Section 1: Health Hazards, Exposure, and Impact

1.1.1.2 Exposure of vulnerable populations to heatwaves

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Methods

Heatwave Definition, Occurrence, and Duration

Heatwaves effects on human health is a growing concern worldwide, particularly for vulnerable populations such as the elderly, infants, and pregnant women. However, there is no universally accepted definition of a heatwave, with various studies employing different temperature thresholds, durations, and metrics to characterize these events [1]. For this analysis, we defined a heatwave as a period of three or more consecutive days in which both the daily minimum and maximum temperatures exceeded the 95th percentile of the local climatology. This definition is based on the approach used by the World Meteorological Organization (WMO) in the "Heatwaves and Health: Guidance on Warning-System Development" [2]. This dual-threshold definition captures both the direct heat stress caused by high daytime temperatures and the physiological strain associated with insufficient nighttime cooling [3], [4] Two climatological baselines were used:

- 1986-2005 reference period.
- 2007-2016 to align with the Paris Agreement.

To determine these events, we utilized daily 2-meter temperature data from the European Centre for Medium-Range Weather Forecasts (ECMWF) ERA5-Land reanalysis dataset [5], gridded at a 0.1° × 0.1° global resolution. For each grid cell and each year from 1980 to 2025, we calculated two primary metrics:

- Heatwave Duration: The total number of days per year spent during a heatwave.
- Heatwave Frequency: The total number of discrete heatwave events per year.

Heatwave Severity (Excess Heat Factor)

To assess the changing intensity of heatwaves, we calculated the Excess Heat Factor (EHF), a metric that accounts for both the long-term climatological anomaly and short-term acclimatization [6].

We classified daily heatwave severity into three tiers—**Low-Intensity**, **Severe**, and **Extreme**—based on the methodology of the Australian Bureau of Meteorology [6].

Vulnerable Groups

We focused on three demographic groups particularly susceptible to heat-related health impacts:

- **Elderly ($\geq$ 65 years):** Age-related decrements in thermoregulation (e.g., reduced sweating) occur significantly by age 65 [7]. Additionally, the risk of underlying chronic conditions such as cardiovascular, renal, and respiratory diseases—secondary aggravators of heat stress—increases with advanced age [8].
- **Infants ($<$ 1 year):** Infants are highly vulnerable due to a high surface area-to-mass ratio (up to 4-fold greater than adults) and a limited behavioral ability to avoid heat [9].
- **Pregnant Women:** Pregnancy places significant physiological strain on the cardiovascular and thermoregulatory systems. Extreme heat exposure during pregnancy has been linked to adverse outcomes including preterm birth, low birth weight, and stillbirth [10].

Population Data Integration

To construct a continuous annual time series of global population distribution from 1980 to 2025, we combined three distinct datasets:

- **1980–1999:** We utilized the **Lancet Countdown 2023 dataset** [11], derived from the ISIMIP Histsoc dataset and NASA GPWv4 land area data. This data was available at a $0.25° \times 0.25°$ resolution and was upscaled to match the ERA5-Land grid resolution of $0.1° \times 0.1°$. We redistributed population counts from the coarser grid to the finer grid while preserving total population and masking out ocean cells.
- **2000–2014:** We used global gridded demographic data from the **WorldPop project** [12] available at a $1\ \text{km} \times 1\ \text{km}$ resolution based on the "top-down unconstrained approach." Age and sex groups were aggregated and then regridded to the ERA5-Land grid by summing values within each 0.1° cell.
- **2015–2025:** We utilized the **updated WorldPop dataset** [13] and aggregated age groups to the ERA5-Land grid by summing values within each cell.

For infant counts we aggregated the age band 0–1 from the respective datasets. For the elderly (≥ 65 years), we summed the age bands 65–70, 70–75, 75–80, and 80+.

Heatwave Exposure Calculation

Exposure to heatwaves for each vulnerable group was calculated by combining heatwave occurrence data with gridded demographic datasets.

For each grid cell, the annual heatwave exposure (in person-days) was computed as:

$$\text{Exposure} = \text{Heatwave Days} \times \text{Population}$$

Where:
- **Heatwave Days:** The total number of heatwave days in that grid cell for the year.
- **Population:** The number of individuals in the vulnerable group residing in that grid cell.

The total annual exposure for each vulnerable group was obtained by summing the exposure across all grid cells globally.

Code and resources to reproduce the results

The results were generated using Python, a copy of the code is available in this public repository https://github.com/FedericoTartarini/paper-lancet-countdown-global. Users who want to reproduce the results will first need to download the datasets listed below. Then they can use the code to reproduce the results, please refer to the README file in the public repository which contains detailed instructions on how to run the Python code.

Updates Introduced for 2026

In this 2026 update, we have introduced:
- the assessment of heatwave severity using the Excess Heat Factor (EHF) metric, allowing us to differentiate between low-intensity, severe, and extreme heatwaves.
- the inclusion of pregnant women as a vulnerable group, recognizing their heightened susceptibility to heat-related health impacts.
- improved demographic data integration by utilizing the latest WorldPop datasets.
- removed the people aged 75+ since this group is already included in the 65+ age group.
- given that the population data now extends to 2025, we did not need to project population estimates beyond 2020 as done in previous years.
- we have included the analysis of heatwave exposure trends under the 2007–2016 baseline, to align with the Paris Agreement.

We are also proposing to include Dr Mitchell Black as a co-author for this indicator.

Bibliography

[1] Z. Xu, G. FitzGerald, Y. Guo, B. Jalaludin, and S. Tong, “Impact of heatwave on mortality under different heatwave definitions: a systematic review and meta-analysis,” *Environment international*, vol. 89, pp. 193–203, 2016.

[2] W. M. Organization, “Heatwaves and health: guidance on warning-system development,” 2015.

[3] J. Liu *et al.*, “Rising cause-specific mortality risk and burden of compound heatwaves amid climate change,” *Nature Climate Change*, vol. 14, no. 11, pp. 1201–1209, 2024.

[4] C. Di Napoli, F. Pappenberger, and H. L. Cloke, “Verification of heat stress thresholds for a health-based heat-wave definition,” *Journal of Applied Meteorology and Climatology*, vol. 58, no. 6, pp. 1177–1194, 2019.

[5] J. Muñoz-Sabater *et al.*, “ERA5-Land: A state-of-the-art global reanalysis dataset for land applications,” *Earth system science data*, vol. 13, no. 9, pp. 4349–4383, 2021.

[6] J. R. Nairn and R. J. Fawcett, “The excess heat factor: a metric for heatwave intensity and its use in classifying heatwave severity,” *International journal of environmental research and public health*, vol. 12, no. 1, pp. 227–253, 2015.

[7] W. L. Kenney and T. A. Munce, “Invited review: aging and human temperature regulation,” *Journal of applied physiology*, 2003.

[8] K. L. Ebi *et al.*, “Hot weather and heat extremes: health risks,” *The lancet*, vol. 398, no. 10301, pp. 698–708, 2021.

[9] M. F. Bin Maideen, O. Jay, C. Bongers, R. Nanan, and J. W. Smallcombe, “Optimal low-cost cooling strategies for infant strollers during hot weather,” *Ergonomics*, vol. 66, no. 12, pp. 1935–1949, 2023.

[10] N. Ravanelli, W. Casasola, T. English, K. M. Edwards, and O. Jay, “Heat stress and fetal risk. Environmental limits for exercise and passive heat stress during pregnancy: a systematic review with best evidence synthesis,” *British journal of sports medicine*, vol. 53, no. 13, pp. 799–805, 2019.

[11] M. Romanello *et al.*, “The 2023 report of the Lancet Countdown on health and climate change: the imperative for a health-centred response in a world facing irreversible harms,” *The Lancet*, vol. 402, no. 10419, pp. 2346–2394, 2023.

[12] WorldPop and Center for International Earth Science Information Network (CIESIN), Columbia University, “Global High Resolution Population Denominators Project - Funded by The Bill and Melinda Gates Foundation (OPP1134076).” [Online]. Available: https://dx.doi.org/10.5258/SOTON/WP00646

[13] M. Bondarenko *et al.*, “The spatial distribution of population broken down by gender and age groupings in 2015-2030 at a resolution of 30 arc (approximately 1km at the equator) R2025A version v1.” [Online]. Available: https://doi.org/10.5258/SOTON/WP00846