RESEARCH ARTICLE

Received: 23 JUL 2026 | Accepted: 15 SEP 2026 | **DOI:** https://doi.org/10.57849/ulisboa.fm.jscml.0000057.2026

JORNAL DA SOCIEDADE DAS CIÊNCIAS MÉDICAS DE LISBOA

Heat-related mortality is attenuating relative to the ÍCARO index but remains substantial: Portugal, 2014–2026

Paulo Nogueira [1]

[1] Faculdade de Medicina, Universidade de Lisboa (FMUL), Lisboa, Portugal. Instituto de Saúde Ambiental (ISAMB), Faculdade de Medicina, Universidade de Lisboa, Lisboa, Portugal. Laboratório Associado TERRA, Lisboa, Portugal

✉ **Corresponding author:**
Paulo Nogueira, Faculdade de Medicina, Universidade de Lisboa.
email: pnogueira@medicina.ulisboa.pt

This work is licensed under CC BY-NC-ND 4.0. To view a copy of this license, visit https://creativecommons.org/licenses/by-nc-nd/4.0

ABSTRACT: **Introduction:** Portugal's ÍCARO index forecasts heat-attributable excess mortality to trigger the public-health response. Because it estimates the excess expected without protective action, the observed-to-predicted ratio is an indirect signature of intervention effectiveness. We quantified the magnitude, temporal structure, dose–response and calibration of heat-related excess mortality against ÍCARO, tested for a recent attenuation trend, and assessed robustness to baseline choice and to a within-summer bias in the fixed-threshold index. **Methods:** Ecological time-series of daily all-cause deaths (SICO-eVM), June–September 2014–2026, excluding 2020–2021. Heat episodes were consecutive days with ÍCARO ≥ 0.2; episode excess (window [start−1, end+2]) was estimated with 95% confidence intervals against six baseline methods (Serfling quasi-Poisson with/without trend; calendar-day median and mean; a five-year reference; a within-year baseline). The ÍCARO-predicted excess (Σ index × expected) was compared with the observed (calibration ratio). Trend (2022–2026) was tested with Mann-Kendall and the index–mortality relationship compared across months. **Results:** Thirty-nine episodes were identified; 29 showed significant excess (largest, 8–17 July 2022: +1276 deaths). Observed excess lay consistently below the ÍCARO prediction across all six baselines (pooled ratio 0.41–0.71); the estimated 2026 excess ranged +380 to +1000 deaths. The season-level ratio declined toward 2026 in every method, but significantly only under demographically adjusted baselines (Mann-Kendall $p = 0.027$), not under fixed historical references ($p \geq 0.22$). The index–mortality slope fell markedly across the summer (0.62 in June to 0.18 in September; $p \approx 10^{-5}$), a robust seasonal bias of the fixed-threshold index. **Conclusion:** Heat waves still cause substantial, significant excess mortality in Portugal, yet the observed burden lies well below the intervention-naïve ÍCARO prediction — consistent with an effective response, with a recent downward trend sensitive to the demographic baseline. The strong within-summer bias argues for adaptive rather than fixed thresholds, and surveillance must continue to translate into sustained preventive action.

KEYWORDS: Extreme Heat; Mortality; Portugal; Public Health Surveillance; Climate Change.

INTRODUCTION

Heat waves are among the deadliest weather-related hazards. The 2003 European heat wave caused more than 70,000 excess deaths [1], roughly 2,000 of which were in Portugal [2], and prompted the widespread adoption of heat-health warning systems and contingency plans across Europe [3]. With anthropogenic climate change, the frequency and intensity of extreme heat events are increasing, and a growing fraction of heat-related mortality is now attributable to human-induced warming [4,5], making the effectiveness of the public health response a matter of direct practical importance.

Portugal was an early adopter. Since 1999, the ÍCARO index, developed by the National Institute of Health Doutor Ricardo Jorge together with the national meteorological service [2,6], forecasts the excess mortality expected during periods of high temperature and triggers escalating levels of the national heat-health contingency plan. Operationally, the index is expressed as a predicted relative excess of deaths — the mortality expected under the modeled temperature exposure in the absence of specific protective action [6,7]. This intervention-naïve construction has an important corollary: if the observed mortality during an episode falls below the ÍCARO prediction, the shortfall is an indirect measure of the combined effect of the public-health response and of population adaptation.

Whether and by how much the observed heat-related mortality burden in Portugal has attenuated relative to the ÍCARO prediction — and whether any such attenuation is changing over time — has not been quantified with recent data. Because such estimates depend on how expected (baseline) mortality is modeled [8], robustness across methods is essential. Using near-real-time daily mortality from the SICO-eVM platform [9], we quantified the magnitude, temporal structure, dose–response and calibration of heat-related excess mortality against the ÍCARO index over 2014–2026, tested for a recent trend, assessed its robustness across six baseline methods, and examined whether the fixed-threshold index carries a systematic within-summer bias.

METHODS

Design and reporting. Ecological time-series study of daily mortality and a daily heat-exposure index in mainland Portugal, reported following the STROBE recommendations [10].

Data sources. Daily counts of all-cause deaths were obtained from the Information System for Death Certificates (SICO) via its mortality surveillance platform (eVM, evm.min-saude.pt) between 1 January 2014 and 15 July 2026. The daily ÍCARO index was obtained from the National Health Service Transparency portal. The current (incomplete) day was excluded, and one day with an implausibly low count (<50, a registration artifact) was removed. All reference periods and model fits excluded 2020 and 2021 due to the COVID-19 pandemic; episodes from those two years were not analyzed.

Analysis window. The primary analysis was restricted to June–September. The ÍCARO values published for May are generated by the earlier Lisbon 2005/2006 model rather than by the operational national ÍCARO, so May exposure is not comparable across the series and was excluded a priori (examined in a sensitivity analysis).

Expected mortality — multiple baselines. Because excess-mortality estimates depend on the baseline, six methods for the expected count E(t) were compared: a Serfling-type quasi-Poisson generalized linear model [8] (log link, linear time trend plus annual and semiannual Fourier harmonics) with and without the trend term; the median and the mean of the same calendar day ±7 days over the pre-COVID reference years 2015–2019; the median over the previous five non-pandemic years; and a within-year baseline (median of non-heat days of the same summer within ±21–60 days). All methods excluded heat-affected days (ÍCARO > 0 and the two following days) and the pandemic years 2020–2021 from the reference. The Serfling model with trend was pre-specified as primary; overdispersion (ϕ) was estimated from the Pearson statistic. The robustness of each conclusion was assessed across the six methods.

Heat episodes and excess. A heat episode was defined, in the primary analysis, as one or more consecutive days with ÍCARO ≥ 0.2 — a conventional operational cut-off, varied in a sensitivity analysis. For each episode, the excess was the sum of observed minus expected deaths over the window [start−1, end+2] days. The 95% confidence interval was $\pm 1.96 \times \sqrt{(\phi \cdot \Sigma E)}$; significance was assessed as z = excess/standard error. The excess predicted by the index was Σ ÍCARO(t)×E(t) over the episode days, consistent with the definition of ÍCARO as a predicted relative excess [6], and the calibration ratio (observed/predicted) was computed per episode and per season.

Lag structure and dose–response. The temporal structure was described using a distributed-lag quasi-Poisson model [11,12] (index at lags 0–21 days; offset: log E(t)). The overall dose–response was defined as the relative excess on day t+1 relative to the index on day t, with binned means and a quadratic HC1 fit.

Within-summer variation. To test for a seasonal bias of the fixed-threshold index, the index–mortality relationship was compared across calendar months. The relative excess at lag +1 was regressed on the index with a quadratic term and a month interaction (HC1 errors), and the observed/predicted ratio was computed by month within index bands (0–0.1, 0.1–0.3, >0.3) to control for intensity. Each season's ratio was also compared with the ratio expected based solely on its within-season timing.

Trend and sensitivity. The season-level ratio was tested for trend over 2022–2026 (Mann-Kendall) and over 2016–2026 (weighted least squares). Sensitivity analyses repeated all analyses, including May, and varying the episode threshold (ÍCARO > 0, ≥ 0.05, ≥ 0.1, ≥ 0.2). Analyses used Python (statsmodels).

RESULTS

The series comprised 4,579 analyzable days (mean 320 deaths/day). The primary Serfling model showed moderate overdispersion (ϕ = 1.75) and a secular upward trend of approximately +3.9 deaths/day per year, consistent with population aging; standardized residuals had a mean of 0.00 and a standard deviation of 1.00. Omitting the trend term substantially worsened the fit (ϕ = 2.46), confirming that the demographic trend is a real feature of the series.

Temporal structure. The mortality response peaked at a lag of +1 day (about +1.6% deaths per 0.1 index units at lag 1, versus +0.7% on the same day), decaying over three to five days. The cumulative effect peaked around the sixth day and then declined modestly, compatible with limited short-term mortality displacement [13,14].

Magnitude of episodes. Thirty-nine heat episodes were identified over 2014–2026, of which 29 showed a statistically significant excess (z > 1.96). Under the primary baseline, the largest was 8–17 July 2022, with +1276 excess deaths (95% CI 1119 to 1433); episode-level results for 2024–2026 are in Table 1 and the daily series in Figure 1. Absolute magnitudes were sensitive to the baseline: the estimated excess of the July 2026 episode, for example, was larger under demographically unadjusted baselines, and the whole-season 2026 excess ranged from +380 to +1000 deaths across the six methods (Table S3). Notably, the 2–9 July 2026 episode reached the highest ÍCARO value in the series (1.67) yet produced fewer excess deaths than several less-intense episodes in earlier years. The overall dose–response was concave, saturating near 25–30% relative excess above ÍCARO 0.8 [15] (Figure S2).

TABLE 1. Individual heat episodes in the 2024–2026 seasons under the primary baseline: dates, peak ÍCARO, observed excess with 95% confidence interval, ÍCARO-predicted excess, and observed/predicted ratio.

Season	Dates	ÍCARO max	Observed excess (95% CI)	Predicted	Ratio
2024	23–25 Jul	0.62	+242 (134 to 350)	354	0.68
2024	10–11 Aug	0.36	+48 (−50 to 146)	192	0.25
2024	16–17 Aug	0.39	+35 (−63 to 133)	172	0.20
2025	29 Jun–1 Jul	0.48	+284 (175 to 393)	350	0.81
2025	30 Jul–6 Aug	1.21	+502 (356 to 649)	1591	0.32
2025	9–18 Aug	1.39	+552 (392 to 711)	2599	0.21
2026	12 Jun	0.20	+27 (−63 to 117)	60	0.44
2026	2–9 Jul	1.67	+353 (205 to 501)	1868	0.19

Excess window [start−1, end+2]. Excess in deaths (Serfling, trend-adjusted). Magnitudes are ≈1.5–2.6× larger under demographically unadjusted baselines (Table S3).

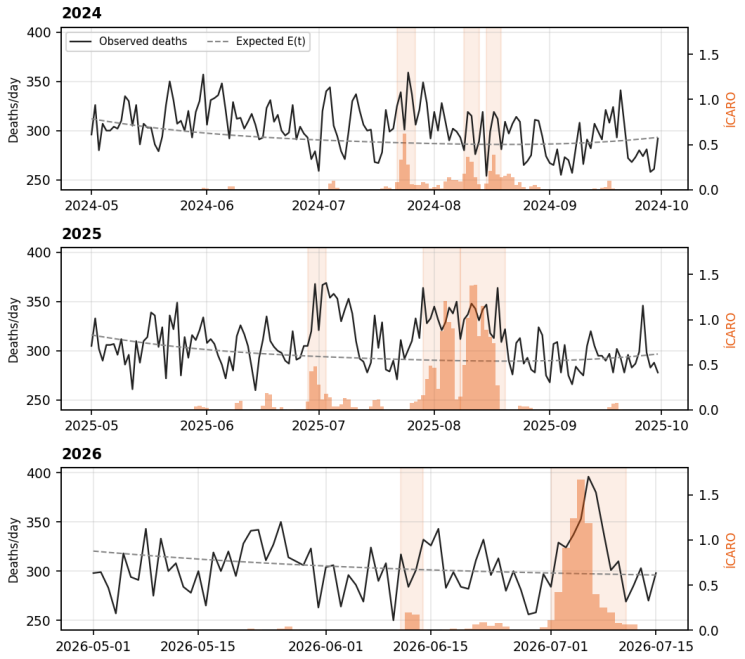

Fig 1. Daily all-cause deaths (solid) versus modeled expected deaths E(t) (dashed, primary baseline) for the 2024, 2025, and 2026 seasons; orange bars show the daily ÍCARO index (right axis) and shaded bands mark heat-episode windows [start−1, end+2]. The 2026 season is shown through 15 July.

Calibration and attenuation. Under the primary baseline, the season-level ratio (Table 2; Figure 2) declined from 0.70 (2022) to 0.56, 0.45, 0.29, and 0.20 (2026, provisional). The observed excess was consistently below the ÍCARO prediction (Figure 3). This was robust across all six baseline methods, with pooled observed-to-predicted ratios ranging from 0.41 to 0.71 (Table S3). Every method showed a decline toward 2026 (Figure S3A); however, the decline was strictly monotone and statistically significant only under the two demographically adjusted baselines – the Serfling model with trend and the within-year baseline (both Mann-Kendall p = 0.027) – and was not significant under the fixed 2015–2019 references (p ≥ 0.22), where uncorrected demographic growth inflates the excess of recent seasons. Across the full 2016–2026 period, the linear trend was not significant even under the primary baseline (p = 0.32).

Within-summer variation. The index–mortality relationship weakened markedly as the summer progressed, and this was the most robust finding. Under the primary baseline, the observed/predicted ratio fell from 1.08 in June to 0.58 (July), 0.34 (August) and 0.15 (September), and the dose–response slope declined monotonically (0.62, 0.47, 0.38 and 0.18 per unit index; linear month-interaction p ≈ 1×10^{-5}; Figure 4). Every one of the six baseline methods reproduced the same monotone June-to-September decline (Figure S3B), and the gradient persisted within index bands (Figure 4A), so it is not an artifact of the more intense events of late summer. This is the expected signature of within-summer physiological acclimatization and depletion of susceptible individuals [16,17], which the fixed-threshold ÍCARO does not capture. When each season's ratio was compared with that expected from its month composition alone (Table S2), the recent decline was attenuated but persisted; the very low 2026 ratio occurred despite an early-July event, leaving a large negative residual (−0.40).

Sensitivity analyses. Excluding May had no effect (no May day reached the episode threshold; maximum May index 0.09). Varying the episode threshold (Table S1, Figure S1) left the central findings unchanged: the pooled ratio remained 0.42–0.49, and 2026 showed strong attenuation at every threshold, with the strictly monotone recent trend again specific to the ≥ 0.2 definition.

TABLE 2. Season-level observed versus ÍCARO-predicted excess mortality and attenuation ratio under the primary (Serfling, trend-adjusted) baseline (heat episodes with ÍCARO ≥ 0.2, June–September, 2016–2026; 2020–2021 excluded because of COVID-19). Absolute excess is baseline-dependent — see Table S3 for the range across methods.

Season	Episodes (n)	Observed excess (95% CI)	ÍCARO-predicted	Ratio (95% CI)
2016	7	+1094 (820 to 1367)	3245	0.34 (0.25–0.42)
2017	2	+453 (307 to 599)	634	0.71 (0.48–0.95)
2018	4	+821 (627 to 1015)	1466	0.56 (0.43–0.69)
2022	4	+1989 (1736 to 2242)	2842	0.70 (0.61–0.79)
2023	2	+523 (372 to 674)	938	0.56 (0.40–0.72)
2024	3	+325 (150 to 501)	717	0.45 (0.21–0.70)
2025	3	+1316 (1077 to 1553)	4540	0.29 (0.24–0.34)
2026 †	2	+379 (206 to 553)	1928	0.20 (0.11–0.29)

† 2026 season incomplete (data through 15 July 2026). Excess and confidence intervals in deaths; ratio = observed/predicted. Across the six baseline methods, the pooled ratio ranged from 0.41 to 0.71.

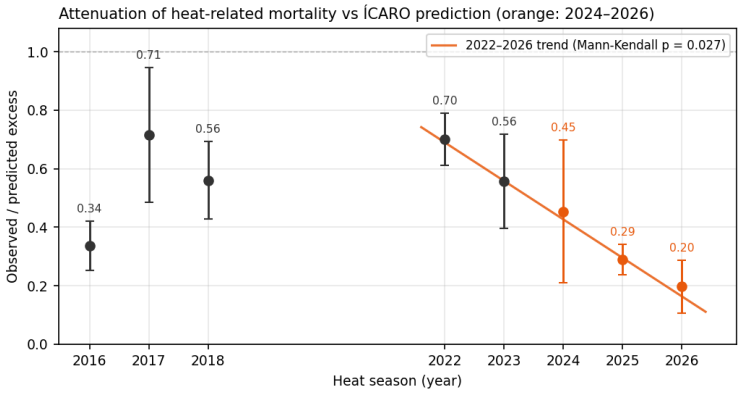

Fig 2. Season-level observed/predicted excess-mortality ratio (primary baseline) with 95% confidence intervals, 2016–2026 (2020–2021 excluded). Orange denotes 2024–2026; the line is the inverse-variance-weighted 2022–2026 trend (Mann-Kendall p = 0.027). A ratio of 1 (dashed) would indicate observed excess equal to the intervention-naïve prediction. See Figure S3A for all six baseline methods.

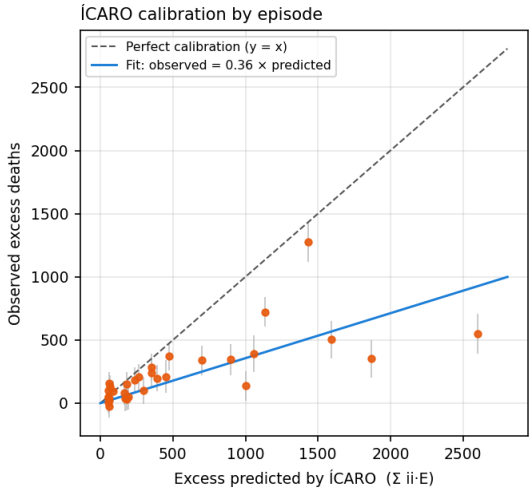

Fig 3. Calibration of the ÍCARO index by episode (primary baseline): observed excess versus predicted excess (Σ index × expected), with 95% confidence intervals, excluding 2020–2021. Dashed line, perfect calibration (y = x); blue line, fitted proportionality (slope 0.36).

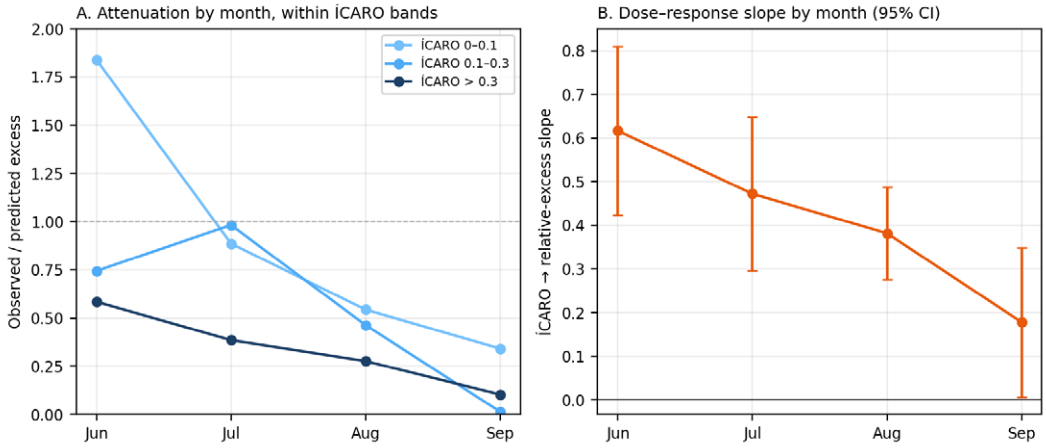

Fig 4. Within-summer variation in the ÍCARO–mortality relationship (June–September, excluding 2020–2021). (A) Observed/predicted excess ratio by month within three ÍCARO bands, showing the gradient persists at fixed index level. (B) Dose–response slope by month with 95% confidence intervals, declining monotonically from June to September. The pattern, reproduced by all six baseline methods (Figure S3B), indicates a seasonal bias of the fixed-threshold index.

DISCUSSION

Three findings emerge, with differing levels of robustness. First, heat waves continue to impose a substantial and statistically significant mortality burden: most episodes since 2014 carried a significant excess, and the worst exceeded 1,200 deaths. Second, the observed excess lies consistently and markedly below the ÍCARO prediction — between about one third and seven tenths of the intervention-naïve level, depending on the baseline, but always below it. Third, the fixed-threshold index carries a strong and entirely robust within-summer bias.

Because the ÍCARO index estimates the excess expected without protective action, a ratio below one

is the expected signature of effective prevention and adaptation, and its decline toward the most recent seasons is consistent with an increasingly effective response – earlier and broader warnings, activation of contingency levels, and municipal measures such as climatized shelters. This is consistent with international evidence that the heat–mortality relationship has weakened where warning systems and adaptation have been implemented, notably in France after the 2003 heat wave [18], across several European cities [19], and in systematic and single-country assessments of planned adaptation [20,21]. This interpretation must, however, be qualified. The magnitude of the excess and the statistical significance of the recent downward trend depend on how the demographic increase in mortality is handled: the trend is significant under baselines that adjust for population ageing (a fitted trend or a within-year reference) and not under fixed historical references, where uncorrected ageing inflates the excess of recent seasons and masks the decline. This dependence is itself interpretable – proper demographic adjustment is precisely what isolates the heat-and-response signal – but it means the recent trend should be read as suggestive rather than established.

A distinct and fully robust finding concerns the index itself. Because ÍCARO applies fixed thresholds throughout the season, its predictions carry a systematic seasonal bias: the same index value is associated with far greater relative mortality in June than in August, in every baseline method (Figure 4, Figure S3B). This is consistent with well-described within-summer acclimatization and depletion of susceptible individuals [16,17], and argues for adaptive, seasonally evolving thresholds – such as the GATO approach previously proposed for the Portuguese system [6,7] – rather than the fixed ones currently in operational use. Fixed-threshold surveillance is not unique to Portugal: the Spanish MoMo real-time system likewise estimates heat-attributable mortality from fixed temperature thresholds [22], so the case for fully adopting adaptive thresholds applies across national heat-health surveillance systems and would improve the accuracy of the very triggers that drive the public-health response. Such systems ultimately serve to protect those most at risk, notably isolated older people [23].

Other limitations apply. The 2026 season is incomplete (through mid-July), so its ratio is provisional; event intensity is a further confounder, since seasons dominated by extreme events yield higher ratios because the large predicted excess is never fully abolished; any change in the ÍCARO methodology over time would affect the denominator; all-cause mortality may include concomitant causes; and the ecological design precludes individual attribution. The small number of seasons limits the power of the trend tests. A joint model that simultaneously adjusts for demographic trend, event intensity, and within-season timing – ideally linked to exposure metrics such as the number of red-warning days – is the natural confirmatory step.

Implications. For surveillance practice, the ÍCARO index remains a valid ordinal predictor of risk and is well suited to triggering graded responses, but it should not be read as a point forecast of the number of deaths, and its calibration would be improved by seasonally adaptive thresholds. Beyond methodology, the persistence of a large, significant heat-mortality burden even amid attenuation is a reminder that surveillance is only useful if it translates into action: as extreme heat becomes more frequent under climate change [4,5], sustained investment in heat-health action plans, timely activation of contingency measures by public authorities, and protective behavior by individuals and communities remain essential to prevent avoidable deaths.

CONCLUSION

Heat waves continue to impose a substantial, statistically significant mortality burden in Portugal, yet the observed excess lies well below the intervention-naïve level predicted by the ÍCARO index – an indirect signal that active heat-health intervention is working, with a recent downward trend that is suggestive but sensitive to the demographic baseline. The index also shows a strong and robust within-summer bias that argues for adaptive rather than fixed thresholds. Confirming the recent attenuation, refining the index toward adaptive thresholds, and sustaining real preventive action are the priorities as extreme heat intensifies.

SUPPLEMENTARY FILES

TABLE S1. Sensitivity to the episode-definition threshold (June–September, 2016–2026; pooled ratio and trend exclude 2020–2021).

Episode threshold	Episodes (n)	Significant (z>1.96)	Pooled ratio	2022 ratio	2026 ratio	Trend *p* (2022–2026)
ÍCARO > 0	111	30	0.47	1.02	0.13	0.086
ÍCARO ≥ 0.05	81	36	0.47	0.87	0.18	0.086
ÍCARO ≥ 0.1	63	38	0.49	0.85	0.20	0.086
ÍCARO ≥ 0.2 (primary)	39	29	0.42	0.70	0.20	0.027

The pooled attenuation and the strong 2026 attenuation are robust to the threshold; the strictly monotone, significant recent trend is specific to the ≥ 0.2 definition.

TABLE S2. Separation of the year-on-year trend from within-season timing (primary baseline). Observed ratio, ratio expected from month composition alone, and residual (attenuation beyond seasonal timing). 2020–2021 excluded.

Season	Observed ratio	Expected from month-timing	Residual (obs − exp)
2016	0.34	0.34	−0.01
2017	0.71	0.89	−0.17
2018	0.56	0.31	+0.25
2022	0.70	0.50	+0.20
2023	0.56	0.34	+0.22
2024	0.45	0.46	−0.01
2025	0.29	0.40	−0.11
2026 †	0.20	0.60	−0.40

† 2026 incomplete. The residual becomes negative in 2024–2026, most strongly in 2026.

TABLE S3. Robustness across six baseline methods for the expected count (June–September; 2020–2021 excluded from all references). For each method: overdispersion φ (Serfling only), estimated 2026 whole-season excess, pooled observed/predicted ratio, Mann-Kendall p for the 2022–2026 season trend, and the within-summer observed/predicted ratio by month.

Baseline method	φ	2026 excess	Pooled ratio	Trend *p* (2022–26)	Month ratios Jun · Jul · Aug · Sep
Serfling + trend (primary)	1.75	+380	0.42	0.027	1.08 · 0.58 · 0.34 · 0.15
Serfling, no trend	2.46	+743	0.51	0.221	1.20 · 0.70 · 0.42 · 0.10
Median ±7 d (2015–2019)	—	+995	0.71	0.462	1.90 · 1.10 · 0.73 · 0.55
Median ±7 d (prev. 5 years)	—	+524	0.66	0.221	1.75 · 1.12 · 0.63 · 0.44
Mean ±7 d (2015–2019)	—	+1000	0.68	0.462	1.82 · 1.05 · 0.68 · 0.50
Within-year (same summer)	—	+558	0.41	0.027	1.36 · 0.60 · 0.38 · 0.23

The attenuation (pooled ratio < 1) and the monotone within-summer decline are present in every method; the significant recent season-trend appears only in the two demographically-adjusted baselines (Serfling with trend; within-year).

SUPPLEMENTARY FILES (CONT.)

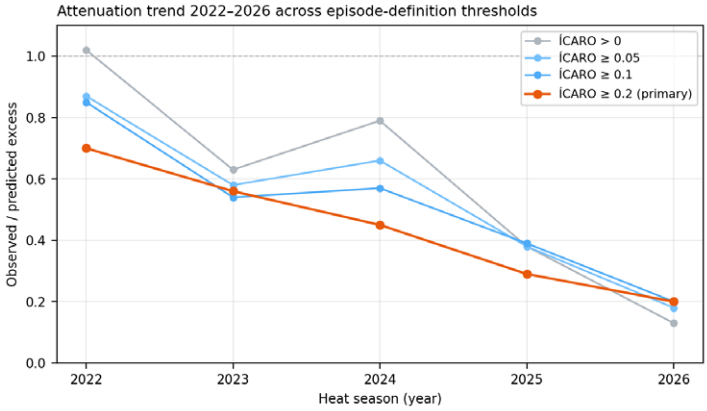

Fig S1. Season-level observed/predicted ratio for 2022–2026 under four episode-definition thresholds. All decline toward ~0.2 by 2026; ≥ 0.2 yields the cleanest monotonic trend.

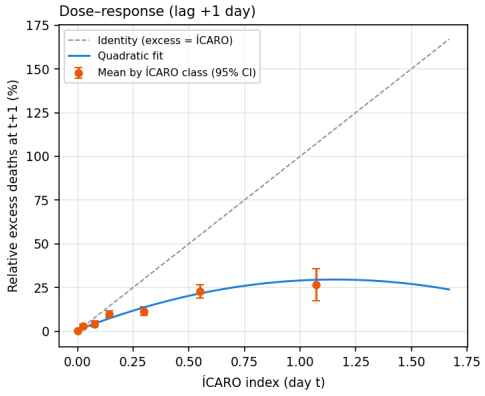

Fig S2. Overall dose–response between the ÍCARO index on day t and the relative excess of deaths on day t+1 (primary baseline; June–September, excluding 2020–2021): binned means (95% CI), identity line (dashed) and quadratic fit. The response saturates near 25–30% above ÍCARO 0.8.

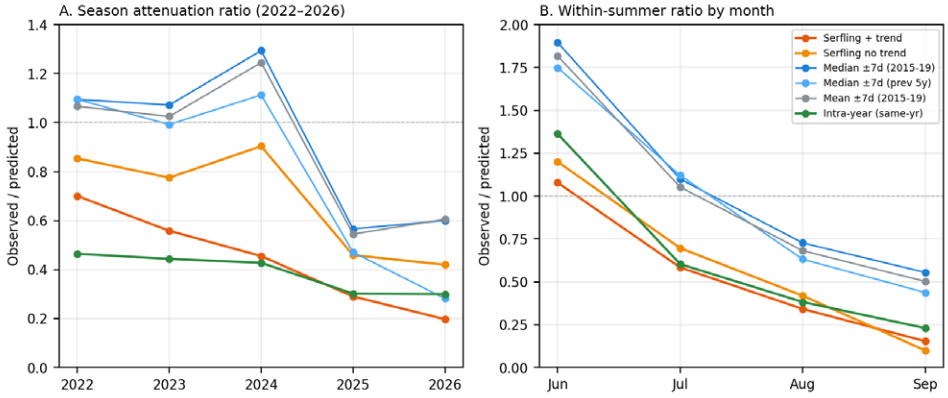

Fig S3. Robustness across the six baseline methods. (A) Season-level observed/predicted ratio 2022–2026 – all methods decline toward 2026, with the demographically adjusted baselines (Serfling with trend; within-year) lowest and cleanest. (B) Within-summer observed/predicted ratio by month – every method shows the same monotone June-to-September decline, confirming the seasonal bias of the fixed-threshold index.

REFERENCES

1. Robine JM, Cheung SL, Le Roy S, Van Oyen H, Griffiths C, Michel JP, et al. Death toll exceeded 70,000 in Europe during the summer of 2003. C R Biol. 2008;331(2):171-8. doi:10.1016/j.crvi.2007.12.001.
2. Nogueira PJ, Falcão JM, Contreiras MT, Paixão E, Brandão J, Batista I. Mortality in Portugal associated with the heat wave of August 2003: early estimation of effect, using a rapid method. Euro Surveill. 2005;10(7):pii=553. doi:10.2807/esm.10.07.00553-en.
3. World Health Organization Regional Office for Europe. Heat–health action plans: guidance. Copenhagen: WHO Regional Office for Europe; 2008.
4. Vicedo-Cabrera AM, Scovronick N, Sera F, Royé D, Schneider R, Tobías A, et al. The burden of heat-related mortality attributable to recent human-induced climate change. Nat Clim Chang. 2021;11:492-500. doi:10.1038/s41558-021-01058-x.
5. Gasparrini A, Guo Y, Sera F, Vicedo-Cabrera AM, Huber V, Tong S, et al. Projections of temperature-related excess mortality under climate change scenarios. Lancet Planet Health. 2017;1(9):e360-7. doi:10.1016/S2542-5196(17)30156-0.
6. Nogueira PJ, Paixão E. Models for mortality associated with heatwaves: update of the Portuguese heat health warning system. Int J Climatol. 2008;28(4):545-62. doi:10.1002/joc.1546.
7. Nogueira PJ. Ondas de calor: modelos de medição, previsão e monitorização dos impactos na saúde [doctoral thesis]. Lisboa: Instituto de Higiene e Medicina Tropical, Universidade NOVA de Lisboa; 2011. Available from: http://hdl.handle.net/10362/64936
8. Serfling RE. Methods for current statistical analysis of excess pneumonia-influenza deaths. Public Health Rep. 1963;78(6):494-506.
9. Nogueira PJ, Machado A, Rodrigues E, Nunes B, Sousa L, Jacinto M, et al. The new automated daily mortality surveillance system in Portugal. Euro Surveill. 2010;15(13):19529. doi:10.2807/ese.15.13.19529-en.
10. von Elm E, Altman DG, Egger M, Pocock SJ, Gøtzsche PC, Vandenbroucke JP; STROBE Initiative. The Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement: guidelines for reporting observational studies. Lancet. 2007;370(9596):1453-7. doi:10.1016/S0140-6736(07)61602-X.
11. Armstrong B. Models for the relationship between ambient temperature and daily mortality. Epidemiology. 2006;17(6):624-31. doi:10.1097/01.ede.0000239732.50999.8f.
12. Gasparrini A, Armstrong B, Kenward MG. Distributed lag non-linear models. Stat Med. 2010;29(21):2224-34. doi:10.1002/sim.3940.
13. Gasparrini A, Armstrong B. The impact of heat waves on mortality. Epidemiology. 2011;22(1):68-73. doi:10.1097/EDE.0b013e3181fdcd99.
14. Hajat S, Armstrong BG, Gouveia N, Wilkinson P. Mortality displacement of heat-related deaths: a comparison of Delhi, São Paulo, and London. Epidemiology. 2005;16(5):613-20. doi:10.1097/01.ede.0000164559.41092.2a.
15. Gasparrini A, Guo Y, Hashizume M, Lavigne E, Zanobetti A, Schwartz J, et al. Mortality risk attributable to high and low ambient temperature: a multicountry observational study. Lancet. 2015;386(9991):369-75. doi:10.1016/S0140-6736(14)62114-0.
16. Anderson GB, Bell ML. Heat waves in the United States: mortality risk during heat waves and effect modification by heat wave characteristics in 43 U.S. communities. Environ Health Perspect. 2011;119(2):210-8. doi:10.1289/ehp.1002313.
17. Åström DO, Forsberg B, Rocklöv J. Heat wave impact on morbidity and mortality in the elderly population: a review of recent studies. Maturitas. 2011;69(2):99-105. doi:10.1016/j.maturitas.2011.03.008.
18. Fouillet A, Rey G, Wagner V, Laaidi K, Empereur-Bissonnet P, Le Tertre A, et al. Has the impact of heat waves on mortality changed in France since the European heat wave of summer 2003? A study of the 2006 heat wave. Int J Epidemiol. 2008;37(2):309-17. doi:10.1093/ije/dym253.
19. De' Donato FK, Leone M, Scortichini M, De Sario M, Katsouyanni K, Lanki T, et al. Changes in the effect of heat on mortality in the last 20 years in nine European cities: results from the PHASE project. Int J Environ Res Public Health. 2015;12(12):15567-83. doi:10.3390/ijerph121215006.
20. Boeckmann M, Rohn I. Is planned adaptation to heat reducing heat-related mortality and illness? A systematic review. BMC Public Health. 2014;14:1112. doi:10.1186/1471-2458-14-1112.
21. Bobb JF, Peng RD, Bell ML, Dominici F. Heat-related mortality and adaptation to heat in the United States. Environ Health Perspect. 2014;122(8):811-6. doi:10.1289/ehp.1307392.
22. Barba-Sánchez R, León-Gómez I, Pérez-Marín L, García-García D, Gómez-Barroso D. Excess mortality attributable to high temperatures during the summers of 2021 to 2024 in Spain: description of the MoMo real-time monitoring system. BMC Public Health. 2026;26:862. doi:10.1186/s12889-026-26354-z.
23. Vandentorren S, Bretin P, Zeghnoun A, Mandereau-Bruno L, Croisier A, Cochet C, et al. August 2003 heat wave in France: risk factors for death of elderly people living at home. Eur J Public Health. 2006;16(6):583-91. doi:10.1093/eurpub/ckl063.

ACKNOWLEDGEMENTS: *The author thanks the institutions responsible for the SICO-eVM mortality platform and for the ÍCARO surveillance system for making these data publicly available.*

CONFLICTS OF INTEREST: *The author declares having contributed, in previous professional roles, to the development and operation of the Portuguese heat-health mortality surveillance (ÍCARO) and daily mortality (eVM) systems referenced herein. No other conflicts of interest are declared.*

FUNDING: *This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.*

ETHICAL CONSIDERATIONS: *The study used exclusively aggregate, anonymised, publicly available data on daily counts of deaths and on a public environmental index; no individual-level or identifiable data were accessed. Under these conditions the study did not require ethics committee approval or informed consent. The author followed the STROBE recommendations for observational studies.*