Inferring daily heat-related mortality risk from weekly death records with machine learning

Using French mortality data, a neural-network daily risk model trained on weekly death totals gives modest but consistent improvement over a DLNM

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Problem

- Improved **daily mortality forecasting** is needed to inform policy decisions *(Janoš et al., 2025)*.
- However, mortality data are often only available at **coarse temporal resolutions** (e.g. weekly).
- Current standard: distributed lag non-linear model (DLNM) based framework to infer daily risks from aggregated mortality data *(Basagaña & Ballester, 2024)*.

This work**:**

- Develops a **machine learning framework** to predict **daily mortality risk** from **arbitrarily aggregated mortality data**.
- Outperforms DLNM-based approaches on held-out data.

Comparison to DLNM

- The DLNM is fitted via quasi-Poisson regression for each region: $\log(\mathbb{E}[D]) = \log(\text{baseline}(t)) + \mathbf{cb}(\mathbf{T}_t)$

  The crossbasis, $\mathbf{cb}(\mathbf{T}_t)$ encodes a parametric exposure–lag response.
- As the baseline is shared: $\exp(\mathbf{cb}(\mathbf{T}_t)) \simeq M(\mathbf{T}_t)$

Datasets

Training:

- Weekly all-cause mortality data from Eurostat between 2000-2017
- Population weighted daily regional temperature data from the TEE datasets (Ronnkvist et al., 2025).

Validation:

- 1,223,346 individual deaths between 2018-2019 from INSEE

Contact

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References

Janoš, T. *et al.* (2025) 'Heat-related mortality in Europe during 2024 and health emergency forecasting to reduce preventable deaths', *Nature Medicine*, 31(12), pp. 4065–4074. doi:10.1038/s41591-025-03954-7.

Basagaña, X. and Ballester, J. (2024) 'Unbiased temperature-related mortality estimates using weekly and monthly health data: A new method for Environmental Epidemiology and climate impact studies', *The Lancet Planetary Health*, 8(10). doi:10.1016/s2542-5196(24)00212-2.

Ronnkvist, S.R. *et al.* (2025) 'What's the tee: Metrics of temperature extremes in Europe nuts regions (1980-2024)', *Scientific Data*, 12(1). doi:10.1038/s41597-025-05352-7.

Methodology

For region, r, day, t, and age bracket, a:

1. We **predict the daily risk factor** using a neural network regressor. Inputs: past 21 days mean temperature, historic regional summer temperature mean and interquartile range.

$$\text{risk}_{r,t,a} = M(T_{r,t}, \mu_{JJA,r,t}, \text{IQR}_{r,t}; \phi_a)$$

2. The weekly expected deaths were fit per region by a Smooth penalized cubic B-spline with a linear trend term (suitable for short term forecasting). This is **the same baseline** as the DLNM:

$$\text{baseline} = \text{b-spline}(\text{df} = 6, \alpha = 10)$$

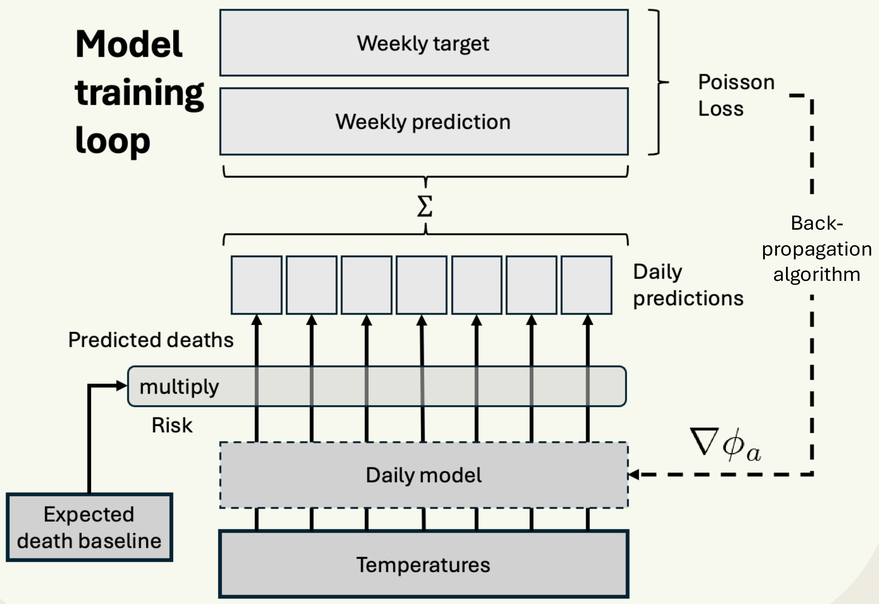
3. The predicted daily deaths are given by:

$$\hat{D}_{r,t,a} = \text{baseline}_{r,t,a} \times \text{risk}_{r,t,a}$$

4. The parameters, ϕ_a for the model M are updated with the backpropagation algorithm by comparing weekly prediction, with weekly ground truth, $\sum_{t=1}^{7} \hat{D}_{r,t,a}, Y_{r,a}$.

$$\text{loss} = \text{Poisson loss}(\textstyle\sum_{t=1}^{7} \hat{D}_{r,t,a}, Y_{r,a})$$

$$\phi_a \leftarrow \text{backpropagation}(\frac{\partial \text{loss}}{\partial \phi_a})$$



Validation

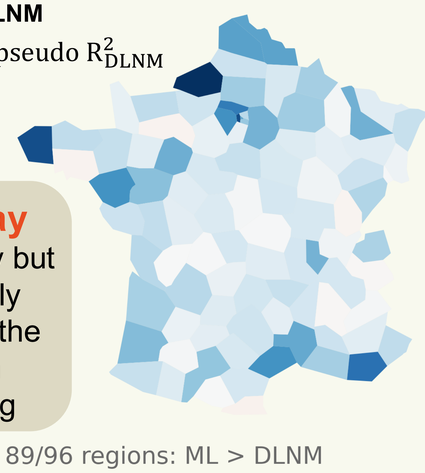
Model improvement relative to the baseline:

$$\text{pseudo-}R^2 = 1 - \frac{MSE_{\text{model}}}{MSE_{\text{baseline}}}$$

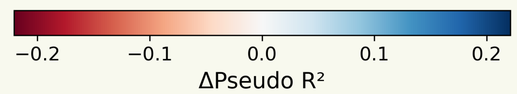
For JJA 2018-2019:

Regional performance for ensemble mean compared to DLNM

$\text{pseudo R}^2_{\text{ML}} - \text{pseudo R}^2_{\text{DLNM}}$



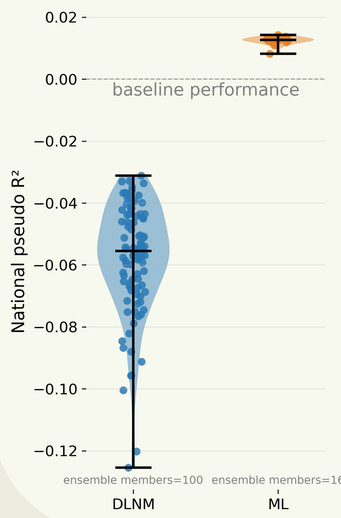
89/96 regions: ML > DLNM



Takeaway

We modestly but consistently outperform the DLNM in forecasting

National performance across ensemble members



Ensemble mean performance on regional heatwave events

7-day period after temperature > 95th percentile