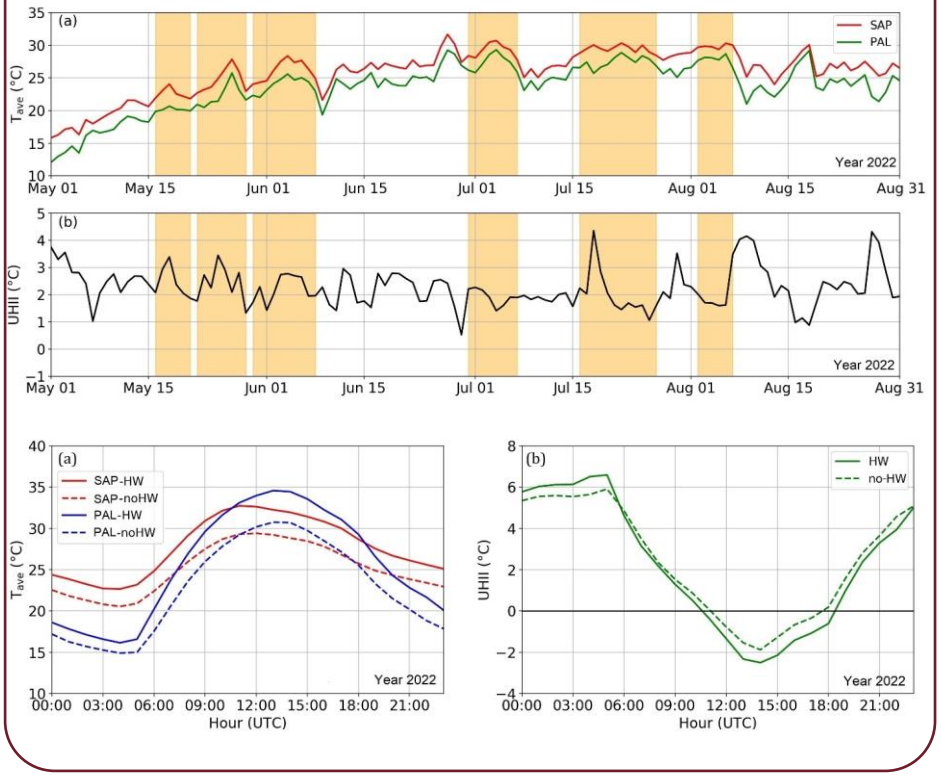
Dataset	Start time UTC	Stop time UTC	ΔT (°C)	Wind speed (m/s)		
				Mean	St. Dev.	Max.
all sea breeze days	11:25	19:01	4.7	2.6	0.4	6.2
HW days	11:36	19:18	5.8	2.8	0.1	6.0
no-HW days	11:22	18:57	4.4	2.5	0.4	6.3



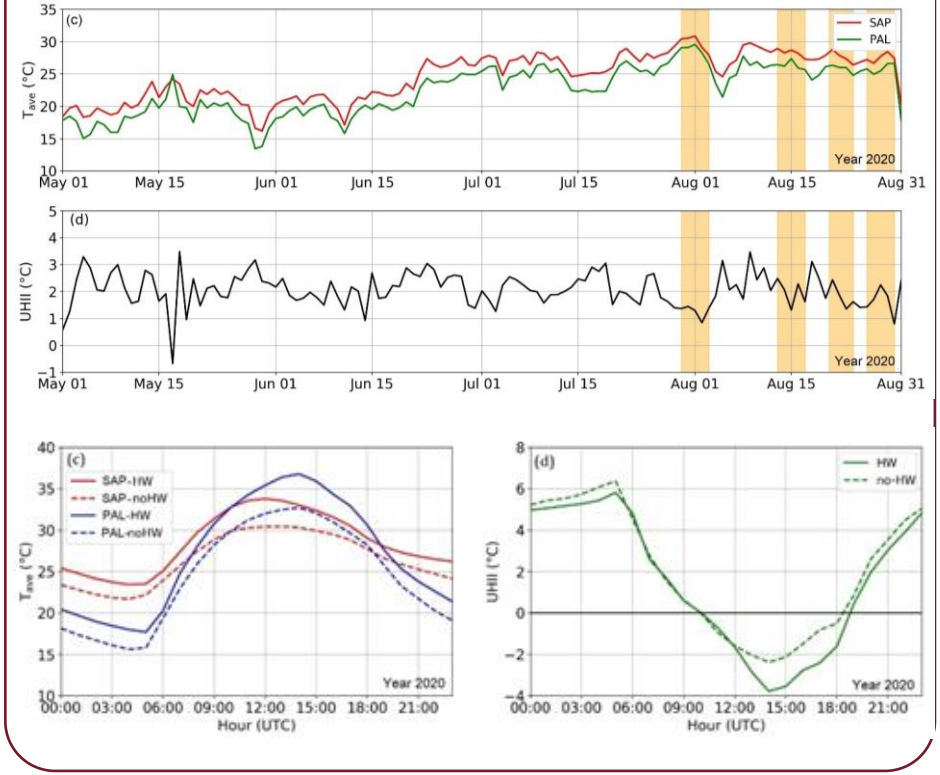
- Heatwaves do not significantly influence the onset time, duration, and intensity of sea breeze
- Cooling effect favored during the heatwaves (5.2 °C and 4.4 °C for HW and no-HW days in 2022, respectively)

URBAN HEAT ISLAND INTENSITY

2022



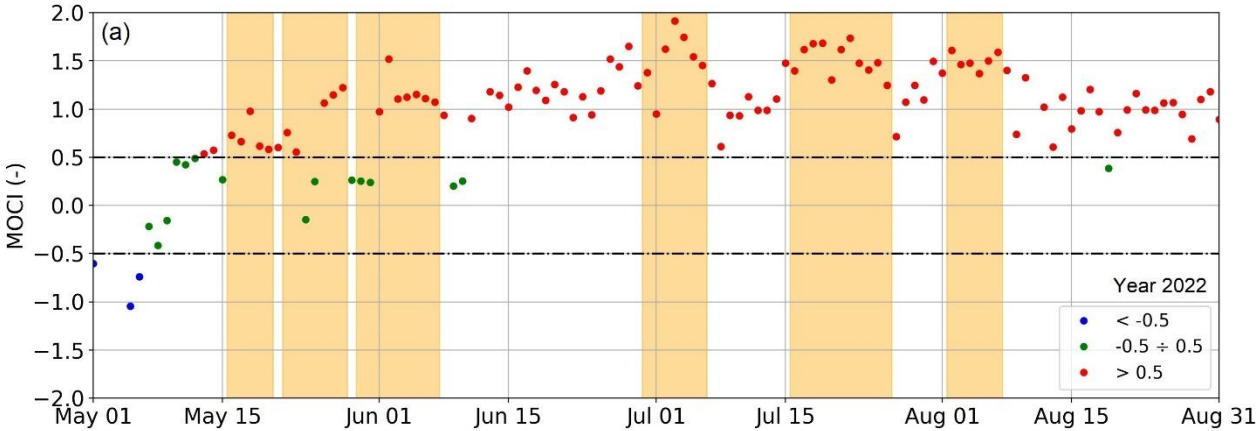
2020



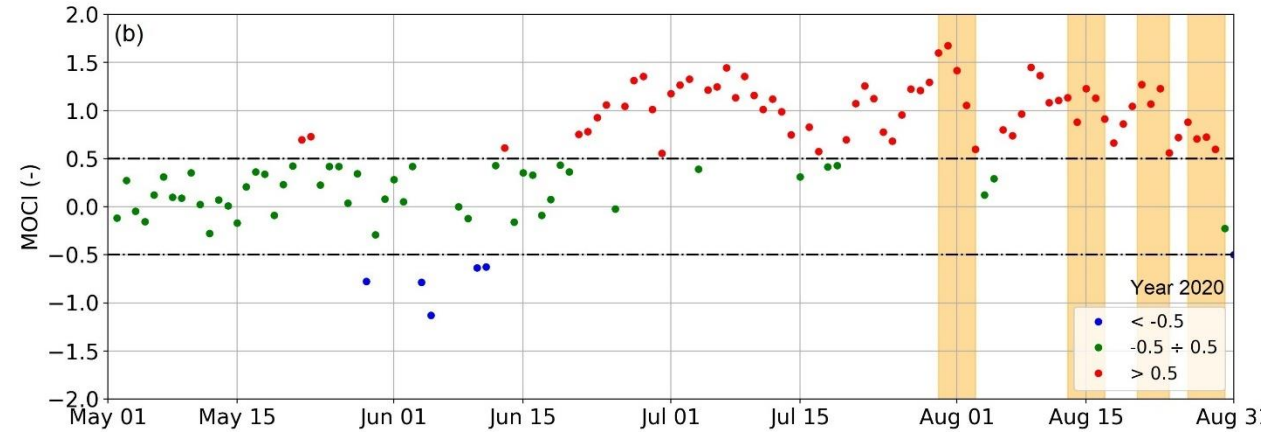
- No synergy between UHI and heatwaves can be evinced by the daily-averaged UHII values
- Daytime: the rural area, despite being characterized by natural land use, without buildings and/or obstacles and, hence, without UHI, records daytime maximum temperatures higher than the city
- Nighttime: the city is warmer than the rural surroundings because of the UHI which limits the nocturnal atmospheric cooling

MEDITERRANEAN OUTDOOR COMFORT INDEX (MOCI)

2022



2020



- Higher daily maxima of MOCI associated with heatwaves in July and August
- Daily maxima of MOCI fall in the comfort range even during heatwaves during May and June

CONCLUSIONS AND REMARKS

- Heatwaves do not significantly influence the development of the sea breeze in terms of onset time, duration, and intensity. Only the cooling effect is favored during the heatwaves.
- Absence of synergy between heatwaves and daily-averaged UHII value, which has a variation between the HW and no-HW sub-datasets of 0.2 °C and 0.5 °C in 2022 and 2020.
- Evident differences between diurnal and nocturnal UHII:
  - during night-time: UHII higher in HW than in no-HW days, further demonstrating the urban heating compared to the rural areas
  - during daytime: lower temperature difference between urban and rural environments.
- The manifestation of a heatwave does not necessarily involve thermo-hygrometric stress, since the latter depends on several weather variables.

Need of a **univocal and globally applicable definition of heatwave** allowing for:

- ❖ comparison of scientific results in different climatic zones
- ❖ assessing and designing climate change mitigation and adaptation strategies also considering regional key factors, often overlooked

Thank you for your attention!

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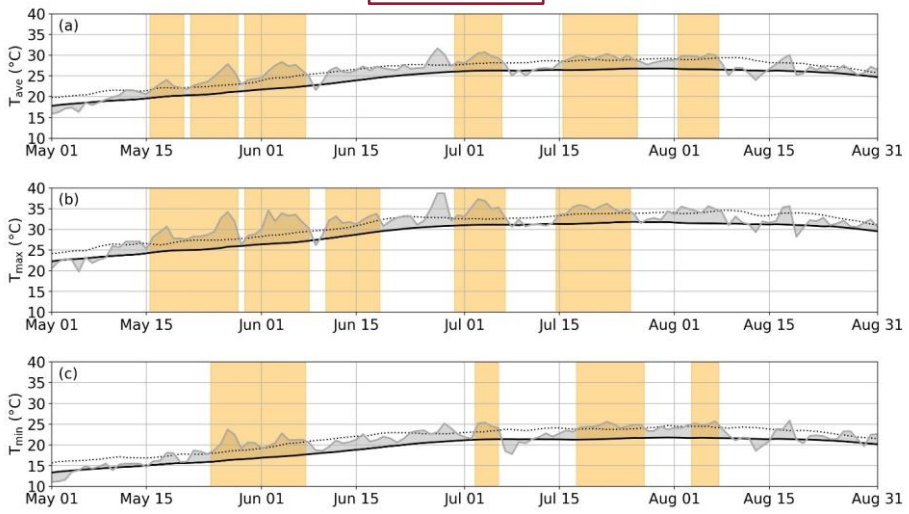
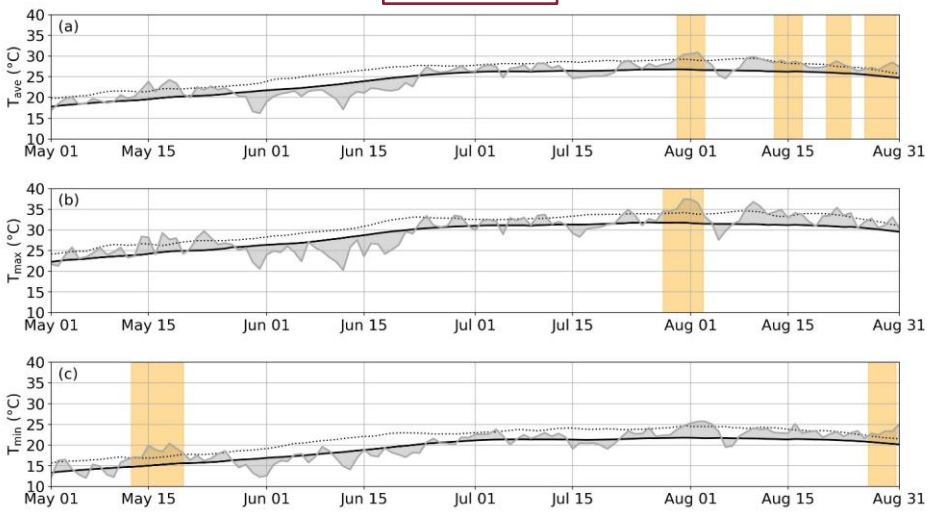
*The authors gratefully acknowledge the **BAQUNIN team** for providing atmospheric data and for the insight and expertise that greatly assisted this work.*

AIR TEMPERATURES DURING SUMMER 2022 AND 2020

2022



2020



	MAY			JUNE			JULY			AUGUST		
	2000-2019	2020	2022	2000-2019	2020	2022	2000-2019	2020	2022	2000-2019	2020	2022
Average	19.7	19.7	**21.4**	24.0	24.0	**26.9**	26.5	26.5	**28.5**	26.1	26.1	**27.3**
Standard deviation	2.6	1.1	**3.1**	1.4	1.4	**1.9**	0.2	0.2	**1.5**	0.5	0.5	**1.8**
Minimum	13.3	13.3	11.1	16.9	16.9	**18.6**	21.1	21.1	17.8	20.2	20.2	18.6
Maximum	26.3	26.3	**34.2**	30.9	30.9	**38.7**	31.8	26.8	**37.3**	31.6	**31.7**	**35.6**
50th percentile	19.8	19.8	**21.8**	24.0	**24.1**	**26.9**	26.4	26.4	**28.8**	26.3	26.3	**27.0**
95th percentile	21.4	21.4	**26.2**	26.0	26.0	**30.0**	26.8	26.8	**30.4**	26.6	**26.7**	**30.0**