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Statistical modelling of combined ozone-temperature events in Europe

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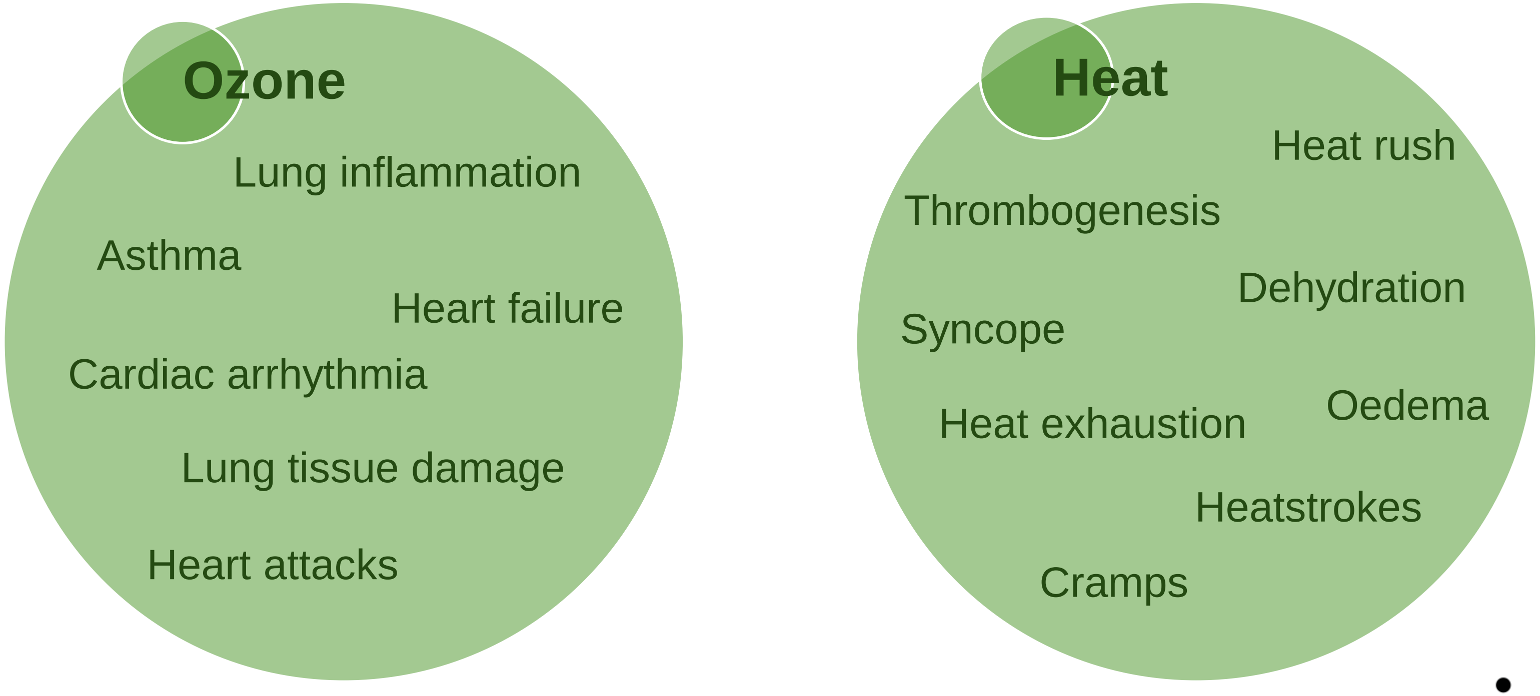
Ground-level ozone and air temperature

Health effects

Air pollution poses the single largest environmental risk to human health in Europe resulting in a substantial public health burden for the European population (EEA 2019). Extreme levels of tropospheric ozone, representing one major air pollutant, has adverse effects on human health. High temperature levels are associated with an exceptionally high mortality rate, only representing the extreme end of a wide range of possible health effects.

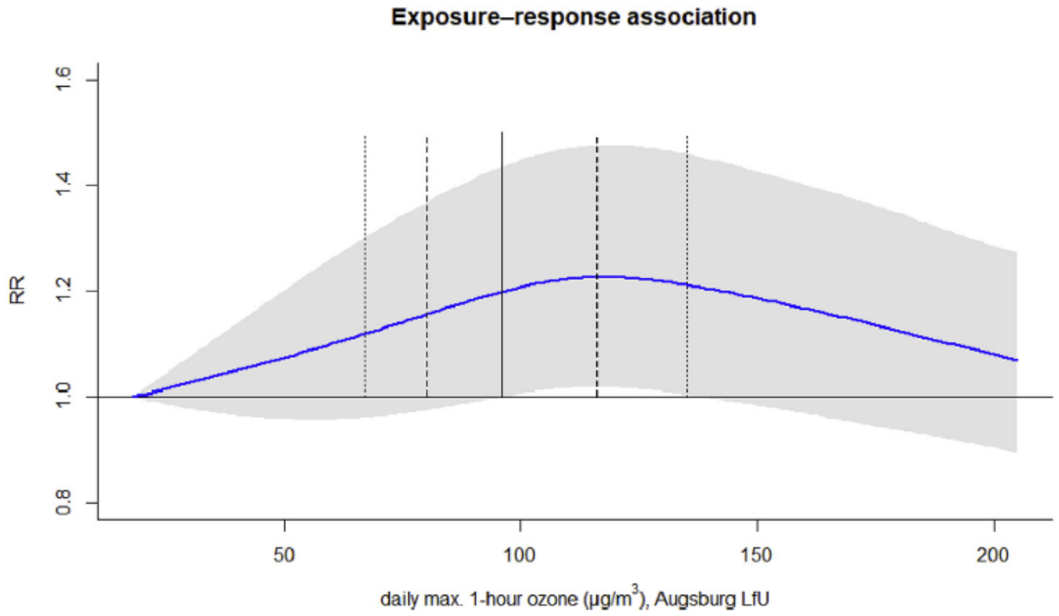
Possible health effects



Exposure-response association

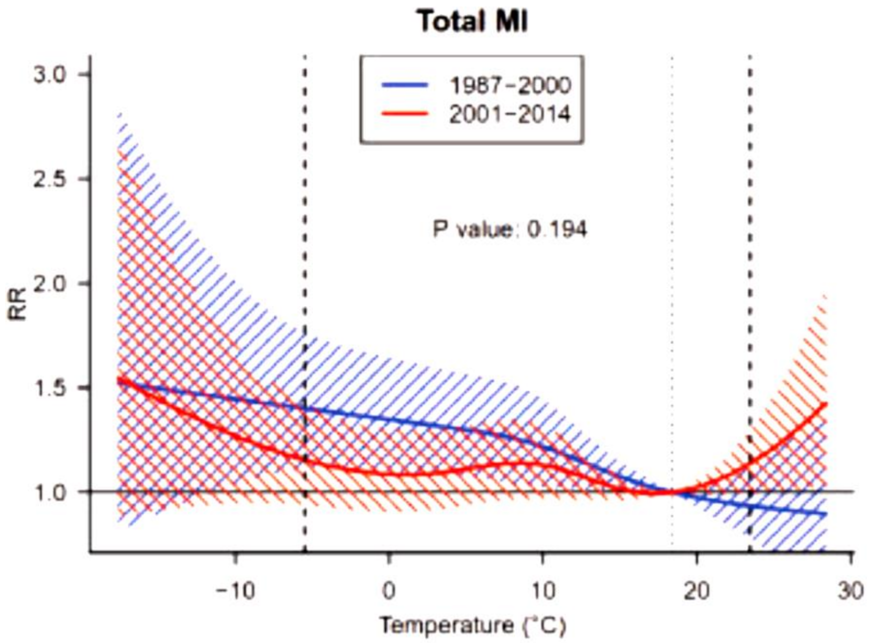
Augsburg (Bavaria) as example

Ozone – Myocardial infarction frequencies



Cumulative exposure-response association of daily maximum 1-hour O_3 concentrations and MI frequencies in Augsburg. Reference value: 18 µg/m³, Grey signature: 95%- confidence interval. Vertical lines: 50%- (solid), 25%-, 75%- (dashed) and 10%-, 90%- (dotted) percentiles of daily maximum 1-hour O_3 concentrations.
Source: Hertig et al. 2019

Air temperature – Myocardial infarction frequencies



Overall lag-cumulative exposure-response relationships between air temperature and myocardial infarction predicted for 1987–2000 (blue) and 2001–14 (red) with 95% confidence interval. A P-value represents the significance test on temporal variation, based on a multivariate Wald test of the reduced coefficients of the interaction terms. The vertical lines represent the minimum myocardial infarction temperature (dotted) and the 1st and the 99th percentiles of the temperature distribution (dashed).
Source: Chen et al. 2019

Ground-level ozone

Formation

Ozone is formed by a photochemical chain reaction primarily based on several differing reactive radicals and including various precursor gases. Hence, it is produced in the presence of sunlight based on the reaction of gases such as volatile organic compounds (VOC), carbon monoxide (CO) or nitrogen oxides (NO_x), with increased reactivity by rising air temperatures and solar radiation.

Natural balance between NO, NO_2 and O_3

without human interactions

Eq. 1) $$NO_2 + h\nu \rightarrow O(^3P) + NO$$

Eq. 2) $$O(^3P) + O_2 \rightarrow O_3$$

Eq. 3) $$O_3 + NO \rightarrow NO_2 + O_2$$

O(3P): oxygen atom at the basic state
Hv: plancks constant times frequency → energy transfer by solar radiation

→ Additional chemical formation of ozone disrupts this null cycle. It is based on chemical processes producing NO_2 from NO by other reactions than shown in Eq. 3 and primarily involving VOC, NOx and CO.

Due to the specific characteristics of ozone formation, high levels of ozone and temperature often coincide, posing an even intensified threat to human health.

Correlation MDA8O3 and TX

85 locations in Central Europe

The current contribution focuses on the co-occurrence of elevated levels of ozone and air temperature. Maximum daily 8-hour average ozone values (MDA8O3, EEA) and observed daily maximum temperatures (TX, ECA&D) of 85 locations in Central Europe are retrieved for analysis. Taking into account different settings of air substances, these stations are classified and grouped by station type and area type resulting in five distinct station classes: *urban traffic (ut), urban background (ub), suburban background (sb), rural background (rb) and rural industrial (ri)*. Since TX and MDA8O3 are primarily correlated in spring and summer, all analyses comprise the months from April to September.

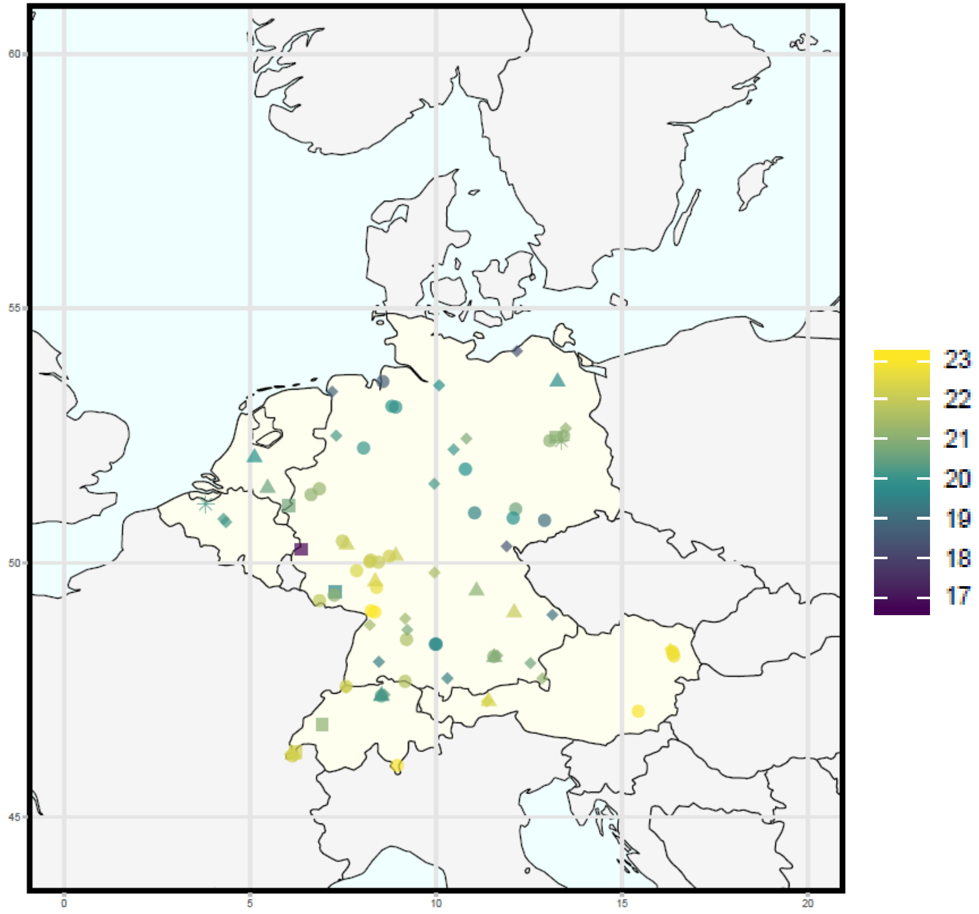
High correlations between MDA8O3 and TX from April to September

Month	Corr
January	0.38
February	0.15
March	0.16
April	**0.58**
May	**0.67**
June	**0.73**
July	**0.81**
August	**0.79**
September	**0.64**
October	0.22
November	0.21
December	0.32

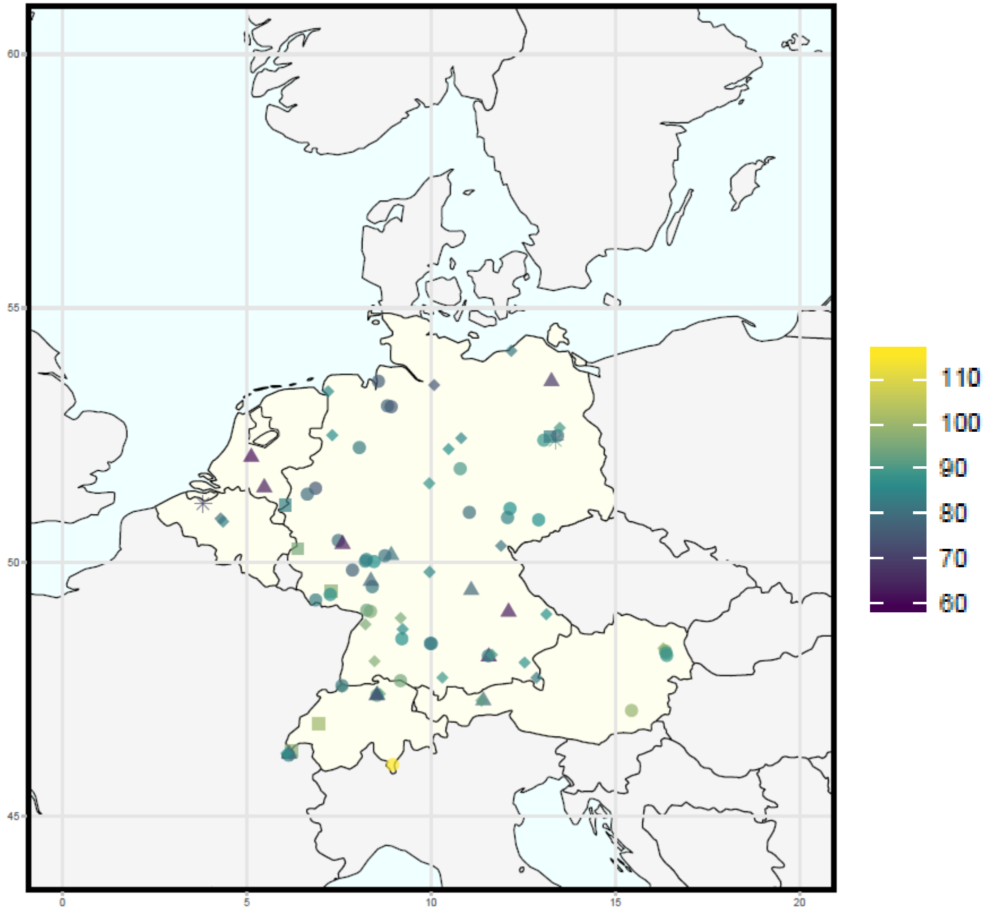
Spearman rank correlation coefficients between observed MDA8O3 concentrations and TX values. Numbers are the mean over all 85 stations in Central Europe.

Ozone and Temperature in Central Europe

Spatial distributions



Mean TX in the months from April to September. Means are calculated for each station over the years from 1993-2012. Shape of points indicate the class of each station.



Mean MDA8O3 in the months from April to September. Means are calculated for each station over the years from 1993-2012. Shape of points indicate the class of each station.

Ozone and Temperature in Central Europe

Station characteristics

Station class	Number of stations	TX_{mean} [°C]	TX_{median} [°C]	TX_{75} [°C]	$MDA8O3_{mean}$ [µg/m³]	$MDA8O3_{median}$ [µg/m³]	$MDA8O3_{75}$ [µg/m³]
rural background	6	20.24	20.25	24.10	92.65	88.95	108.84
rural industrial	2	20.48	20.45	23.90	82.33	78.47	96.27
suburban background	27	20.57	20.68	24.49	88.15	85.63	104.14
urban background	37	21.34	21.43	25.25	86.03	82.95	103.32
urban traffic	13	21.19	21.32	25.13	71.44	69.22	87.22
All stations	85	20.97	21.07	24.88	84.85	82.02	101.34

Observed mean TX and MDA8O3 levels as well as the respective 50^{th} and 75^{th} percentiles in the months from April to September. Numbers are the mean over stations with similar station characteristics. Accordingly, values averaged across all 85 station are also shown.

TX and MDA8O3 characteristics

The mean TX values showed slightly higher values at urban stations in comparison to rural or suburban stations → UHI effects.

The upper 25% of data exceeded on average 100 µg/m³ across all stations for all but two classes.

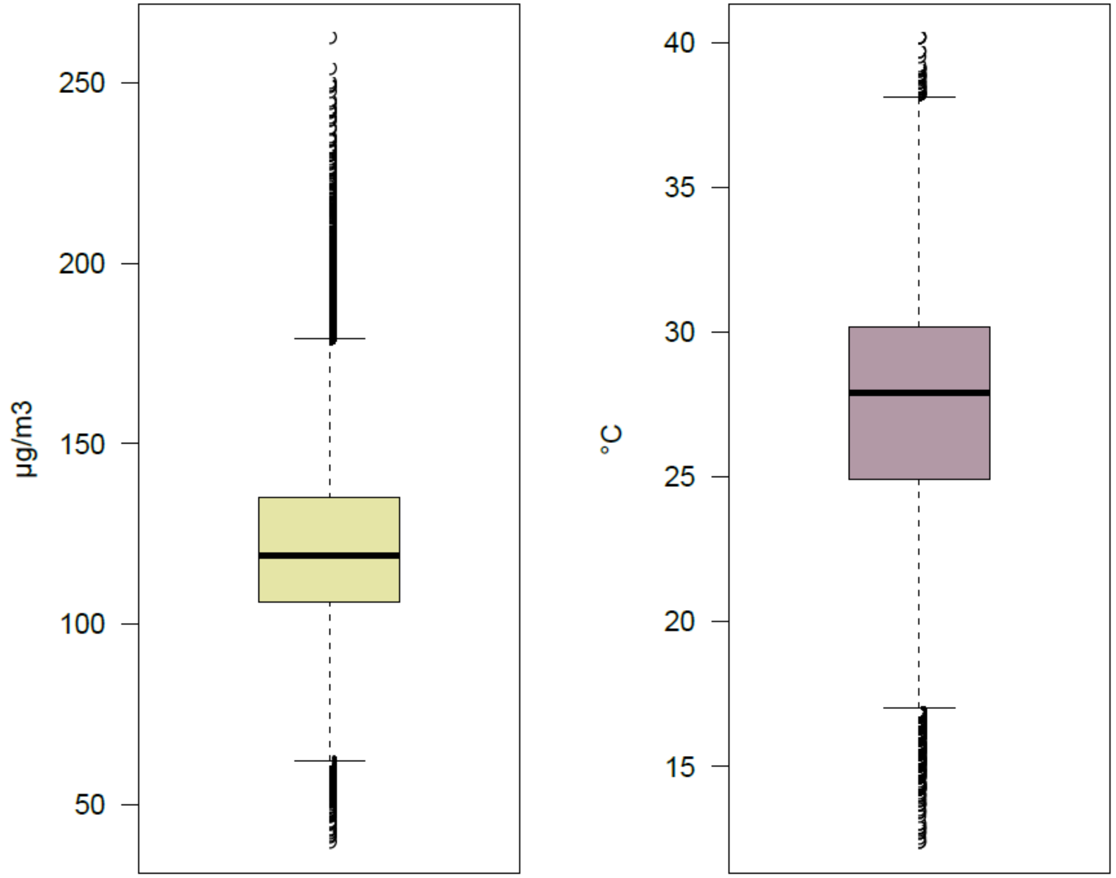
Ozone-temperature events

Definition

Ozone-temperature events are defined based on threshold exceedances (here the 75th percentile) and WHO air quality guidelines (100 µg/m³).

The occurrence of thermal load was connected with co-occurring MDA8O3 exceedances on average on 75% of days in Central Europe. 670 days (ca. 18% of all analyzed days) with ozone-temperature events were overserved on average per station.

On combined event days, mean and median MDA8O3 and TX levels amounted to 121.55 and 119.15 µg/m³ as well as 27.5 and 27.9 °C, respectively.



MDA8O3 and TX values on observed event days in Central Europe. The lower and upper hinges are the 25th and 75th percentile, and the band in the box is the median. Upper whisker extends from the hinge to the largest value, the lower whisker to the smallest value. Both do not extend no further than 1.5*inter-quartile range (IQR) from the hinge. Data points beyond the end of the whiskers (outliers) are plotted individually.

Main drivers

Statistical downscaling models

Meteorological mechanisms and persistence metrics for the occurrence of combined ozone-temperature events are analyzed and main drivers of MDA8O3, TX and combined ozone-temperate events are identified.

Several different regression techniques are applied, for example:

- Multiple Linear Regression (MLR) to assess the main drivers of MDA8O3
- Lasso (least absolute shrinkage and selection) and logistic regression (LR) to assess the main drivers of combined ozone-temperature events

Main drivers are identified by multistep predictor screening and model building processes.

Events
Mean air temperature (850 hPa)
Surface thermal radiation downwards
Ozone persistence
Geopotential height (850 hPa)
Meridional wind (500 hPa)
Relative humidity (500 hPa)

MDA8O3
Ozone persistence
Surface solar radiation downwards
Meridional wind (500 hPa)
Relative humidity (500 hPa)

Main drivers of combined ozone-temperature events and MDA8O3 concentrations in LR and MLR, respectively. Main drivers are sorted in descending order based on their general importance across all stations in Central Europe.

Future work

Projections

Meteorological factors such as temperature not only exhibit inter-annual variability, but are also expected to change in the future due to anthropogenic-induced global climate change.

Thus, frequency and intensity changes of combined ozone-temperate events in the scope of global warming need to be assessed. Projections of these co-occurring events under the constraints of ongoing climate change until the end of the 21st century are planned by integrating projections of general circulation models into the statistical modelling process.

Output of seven models of the Coupled Model Intercomparison Project Phase 5 (CMIP5) will be used in this regard. Potential frequency shifts are then evaluated by comparing the mid- (2031–2050) and late-century (2081–2100) time windows to the base period (1993-2012). Differences in projected changes will be assessed by taking the different station characteristics into account.

In general, an projected increase in event days is expected. As a result, more frequent occurrences of concurrent thermal load and ozone pollution represent an intensified future health burden in Central Europe until the end of the century.

Thank you for your attention ☺

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Further sources

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