Quantifying the synergy of environmental stressors on human mortality

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The 2023 EMS Annual Meeting of the European Meteorological Society
03-08 September 2023, Bratislava, Slovakia

Introduction

- Understanding the effect of environmental stressors on human mortality can be done using statistical modelling of relevant data.
- For example, daily mortality counts $M_t$ (for day $t$) and max daily apparent temperature $T_t$.
- To allow for the aggregated effect of environmental stress over a period of time, regression models called Distributed Lag Models (DLMs) have been proposed:

$$M_t = \text{Poisson}(\mu_t)$$

$$\log(\mu_t) = \alpha + \beta_1 T_t + \beta_2 T_{t-1} + \beta_3 T_{t-2} + \ldots + \beta_r T_{t-r}$$

(1)

- Where the coefficients $\beta_r$ are the contribution to mean mortality count $\mu_t$, from temperature $T_{t-r}$ on day $t - r$ (it being “today”). Extension to Distributed Lag Non-Linear Models or DLNMs (Gasparrini, 2010) allows a non-linear effect from $T_{t-r}$:

$$\log(\mu_t) = \alpha + f(T_{t,0}) + f(T_{t,1}) + f(T_{t,2}) + \ldots + f(T_{t,r}).$$

(2)

- The expression $f(T_{t,r})$ is interpreted as the relative risk (RR) interpreted as:
  - $RR > 1$ means that mortality risk is equal to the mean mortality count, $e^\alpha$;
  - $RR < 1$ or $RR < 0$ means higher or lower risk than average respectively.

Methodology

- Implementing DLMs as Generalized Additive Models or GAMs (Wood, 2011, 2017) enables optimal estimation and straightforward interpretation. Figure 1 shows the RR for the city of Thessaloniki, Greece, based on observational data in the period 2006–2016 (mortality counts and weather station observations).

- Apparent temperature quantifies the stress from both temperature and humidity (see Figure 2), so the peak around 40°C for lags of 0-5 days indicates increased mortality risk during extreme hot-and-humid periods.

- GAMs readily allow inclusion of other stressors such as air pollution, say $A_t$, by extending the function $f(T_{t,r})$ to $f(T_{t,r}, A_{t-r})$ in Equation (2).

- For $A_t$ being PM10 (coarse particulate matter which if $>40$ is considered a health risk), we now have different temperature-lag surfaces for different PM10 values (Figure 3). For Thessaloniki, the increased risk at hot-and-humid conditions is clearly exacerbated by high PM10 levels.

- To better understand the synergy between exposures, the lag dimension can be “integrated out” by summing the risk along lags, for different exposure combinations.

- Figure 4 shows the corresponding cumulative risk surface for apparent temperature and particulate matter (PM10) for Thessaloniki, where hot-and-humid weather combined with high PM10 results in enhanced risk.

- To interpret the estimated risk in terms of observed mortality we compute the Attributable Fraction – defined as the proportion of death counts that are attributed to the exposures.

- Figure 5 shows the Attributable Fraction for 3 pollutants: PM10, Ozone (O3) and Nitrogen Dioxide (NO2).

- We have also quantified the attributable mortality fraction by cause-of-death (cardiovascular disease (CVD), respiratory disease (RD) and elderly mortality (>65 years)). Figure 6 shows this for apparent temperature being between the 75th and 99th sample quantile, for increasing levels of the 3 pollutants from Figure 5.

Conclusions

- This is the first time that the lagged effects of heat-stress and air pollution synergy was studied explicitly at daily temporal resolution.
- Our study confirms the hypothesis that mortality risk due to heat-stress is compounded by air pollution – for the city of Thessaloniki, one of the most polluted cities in Europe.
- During hot-and-humid conditions: respiratory disease mortality is exacerbated for high Ozone and NO2 pollution, while elderly mortality is heightened by high PM10 levels.
- Further analysis is needed to also allow for the interactions between pollutants.

References