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How have temperature and atmospheric constituents changed in the Rome area (Italy) during the last two decades?

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ABSTRACT

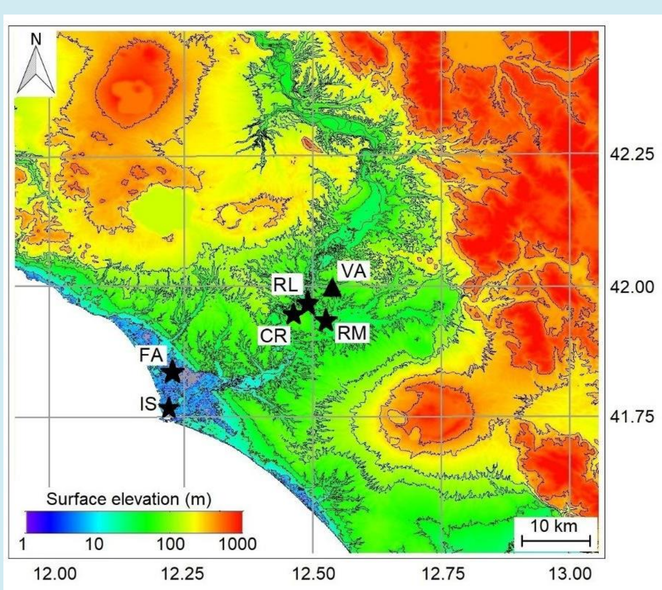
Due to its geographical position, the Rome area, located on the western coast of the Italian peninsula, in the heart of the Mediterranean basin, is typically subjected to the sea/land breeze regime and to the synoptic interaction between high/low circulation systems over the Central-Eastern Mediterranean basin and Continental Europe.

In this work, the trends over two-decade (2000-2020) of daily temperatures (average, minimum and maximum) and in-situ pollutant concentrations (nitrogen oxides, ozone, and particulate matter with aerodynamic diameter less than 10 um) measured in Rome and in the surrounding area are investigated. Data are provided by in-situ stations located in downtown Rome and in the neighbouring coastal area.

All datasets are undergone an accurate pre-processing. Moreover, meteorological datasets have been subjected to a homogenisation procedure, in order to identify and remove non-climatological signals. The statistical analysis, performed using the Seasonal Kendall test, reveals a positive trend for the average, minimum, and maximum daily temperatures both in the city and in the coastal area, confirming the intense warming occurring in the Mediterranean area, with serious implications on human health and thermo-hygrometric well-being. Otherwise, the analysis of in-situ concentrations and columnar amounts shows that the urban air quality level is improving.

The results of this study provide a baseline to be used as a benchmark for present climate observations and as a reference for future measurements and offer useful indications to policymakers for the optimal design and implementation of local actions for climate change adaptation and air pollution mitigation.

STUDY AREA AND DATASETS



Station	Coordinates	Environment	Variable	Time interval
Collegio Romano (CR)	41.90° N, 12.48° E	Urban	T_{ave}, T_{min}, T_{max}, RH, TP	2000-2020
Roma Macao (RM)	41.91° N, 12.51° E	Urban	T_{ave}, T_{min}, T_{max}, TP	2000-2020
Roma Lanciani (RL)	41.92° N, 12.52° E	Urban	RH	2005-2020
Fiumicino Airport (FA)	41.80° N, 12.24° E	Coastal	T_{ave}, T_{min}, T_{max}, RH	2000-2020
Isola Sacra (IS)	41.76° N, 12.23° E	Coastal	TP	2000-2020
Villa Ada (VA)	41.93° N, 12.51° E	Urban background	C_6H_6, SO_2, CO, NO_x, NO, NO_2, O_3, PM_{10}	2000-2020

METEOROLOGICAL VARIABLES:

- *daily-averaged air temperature* (**T_{ave}**, °C),
- *daily minimum air temperature* (**T_{min}**, °C)
- *daily maximum air temperature* (**T_{max}**, °C)
- *daily-averaged relative humidity* (**RH**, %)
- *daily total precipitation* (**TP**, mm)
- *water vapour mixing ratio* (**MR**, g kg^{-1}), from RH and T_{ave}
- *heat index* (**HI**, °C) (*Awasthi et al., 2021*) computed as:

$$HI = -42.38 + 2.049015 \cdot T + 10.143331 \cdot RH - 0.224755 \cdot T \cdot RH - 0.006837 \cdot T^2 - 0.004817 \cdot RH^2 + 0.001229 \cdot T^2 \cdot RH + 0.000853 \cdot T \cdot RH^2 - 0.000002 \cdot T^2 \cdot RH^2$$

AIR QUALITY VARIABLES:

Daily-averaged surface in-situ concentrations:

- *nitrogen dioxide* (**NO_2**)
- *nitrogen monoxide* (**NO**)
- *carbon monoxide* (**CO**)
- *particulate matter* (**PM_{10}**)
- *ozone* (**O_3**)
- *benzene* (**C_6H_6**)
- *sulfur dioxide* (**SO_2**)

DATA PRE-PROCESSING

All the data used in this study have been previously validated by the institutional entities responsible for the data production and distribution.

The further pre-processing and quality control consists of:

1. **Preliminary screening**: datasets underpass a first screening through visual inspection to remove gross errors
2. **Data discarding**: the months during which the amount of daily data is less than 80% are discarded (*WMO, 2017*)
3. **Data homogenization**: all meteorological monthly series are subjected to a homogenization procedure to identify and remove non-climatological signals by applying the Craddock test (Craddock 1979) in a pairwise comparison of stations.

Thanks to the proximity of the meteorological stations of RM and RL and of FA and IS, the pairs of stations are considered as single sites (namely RM/RL and FA/IS, respectively).

TREND ANALYSIS

Seasonal Kendall test (SK test): non-parametric test, which analyses data for monotonous trends with seasonal variability, de-seasonalising the datasets and considering the annual variability of the variables (*Hirsch and Slack, 1984*).

The **Seasonal Kendall score *S*** is computed as:

$$S = \sum_{k=1}^{m} \sum_{j=1}^{n-1} \sum_{i=j+1}^{n} sign(x_{ik} - x_{jk})$$

where m is the total number of months, x is the investigated variable, n is the number of years, and the sign is computed by subtracting to the annual average of each i-th year the annual average of the j-th previous year.

Positive (negative) S values indicate a positive (negative) trend. When the absolute value of S is close to zero, no trend is detected.

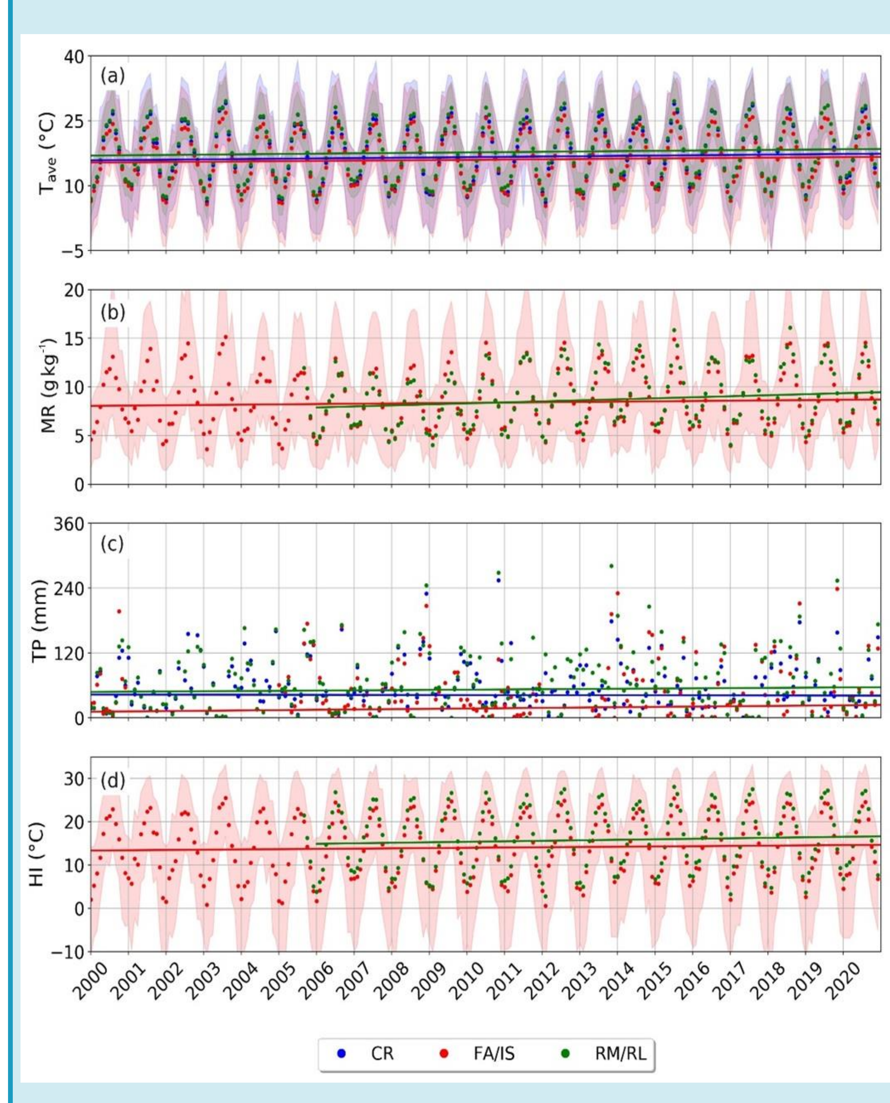
Kendall correlation coefficient: $\tau = \frac{S}{n(n-1)/2}$

The value of τ ranges between -1 and 1. It indicates the strength of the monotonic association between the variable x and time.

A significance level α=5% is here assumed.

RESULTS

statistically significant **increasing trend** – statistically significant **decreasing trend** – no statistically significant trend



T_{ave}

Site	τ	Slope (°C/year)
CR	0.22	0.07
FA/IS	0.20	0.06
RM/RL	0.20	0.07

T_{max}

Site	τ	Slope (°C/year)
CR	0.12	0.04
FA/IS	0.13	0.01
RM/RL	0.28	0.10

T_{min}

Site	τ	Slope (°C/year)
CR	0.31	0.12
FA/IS	0.11	0.01
RM/RL	0.07	0.02

MR

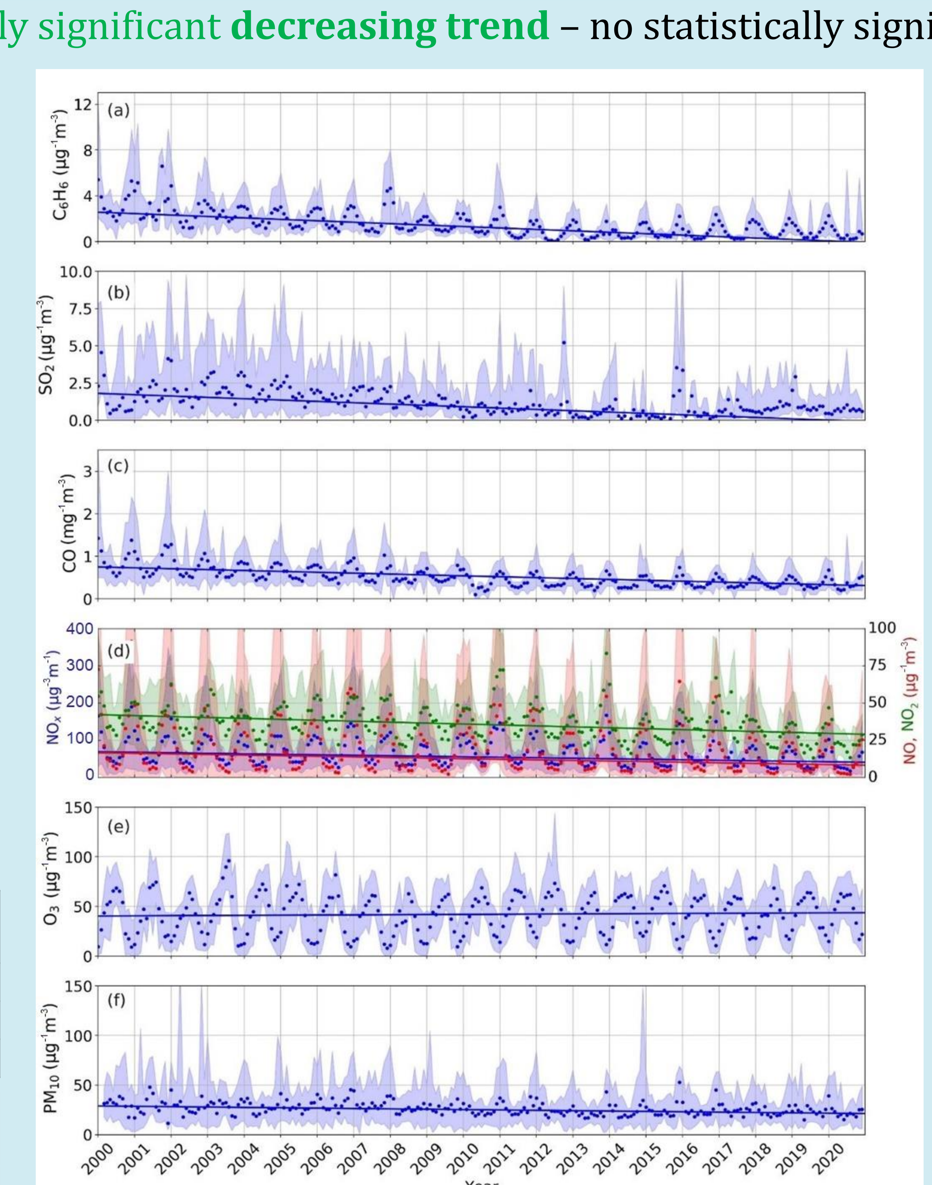
Site	τ	Slope (g/kg year)
FA/IS	0.15	0.03
RM/RL	0.36	0.10

TP

Site	τ	Slope (mm/year)
CR	-0.02	-0.08
FA/IS	0.23	0.57
RM/RL	0.05	0.40

HI

Site	τ	Slope (°C/year)
FA/IS	0.21	0.06
RM/RL	0.25	0.11



C_6H_6

τ	Slope (μg/m³ year)
-0.73	-0.12

SO_2

τ	Slope (μg/m³ year)
-0.46	-0.09

CO

τ	Slope (mg/m³ year)
-0.75	-0.02

NO_x

τ	Slope (μg/m³ year)
-0.45	-1.28

NO

τ	Slope (μg/m³ year)
-0.45	-0.38

NO_2

τ	Slope (μg/m³ year)
-0.36	-0.60

O_3

τ	Slope (μg/m³ year)
0.11	0.15

PM_{10}

τ	Slope (μg/m³ year)
-0.26	-0.35

CONCLUSIONS

- In the city of Rome, i.e., in a metropolis with a well-established historical development and a rather limited urban transformation, the thermal discomfort due to rising temperatures is growing. It means that an increase in energy consumption for cooling is expected and, consequently, this will lead to a further worsening of urban thermal comfort.
- The air quality level is improving, even if the tendency for NO_2 and O_3 is weak. Therefore, the regional and national regulations adopted in recent years are working and it is necessary to intensify the reduction of local emissions as much as possible through environmental protection policies and limiting the use of cars, supporting the renewal of the vehicle fleet, and encouraging the transition to hybrid and electric automobiles. Moreover, the O_3 increasing trend suggests that more attention should be paid to this pollutant. This trend might derive both from the decrease of NO_x and from the combined effect of higher temperatures and lower precipitations, which, in the rural areas surrounding the city, can produce water stress for the vegetation and, in turn, can affect the O_3 concentration favoring formation of O_3 precursors and limiting O_3 removal.

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