Intra- and inter-city variability of $PM_{2.5}$ concentrations over Greece

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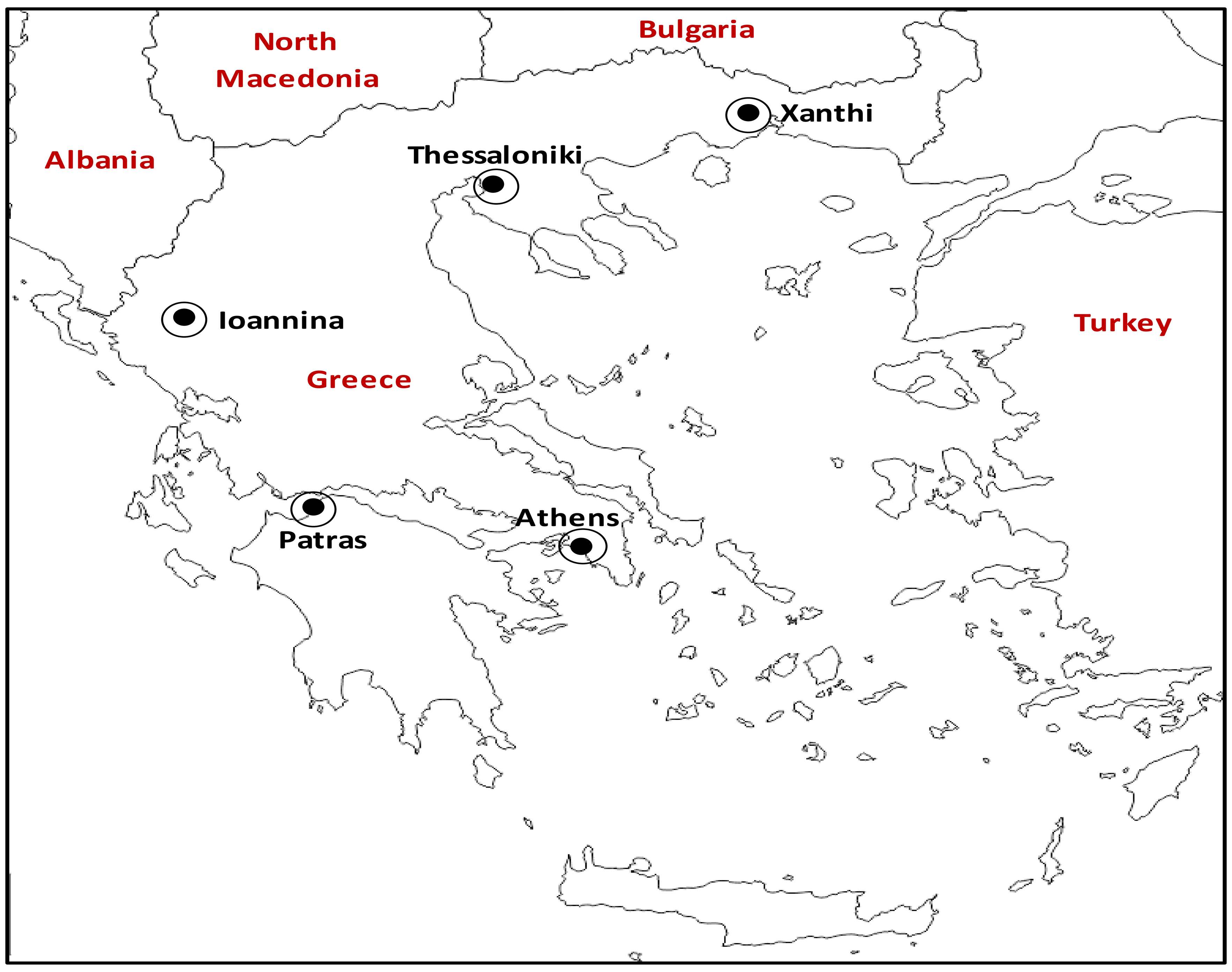
1. Monitoring sites and measurements

Hourly $PM_{2.5}$ concentrations (μg/m^3) for the time interval from 1/7/2019 to 30/6/2021, were derived from a dense network of fourteen Purple Air PA-II low cost sensors installed in five continental Greek cities namely: Athens (4 sensors), Patras (3 sensors), Ioannina (2 sensors), Xanthi (2 sensors) and Thessaloniki (3 sensors). Hourly Wind Speed (WS) and Temperature (T) measurements in m/sec and °C respectively, were also obtained from meteorological stations situated inside four out of the five cities namely: Athens, Patras, Ioannina and Thessaloniki.



Station	City	Abbreviation
Thissio	Athens	THI
Vouliagmeni	Athens	VOU
Piraeus Marina Zeas	Athens	PIR
Pefki	Athens	PEF
Anatoli	Ioannina	ANA
Vilara	Ioannina	VIL
Xanthi Center	Xanthi	XAC
Xanthi Democritus University of Thrace	Xanthi	XAD
Agia	Patras	AGI
Agios Angreas	Patras	AGA
University of Patras	Patras	UPA
Kardia	Thessaloniki	KAR
Dimotiko	Thessaloniki	DIM
Vasilika	Thessaloniki	VAS

2. Levels of $PM_{2.5}$ among the various cities

Higher average levels of $PM_{2.5}$ were measured at all sampling sites during cold period (October 16th – April 15th) and were attributed to a combination of traffic and heating emissions with lower boundary layer height. Peak average $PM_{2.5}$ concentrations during cold period were detected from the two sensors located at the high altitude city of Ioannina and were associated to the extensive use of biomass burning for heating purposes. During warm seasons (April 16th – October 15th), low average $PM_{2.5}$ concentrations were reported by all sensors indicating almost uniform aerosol pollution levels in Greece.

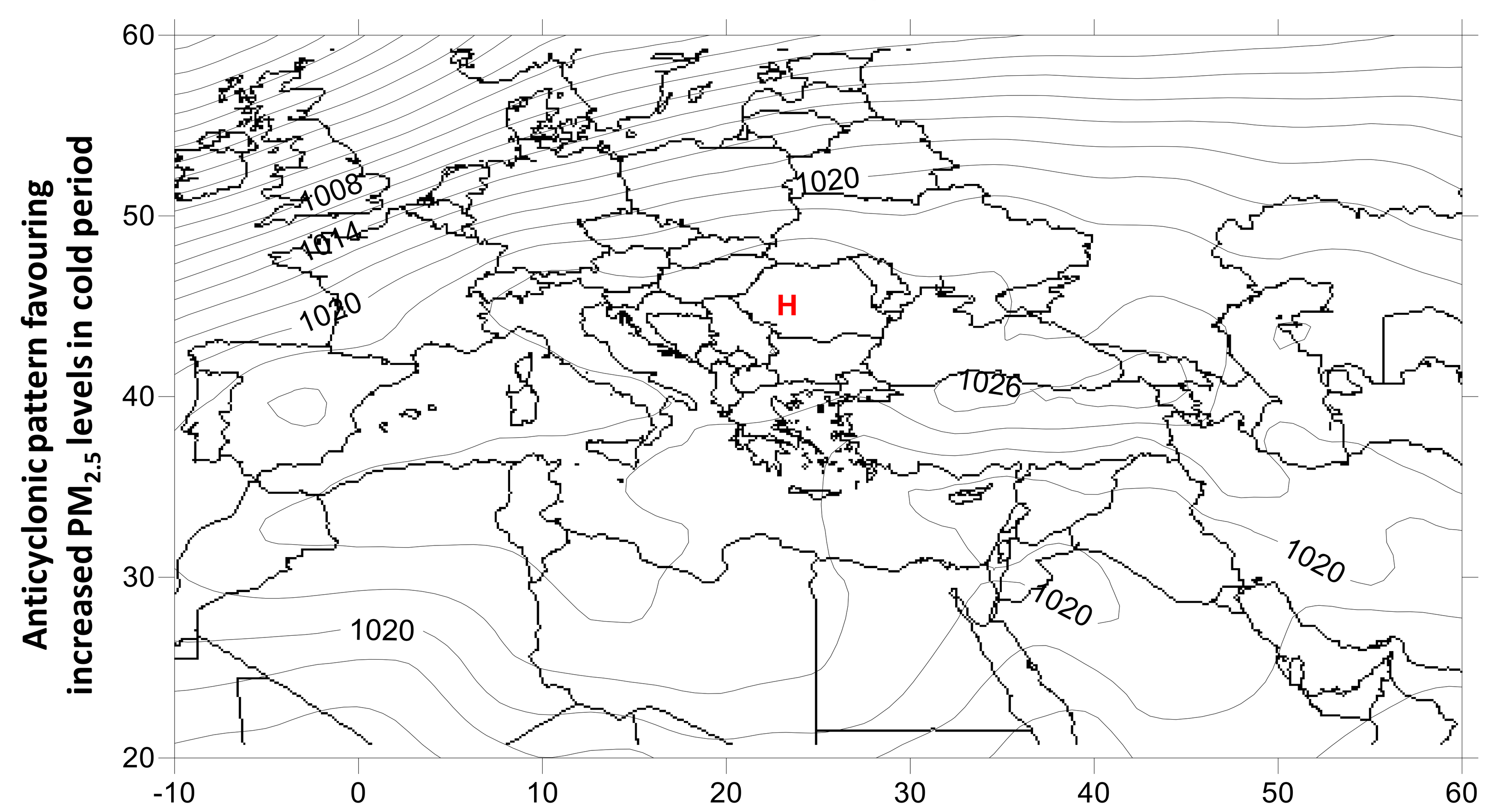
Station	City	$PM_{2.5}$ Cold Period (μg/m^3)	$PM_{2.5}$ Warm Period (μg/m^3)
THI	Athens	16.0	9.9
VOU	Athens	9.6	8.5
PIR	Athens	15.7	10.2
PEF	Athens	14.9	9.4
ANA	Ioannina	37.5	10.0
VIL	Ioannina	37.0	9.1
XAC	Xanthi	24.2	9.7
XAD	Xanthi	11.8	8.0
AGI	Patra	12.6	8.4
AGA	Patra	17.1	9.1
UPA	Patra	8.7	8.1
KAR	Thessaloniki	20.7	10.8
DIM	Thessaloniki	18.7	10.2
VAS	Thessaloniki	23.7	10.3

3. Intra- and inter-city covariance of $PM_{2.5}$ levels – The WS and T effect

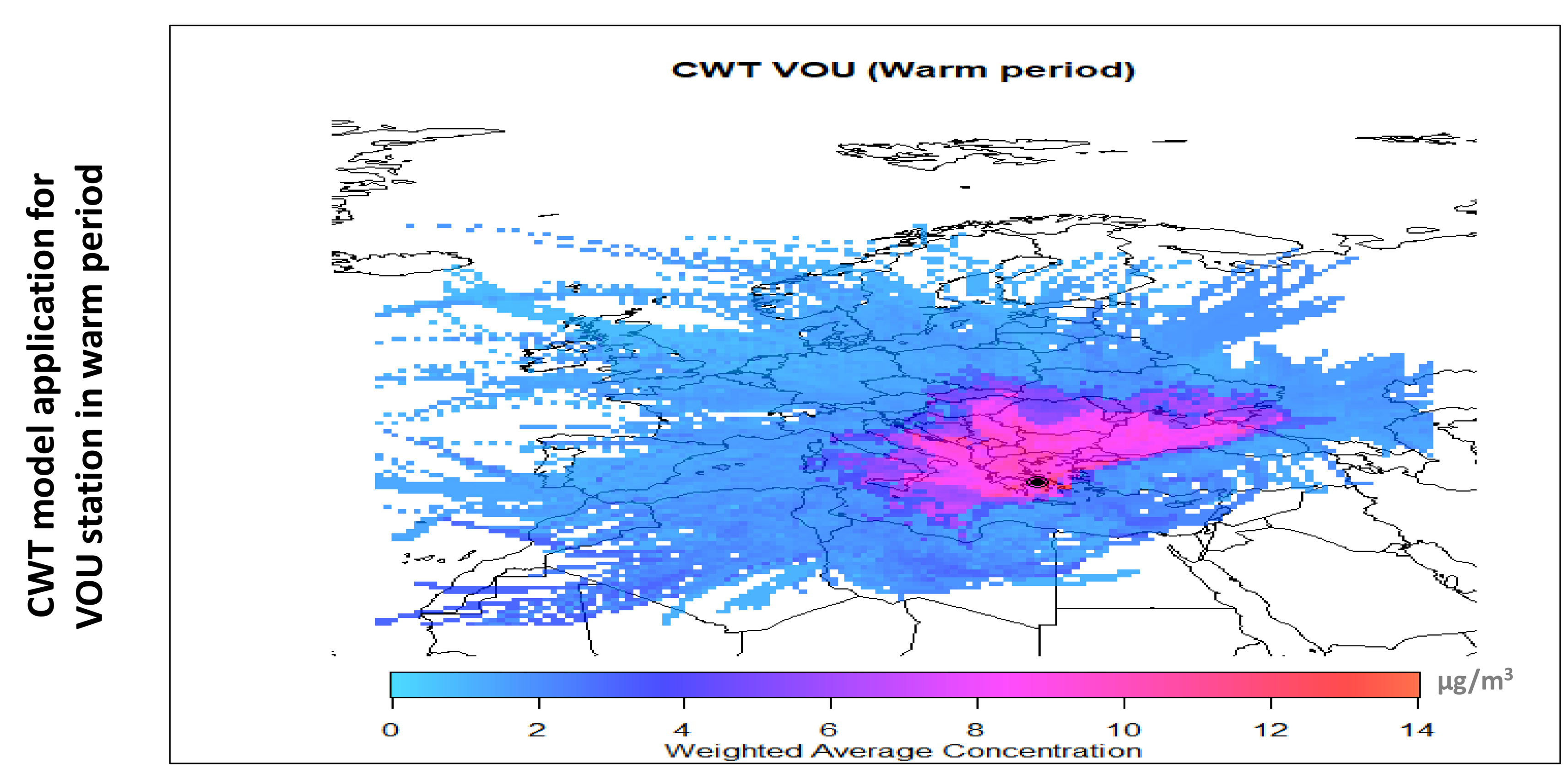
Increased Pearson Correlation Coefficients (PCCs), statistically significant at the 0.01 level, were calculated among daily $PM_{2.5}$ concentrations monitored at the 14 sampling sites within both cold and warm periods, therefore a covariance of $PM_{2.5}$ levels in continental Greece was detected. As expected, intra-city correlations were stronger than inter-city correlations during both seasons. Despite the homogenous low $PM_{2.5}$ levels over continental Greece during warm seasons, inter-city correlations in most cases were stronger during cold seasons probably due to the simultaneous effect of heating emissions. This was verified by the negative PCCs calculated during cold period among daily $PM_{2.5}$ concentrations and daily temperature values. Regarding the effect of wind speed, $PM_{2.5}$ dispersion was more clearly identified in cold period.

4. The effect of synoptic circulation and long range transport

A K-Means cluster analysis of gridded daily sea level pressure data was used to produce synoptic circulation patterns. Peak average concentrations of $PM_{2.5}$ in cold period were related to the influence of an extended anticyclonic field covering the entire Mediterranean region Southern Europe and the Northern coast of Africa, thus triggering a pollutant accumulation process due to atmospheric stagnation. The highest likelihood of exceedances of the WHO daily limit for $PM_{2.5}$ (25 μg/m^3) at all urban sampling sites was also associated with the same anticyclonic pattern, however at background suburban sampling sites such as VOU, XAD and UPA, the WHO daily limit for $PM_{2.5}$ was never or infrequently violated. On the contrary, the synoptic types of warm period were characterized by low $PM_{2.5}$ concentrations at all stations, whilst the probability for violations of the daily WHO limit for $PM_{2.5}$ was practically negligible.



The application of the Concentration Weighted Trajectory (CWT) model for the three studied background suburban sampling sites VOU, UPA and XAD in the cities of Athens, Patras and Xanthi respectively in warm period, when the influence of local emissions is weaker, revealed homogenous results indicating that increased concentrations of $PM_{2.5}$ were primarily connected to regional Northern and all around air flows across Greece and Balkan Peninsula.



5. Conclusions

- An intra- and inter-city covariance of $PM_{2.5}$ concentrations was detected
- Stagnant anticyclonic conditions triggered daily $PM_{2.5}$ episodes in cold seasons
- Uniform low $PM_{2.5}$ levels were detected across Greece in warm seasons
- Regional Northern and all around air flows raised $PM_{2.5}$ levels in warm seasons

6. Acknowledgments

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