

Ambient temperature and the volume and severity of 621,790 myocardial infarction admissions. A national case-crossover study

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Abstract

Whether temperature shifts myocardial infarction (MI) presentations toward intensive care and death is unclear, because national data infer severity from codes or intensive care unit (ICU) use of unknown validity. In the Medical Information Mart for Intensive Care IV (MIMIC-IV, 7,654 MI admissions) we measured how well codes, an ICU stay and death capture structured severity (vasopressor, mechanical support, ventilation, resuscitation or lactate 4 mmol/L or more in 24 hours). In Brazil (621,790 public hospital MI admissions, January 2023 to June 2026) linked to reanalysis temperature, conditional Poisson case-crossover models with distributed lags estimated all, ICU, non-ICU and fatal admissions, plus case-case odds of ICU admission and death. In MIMIC-IV an ICU stay captured 95 percent of measured severity (93 percent of a phenotype recorded independently of ICU location), death 25 percent and shock or arrest codes 51 percent. In Brazil, relative to the median, the hottest days carried 6.5 percent fewer admissions (relative risk 0.94, 95 percent confidence interval 0.91 to 0.96) and the coldest 2 percent more (1.02, 0.99 to 1.05). Admissions with and without an ICU stay changed in parallel (ratio 1.01, 0.94 to 1.08), fatal admissions did not differ, and temperature did not change the odds of ICU admission (0.97, 0.89 to 1.05) or death (0.89, 0.77 to 1.03). MI admissions were fewest on the hottest days and modestly more frequent on the coldest, without a shift toward intensive care or death. An ICU stay is a sensitive marker of measured severity; codes are not.

1. Introduction

Ambient temperature is one of the few external triggers of myocardial infarction (MI) that can be measured for every patient. Cold has a well documented day to day association with MI incidence, heat has become a trigger of comparable concern in recent warm years, and extreme temperatures raise cardiovascular death across countries [1–3]. In the United States, the emergency department (ED) visit rate for MI rose in the hot summer of 2023 compared with the five preceding summers [4].

What temperature does to the severity of the presentation is less clear. If extremes only bring forward infarctions that would have occurred anyway, the case mix should not change; if they precipitate larger or later presenting infarctions, the share of admissions needing intensive care and the case fatality should rise on those days. The distinction matters for emergency departments and critical care capacity, because intensive care unit (ICU) use for stable MI is already variable and often unrelated to measured risk [5–7].

Answering the question requires severity to be measured and the calendar date and place to be real, two things that rarely coexist. National administrative data carry diagnosis codes whose validity for MI is good but whose validity for severity is uncertain [8, 9], and research databases such as the Medical Information Mart for Intensive Care IV (MIMIC-IV) carry structured records of vasopressors, ventilation and laboratory values but remove the calendar date [10, 11]. Brazil publishes admission level microdata with real dates and municipality of residence within months [12], and in the years 2023 to 2025 experienced repeated record heat, which makes it a natural setting to ask whether heat has become at

least as important as cold. Combining the two data sets allows the severity markers available nationally, an ICU stay, death and diagnosis codes, to be characterized where the truth is recorded before they are applied where it is not.

We linked three and a half years of national MI admissions to reanalysis temperature and estimated the effect of cold and heat on admissions overall and by type, on admissions with and without an ICU stay, on fatal admissions and on coronary intervention, and among admissions on the odds of ICU admission and death. Before that, in MIMIC-IV, we measured how well the markers available in national data, an ICU stay, in hospital death and diagnosis codes, agree with structured records of vasopressor use, ventilation, mechanical support, resuscitation and lactate, so that each marker could be read for what it captures.

We prespecified four hypotheses. First, days above the 95th percentile of local temperature and below the 5th percentile carry a higher risk of MI admission than days at the median, heat within 0 to 3 days and cold within 0 to 7 days, and the heat association is at least as large as the cold association. Second, the association is stronger for ST elevation MI (STEMI) than for non ST elevation MI (NSTEMI), a comparison we treat as exploratory because three quarters of Brazilian MI carries an unspecified code. Third, temperature extremes raise the risk of admissions needing intensive care and of fatal admissions more than the risk of MI overall. Fourth, an ICU stay is a sensitive but non specific marker of measured severity, death a specific but insensitive one, and broad code based phenotypes lack specificity while narrow shock or arrest codes are specific but insensitive, so that severity in national data is best carried by recorded care.

2. Methods

2.1. Design

This was a two data set study. MIMIC-IV, in which severity is recorded but the calendar date is removed, was used to measure what an ICU stay, in hospital death and diagnosis codes capture of structured severity. The Brazilian Hospital Information System (SIH/SUS), in which dates and places are real but severity is not recorded, was used for the temperature analyses with those markers as outcomes. The study followed the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) and the REporting of studies Conducted using Observational Routinely-collected health Data (RECORD) recommendations [13, 14] (Online Resource 1, Table S5). The code sets (Table S1) and the extraction and analysis scripts are given in Online Resource 1.

2.2. Brazilian cohort, source and population

SIH/SUS records every hospital admission reimbursed by the Brazilian public system as an admission authorization (AIH), with principal and secondary diagnoses coded with the International Classification of Diseases, 10th Revision (ICD-10), procedures, ICU days, discharge status, dates of admission and discharge and municipality of residence [12, 15]. Monthly reduced files for all 27 states from January

2023 to July 2026 were downloaded from the Department of Informatics of the Unified Health System (DATASUS); records with a principal diagnosis of I21.0 to I21.4 or I21.9 were kept, continuation records removed and one record kept per authorization. Adults aged 18 years or more admitted between 1 January 2023 and 30 June 2026 formed the analysis cohort. The public system covers about seven in ten Brazilians; private admissions are not included.

2.3. Brazilian cohort, outcomes

Outcomes were daily counts of MI admissions, overall and by type (STEMI I21.0 to I21.3, NSTEMI I21.4, unspecified I21.9), of admissions with and without one or more ICU days, of fatal admissions and of admissions with a coronary intervention (group 04.06.03 of the Unified Health System procedure table, SIGTAP). Among admissions, ICU admission, in hospital death and coronary intervention were also analysed as binary outcomes. Secondary diagnosis fields (DIAG_SECUN, CID_ASSO, CID_MORTE and DIAGSEC1 to DIAGSEC9) were examined for a code based severity composite (cardiogenic shock, cardiac arrest, ventricular arrhythmia, mechanical complication, heart failure).

2.4. Exposure

Daily mean, maximum and minimum temperature at 2 m, relative humidity, surface pressure and precipitation were obtained from the NASA Prediction Of Worldwide Energy Resources (POWER) project, which serves the Modern-Era Retrospective analysis for Research and Applications, version 2 (MERRA-2) reanalysis on a 0.5 by 0.625 degree grid [16, 17]. Each municipality of residence was assigned to the grid cell containing its centroid (2022 boundaries of the Brazilian Institute of Geography and Statistics, IBGE) and each admission was linked by cell and admission date. Because the country spans tropical and subtropical climates, temperature was expressed as the percentile of the cell specific distribution over December 2022 to June 2026, so that cold and heat are defined relative to local climate. Heat wave days were runs of at least three days above the cell 90th percentile of daily maximum and cold spell days runs of at least three days below the 10th percentile of daily minimum.

2.5. MIMIC-IV data set

MIMIC-IV version 3.1 contains deidentified records of patients admitted to Beth Israel Deaconess Medical Center, Boston, between 2008 and 2022, with dates shifted into the future but the hour of day preserved [10, 11]. We included the first admission of each adult with a principal diagnosis of MI (ICD-9 Clinical Modification 410.x1 and ICD-10 Clinical Modification I21), excluding subsequent MI codes, and classified type as STEMI, NSTEMI, type 2 or unspecified. Structured severity was a composite of a vasopressor or inotrope, mechanical circulatory support, invasive ventilation, a resuscitation procedure or lactate of 4 mmol/L or more within 24 hours of admission, taken from medication, procedure and laboratory records. Against this reference we measured, in all admissions and by type, the sensitivity, specificity and predictive values of an ICU stay, ICU admission within 6 hours of ED registration, in hospital death, either an ICU stay or death, a broad code composite (shock, arrest, ventricular arrhythmia, mechanical complication or heart failure codes) and a narrow shock or arrest code composite, with Jeffreys intervals. Because vasopressor and ventilation records in MIMIC-IV come from the ICU module,

an ICU stay captures them by construction; the same markers were therefore also benchmarked against a phenotype recorded independently of ICU location, mechanical circulatory support, resuscitation or lactate of 4 mmol/L or more, and the components were compared by ICU status (Online Resource 1, Table S1).

2.6. Statistical analysis

Temperature and MI admissions were analysed with a time stratified case-crossover design fitted as a conditional Poisson model, in which daily counts in each grid cell are compared within strata of cell, year, month and day of week, so that seasonality, long term trend and weekly patterns are controlled by design [18–20]; strata without an event of the outcome under analysis were excluded. Temperature entered as a distributed lag non-linear cross-basis over lags 0 to 7 with natural splines for the exposure (knots at the 10th, 75th and 90th percentiles) and for the lag dimension [21, 22], with adjustment for relative humidity and national holidays. For the prespecified hypotheses, cumulative relative risks (RR) were taken relative to the median of local temperature, heat (95th and 99th percentiles) over lags 0 to 3 and 0 to 7 and cold (5th and 1st) over lags 0 to 7; the heat association was compared with the cold association as the ratio of the two RR (99th versus 1st, both relative to the median) with its variance from the model coefficients, and STEMI with NSTEMI as the ratio of their RR, treating the two count models as independent. To describe the full exposure-response, each model was also centred at its percentile of minimum risk. The shift in case mix was expressed as the ratio of the RR for admissions with an ICU stay to the RR for admissions without.

Case-case models estimated, among admissions, the odds of ICU admission, in hospital death and coronary intervention as a function of the same cross-basis with fixed effects for each grid cell in each calendar month and adjustment for age, sex, humidity and holidays. A quantitative bias analysis of the code based severity composite, using the MIMIC-IV two by two table, was prespecified but could not be performed because the composite was too sparse in SIH. Analyses used R 4.5 (dlnm, gnm, fixest), Python 3.12 and DuckDB. Sample size was determined by the number of eligible admissions; no formal a priori calculation was performed.

2.7. Ethics and transparency

SIH/SUS microdata are anonymized public data. MIMIC-IV is a deidentified resource approved for research by the institutional review board of Beth Israel Deaconess Medical Center with a waiver of informed consent; the authors completed PhysioNet credentialing and signed the data use agreement, and no record level MIMIC-IV data left the credentialed environment. No additional ethical approval was required. A large language model (Claude, Anthropic) was used to draft the manuscript structure, the methods text, the analysis code and the reference list; the authors reviewed and edited all content and take full responsibility for it.

3. Results

3.1. The two cohorts

The MIMIC-IV cohort comprised 7,654 admissions (median age 70 years, 35.1 percent women; NSTEMI 71.4 percent, STEMI 24.9 percent), of which 48.5 percent had an ICU stay, 16.0 percent met the structured severity composite, 46.3 percent underwent percutaneous coronary intervention and 5.3 percent died in hospital. The Brazilian cohort comprised 621,790 admissions within the analysis window from 5,550 municipalities in 1,389 grid cells (median age 64 years, 36.5 percent women; STEMI 21.4 percent, NSTEMI 4.6 percent, unspecified 74.1 percent), of which 40.8 percent had an ICU stay (median 3 ICU days), 36.6 percent underwent a coronary intervention and 7.3 percent died in hospital (Table 1; Online Resource 1, Fig. S1). Regional distribution and exposure summaries are in Online Resource 1 (Table S4).

Table 1

The two cohorts. MI admissions in the Brazilian public hospital system, 1 January 2023 to 30 June 2026, overall and by coded type, and the MIMIC-IV cohort, 2008 to 2022.

Characteristic	Brazil, all	Brazil, STEMI	Brazil, NSTEMI	Brazil, unspecified	MIMIC-IV, all
Admissions, n	621,790	132,964	28,313	460,513	7,654
Age, years, median (IQR)	64 (56–72)	63 (55–72)	64 (56–73)	64 (56–72)	70 (60–79)
Women, n (%)	226,694 (36.5)	46,708 (35.1)	10,866 (38.4)	169,120 (36.7)	2,689 (35.1)
STEMI / NSTEMI / other, %	21.4 / 4.6 / 74.1				24.9 / 71.4 / 3.7
ICU admission, n (%)	253,859 (40.8)	57,536 (43.3)	10,558 (37.3)	185,765 (40.3)	3,711 (48.5)
ICU days among ICU patients, median (IQR)	3 (2–5)	3 (2–5)	3 (2–5)	3 (2–5)	2 (1–4)
Coronary intervention (SIGTAP 04.06.03), n (%)	227,601 (36.6)	56,863 (42.8)	10,111 (35.7)	160,627 (34.9)	3,542 (46.3) ^a
In hospital death, n (%)	45,572 (7.3)	9,154 (6.9)	1,374 (4.9)	35,044 (7.6)	404 (5.3)
Length of stay, days, median (IQR)	4 (2–8)	4 (2–7)	4 (2–8)	4 (2–8)	n.a.
Structured presentation severity, n (%)	not recorded				1,223 (16.0)
IQR, interquartile range; ICU, intensive care unit; MI, myocardial infarction; STEMI and NSTEMI, ST elevation and non ST elevation MI; PCI, percutaneous coronary intervention; CPR, cardiopulmonary resuscitation. Brazil, ICU admission is one or more ICU days on the admission authorization and coronary intervention any SIGTAP procedure in group 04.06.03. MIMIC-IV, first MI admission per patient; ^a PCI by procedure code; structured severity is vasopressor or inotrope, mechanical circulatory support, invasive ventilation, CPR or lactate 4 mmol/L or more within 24 hours; other is type 2 or unspecified MI.					

The secondary diagnosis fields were empty in every record of the extracted Brazilian files, and in a sample file the newer secondary diagnosis fields were completed in about 9 percent of admissions, so the code based severity composite was not analysable in Brazil and the prespecified bias analysis was not performed.

3.2. What ICU stay, death and codes measure in MIMIC-IV

An ICU stay captured 95.2 percent of admissions with structured severity (sensitivity 95.2 percent, 95 percent confidence interval 93.9 to 96.3) with a negative predictive value of 98.5 percent, but only 31.4 percent of ICU stays involved measured severity (specificity 60.4 percent). Against the phenotype

recorded independently of ICU location (mechanical circulatory support, resuscitation or lactate 4 mmol/L or more, present in 11.0 percent), an ICU stay retained a sensitivity of 93.0 percent (91.1 to 94.6), 94.5 percent in STEMI and 92.3 percent in NSTEMI, so its sensitivity is not an artefact of where vasopressors and ventilation are recorded. Among ICU patients 14.8 percent received mechanical circulatory support and 8.4 percent had a lactate of 4 mmol/L or more, against 0.8 and 0.7 percent among patients never admitted to an ICU; death occurred in 9.6 versus 1.2 percent. ICU admission within 6 hours of ED registration was less sensitive (68.9 percent) and more specific (82.7 percent). In hospital death was specific (98.5 percent) but captured a quarter of measured severity (25.1 percent), and an ICU stay or death captured 96.6 percent (Table 2).

Table 2

MIMIC-IV. What an ICU stay, in hospital death and diagnosis codes capture of structured presentation severity (n = 7,654), against the full structured composite (present in 16.0 percent) and against a phenotype recorded independently of ICU location.

Marker	Prevalence, %	Sensitivity (95% CI)	Specificity (95% CI)	PPV (95% CI)	NPV	Sensitivity, STEMI / NSTEMI
Any ICU stay	48.5	95.2 (93.9 to 96.3)	60.4 (59.2 to 61.6)	31.4 (29.9 to 32.9)	98.5	96.1 / 94.8
ICU admission within 6 h of ED registration	25.5	68.9 (66.3 to 71.5)	82.7 (81.8 to 83.6)	43.2 (41.0 to 45.4)	93.3	87.9 / 51.3
In hospital death	5.3	25.1 (22.7 to 27.6)	98.5 (98.2 to 98.8)	76.0 (71.6 to 80.0)	87.4	29.2 / 20.5
ICU stay or in hospital death	49.1	96.6 (95.5 to 97.5)	59.9 (58.7 to 61.1)	31.5 (30.0 to 33.0)	98.9	97.2 / 96.6
Code severe composite	46.0	77.3 (74.9 to 79.6)	59.9 (58.7 to 61.1)	26.8 (25.4 to 28.3)	93.3	81.7 / 73.4
Shock or arrest code	10.5	51.4 (48.6 to 54.2)	97.3 (96.8 to 97.6)	78.1 (75.2 to 80.9)	91.3	n.r.
Against the location independent phenotype (MCS, CPR or lactate; 11.0 percent)						
Any ICU stay	48.5	93.0 (91.1 to 94.6)	57.0 (55.9 to 58.2)	21.2 (19.9 to 22.5)	98.5	94.5 / 92.3
Reference standards, structured composite of vasopressor or inotrope, mechanical circulatory support (MCS), invasive ventilation, CPR or lactate 4 mmol/L or more within 24 hours of admission; location independent phenotype, MCS, CPR or lactate 4 mmol/L or more. Jeffreys intervals. ICU, intensive care unit; CPR, cardiopulmonary resuscitation; STEMI and NSTEMI, ST elevation and non ST elevation myocardial infarction. PPV, positive predictive value; NPV, negative predictive value; n.r., not reported. Vasopressor and ventilation records come from the ICU module, so an ICU stay captures them by construction; among ICU patients 14.8 percent received MCS and 8.4 percent had lactate 4 mmol/L or more, against 0.8 and 0.7 percent among patients never admitted to an ICU.						

Marker	Prevalence, %	Sensitivity (95% CI)	Specificity (95% CI)	PPV (95% CI)	NPV	Sensitivity, STEMI / NSTEMI
In hospital death	5.3	31.2 (28.1 to 34.3)	97.9 (97.6 to 98.2)	65.1 (60.4 to 69.6)	92.0	34.7 / 26.4
Code severe composite	46.0	81.0 (78.3 to 83.6)	58.3 (57.2 to 59.5)	19.4 (18.1 to 20.8)	96.1	82.9 / 79.1
Shock or arrest code	10.5	58.1 (54.7 to 61.4)	95.4 (94.9 to 95.9)	60.9 (57.5 to 64.2)	94.8	66.0 / 49.6
Reference standards, structured composite of vasopressor or inotrope, mechanical circulatory support (MCS), invasive ventilation, CPR or lactate 4 mmol/L or more within 24 hours of admission; location independent phenotype, MCS, CPR or lactate 4 mmol/L or more. Jeffreys intervals. ICU, intensive care unit; CPR, cardiopulmonary resuscitation; STEMI and NSTEMI, ST elevation and non ST elevation myocardial infarction. PPV, positive predictive value; NPV, negative predictive value; n.r., not reported. Vasopressor and ventilation records come from the ICU module, so an ICU stay captures them by construction; among ICU patients 14.8 percent received MCS and 8.4 percent had lactate 4 mmol/L or more, against 0.8 and 0.7 percent among patients never admitted to an ICU.						

The broad code composite had sensitivity 77.3 percent (74.9 to 79.6), specificity 59.9 percent and positive predictive value 26.8 percent, the last driven by heart failure codes; the narrow shock or arrest composite was specific (97.3 percent) but captured half of the structured phenotype (sensitivity 51.4 percent, 48.6 to 54.2), and against the location independent phenotype the two composites gave sensitivities of 81.0 and 58.1 percent with specificities of 58.3 and 95.4 percent. An ICU stay was therefore a far more sensitive marker of measured severity than any code, and death a far more specific one.

3.3. Temperature and MI admissions in Brazil

MI admissions fell steadily as temperature rose, with the minimum risk at the 99th percentile of local temperature (Fig. 1). Relative to the median, the hottest days carried fewer admissions, RR 0.94 (95 percent confidence interval 0.91 to 0.96) at the 99th percentile and 0.95 (0.93 to 0.97) at the 95th, cumulated over lags 0 to 7, and 0.98 (0.96 to 1.00) at the 99th percentile in the prespecified heat window of lags 0 to 3. The coldest days carried slightly more, RR 1.02 (0.99 to 1.05) at the 1st percentile and 1.02 (1.00 to 1.05) at the 5th over lags 0 to 7 (Table 3; all outcomes and lag windows in Online Resource 1, Table S3). Between the extremes the difference was 9 percent, RR 1.09 (1.05 to 1.13) at the 1st percentile relative to the 99th, rising to 1.10 (1.06 to 1.14) at the 10th (Online Resource 1, Table S2). The first hypothesis was therefore not supported for heat, which carried no excess in either lag window, and only weakly for cold, and the heat association was smaller than the cold association (ratio of RR 0.92, 0.88 to 0.95, P below 0.001).

Table 3

Prespecified contrasts. Cumulative relative risk of MI admission on cold and hot days relative to the median of local temperature, in the prespecified lag windows, and the heat versus cold contrast, Brazil 2023 to 2026.

Outcome	Cold, 1st vs median, lag 0–7	Cold, 5th vs median, lag 0–7	Heat, 95th vs median, lag 0–3	Heat, 99th vs median, lag 0–3	Heat, 95th vs median, lag 0–7	Heat, 99th vs median, lag 0–7	Heat (99th) versus cold (1st), ratio of RR
All MI admissions	1.02 (0.99 to 1.05)	1.02 (1.00 to 1.05)	0.99 (0.98 to 1.01)	0.98 (0.96 to 1.00)	0.95 (0.93 to 0.97)	0.93 (0.91 to 0.96)	0.92 (0.88 to 0.95), P < 0.001
STEMI	1.02 (0.96 to 1.07)	1.02 (0.97 to 1.06)	0.99 (0.96 to 1.03)	1.00 (0.96 to 1.05)	0.94 (0.90 to 0.98)	0.95 (0.89 to 1.00)	0.93 (0.86 to 1.01), P 0.08
NSTEMI	1.00 (0.88 to 1.13)	1.00 (0.90 to 1.10)	1.02 (0.95 to 1.10)	1.00 (0.91 to 1.10)	0.98 (0.90 to 1.08)	0.98 (0.86 to 1.10)	0.98 (0.83 to 1.16), P 0.80
Unspecified MI	1.02 (0.99 to 1.05)	1.03 (1.00 to 1.05)	0.99 (0.97 to 1.01)	0.98 (0.95 to 1.00)	0.95 (0.93 to 0.97)	0.93 (0.90 to 0.96)	0.91 (0.87 to 0.95), P < 0.001
Admissions with coronary intervention	0.98 (0.94 to 1.02)	1.00 (0.96 to 1.03)	1.00 (0.97 to 1.02)	0.99 (0.95 to 1.02)	0.97 (0.94 to 1.00)	0.95 (0.91 to 0.99)	0.97 (0.91 to 1.03), P 0.26
Relative risks (RR) with 95 percent confidence intervals (CI) from conditional Poisson case-crossover models with strata of grid cell, year, month and day of week, adjusted for relative humidity and national holidays; temperature is the percentile of the cell specific distribution and the reference is the 50th percentile. The ratio of RR compares the 99th with the 1st percentile, both relative to the median, cumulated over lags 0 to 7, with its variance from the model coefficients; a ratio below one means the heat association is smaller than the cold association. STEMI versus NSTEMI, ratio of RR 1.02 (0.89 to 1.17, P 0.79) at the 1st and 0.97 (0.85 to 1.11, P 0.67) at the 99th percentile. Estimates relative to the percentile of minimum risk are in Online Resource 1, Table S2. MI, myocardial infarction; STEMI and NSTEMI, ST elevation and non ST elevation MI.							

STEMI followed the same pattern (99th versus median 0.95, 0.90 to 1.00; 1st versus median 1.02, 0.96 to 1.07), with no evidence of a difference from NSTEMI (ratio of RR at the 1st percentile 1.02, 0.89 to 1.17, P 0.79; at the 99th 0.97, 0.85 to 1.11, P 0.67), although the NSTEMI estimates were imprecise.

Unspecified MI, the largest group, gave 0.93 (0.90 to 0.96) at the 99th and 1.02 (0.99 to 1.06) at the 1st percentile. Admissions with a coronary intervention gave 0.95 (0.91 to 0.99) at the 99th and 0.98 (0.94 to 1.02) at the 1st percentile.

3.4. Temperature, intensive care and death

Admissions with and without an ICU stay changed in parallel across the whole temperature range, 0.94 (0.90 to 0.97) and 0.94 (0.90 to 0.97) at the 99th percentile and 1.02 (0.98 to 1.07) and 1.02 (0.98 to 1.05) at the 1st, relative to the median, with a ratio of RR for admissions with versus without an ICU stay of 1.01 (0.94 to 1.08) at the 1st percentile relative to the 99th and close to one at every percentile (Table 4). Fatal admissions gave 1.06 (0.97 to 1.16) at the 1st and 1.00 (0.91 to 1.10) at the 99th percentile relative to the median.

Table 4

Temperature and the severity of MI admissions. Cumulative relative risks (lag 0 to 7) for admissions with and without an ICU stay and for fatal admissions relative to the median, their ratio, and case-case odds ratios among admissions.

Outcome	1st percentile	10th percentile	90th percentile	99th percentile
Admissions with an ICU stay	1.02 (0.98 to 1.07)	1.02 (1.00 to 1.05)	0.97 (0.94 to 1.00)	0.93 (0.90 to 0.97)
Admissions without an ICU stay	1.02 (0.98 to 1.05)	1.03 (1.00 to 1.05)	0.96 (0.94 to 0.99)	0.93 (0.90 to 0.97)
Fatal admissions	1.06 (0.97 to 1.16)	1.04 (0.97 to 1.11)	0.97 (0.90 to 1.05)	1.00 (0.91 to 1.10)
Ratio of RR, ICU versus no ICU (reference 99th) ^a	1.01 (0.94 to 1.08)	1.00 (0.93 to 1.06)	1.01 (0.95 to 1.06)	1 (ref)
Case-case OR, ICU admission (reference 99th)	0.97 (0.89 to 1.05)	0.97 (0.90 to 1.04)	0.99 (0.93 to 1.05)	1 (ref)
Case-case OR, in hospital death (reference 99th)	0.89 (0.77 to 1.03)	0.87 (0.76 to 1.00)	0.88 (0.79 to 0.99)	1 (ref)
Case-case OR, coronary intervention (reference 99th)	0.94 (0.86 to 1.02)	0.98 (0.91 to 1.05)	1.03 (0.96 to 1.09)	1 (ref)
Conditional Poisson models as in Table 3, reference the 50th percentile unless stated. ^a Ratio of RR from the delta method on the log scale, with both RR relative to the 99th percentile (the percentile of minimum risk of both models). Case-case odds ratios from logistic regression with fixed effects for each grid cell in each calendar month, adjusted for age, sex, relative humidity and national holidays, relative to the 99th percentile. RR, relative risk; OR, odds ratio; ICU, intensive care unit.				

Among admissions, cold days did not change the odds of ICU admission (case-case odds ratio 0.97, 0.89 to 1.05, at the 1st versus the 99th percentile) or of coronary intervention (0.94, 0.86 to 1.02). The odds of in hospital death were lower at the 1st (0.89, 0.77 to 1.03), 10th (0.87, 0.76 to 1.00) and 90th percentiles (0.88, 0.79 to 0.99) than on the hottest days, a pattern that indicates a slightly higher case fatality on the hottest days rather than on cold days, with intervals that include or approach one (Table 4, Fig. 2).

4. Discussion

4.1. Principal findings

Across Brazil in 2023 to 2026, MI admissions fell steadily as local temperature rose. The hottest days carried about 6.5 percent fewer admissions than the median and the coldest days about 2 percent more, a 9 percent difference between the extremes, and there was no heat excess in the short lag window in which heat is expected to act. The pattern was similar for STEMI and unspecified MI and for admissions with and without an ICU stay, and temperature did not change the odds that an admitted patient needed intensive care, underwent an intervention or died. In MIMIC-IV, where severity is measured, an ICU stay captured nearly all admissions with physiologic instability, so a shift toward sicker presentations on cold days would have appeared as a steeper change in ICU admissions; it did not.

4.2. Fewer admissions in the heat, few more in the cold

The cold association is one of the best replicated findings in environmental cardiology, with nationwide Swedish data showing a day to day rise in MI with low temperature [1] and long series in Germany showing that the heat association has grown over recent decades while the cold association has not [2]. Extreme heat and cold both raise cardiovascular death across countries [3], and the hot summer of 2023 was accompanied by more ED visits for MI in the United States [4]. In Brazil, despite record heat in the study years, we found no heat excess for admissions; the hottest days carried the fewest, the cold excess relative to the median was small, and the 9 percent difference between the coldest and hottest days is mostly a heat deficit. Temperature was defined relative to local climate, so the 99th percentile in a tropical cell is a hot day within an already hot climate and populations may be acclimatized; heat may act mainly on cardiovascular death outside hospital, which SIH does not record, and admissions would fall if some events on hot days are fatal before hospital or if care seeking falls in extreme heat; and cold in the South and Southeast, where half of admissions occur, combines low temperatures with housing that is not built for them.

4.3. No shift in severity

The clinically important question for emergency departments is not only whether more MI arrives on extreme days but whether what arrives is sicker. The answer here is no, and the MIMIC-IV benchmark says how much weight that answer can bear. Because 95 percent of patients with measured instability had an ICU stay, admissions with an ICU stay are a sensitive count of severe presentations, and they changed with temperature by the same proportion as admissions without, with a ratio close to one at every percentile; the case-case odds of ICU admission were unchanged, and fatal admissions did not rise more than admissions overall. Temperature therefore appears to change volume rather than acuity. These findings support the use of cold forecasts for capacity planning but provide no evidence to justify temperature based changes in triage or disposition thresholds; the difference in MI arrivals between the coldest and hottest days, about a tenth, is spread over the following week rather than concentrated on

the day itself. The small excess in case fatality on the hottest days, imprecise and not prespecified, deserves testing in data with out of hospital deaths.

4.4. What the second data set adds

Administrative codes identify MI with acceptable accuracy [8], but codes for shock and arrest are not the same as measured shock and arrest [9]. In a well coded United States center they captured half of the patients who received vasopressors, mechanical support, ventilation or resuscitation, a broader composite that includes heart failure codes flagged almost half of all admissions with a positive predictive value of 27 percent, and in SIH the secondary diagnosis fields were, in practice, empty. An ICU stay was present in 95 percent of admissions with measured instability, in 93 percent of those with instability recorded independently of ICU location, and absent in 98.5 percent of admissions without it, at the price of a positive predictive value of 31 percent, because most ICU stays for MI are monitoring rather than treatment of instability [5–7]; death was the mirror image, specific but insensitive. A change in ICU admissions that outpaces other admissions is therefore a sensitive test for a shift toward instability, and its absence here is informative; a change in fatal admissions is a specific test with low power. National studies of MI severity should rely on recorded care and death rather than diagnosis codes, state which property each marker has and, where possible, characterize it where severity is measured.

4.5. Strengths and limitations

Strengths include national scale with real dates and locations, a case-crossover design that controls seasonality, trend, day of week and slowly varying confounders by construction, distributed lag modelling of both heat and cold on a locally relative scale, outcomes defined from recorded care rather than codes, and characterization of those outcomes against measured severity in a second data set.

The limitations are substantial. SIH covers public system admissions only and lacks laboratory values, Killip class and the hour of arrival. Three quarters of MI were coded as unspecified, so the STEMI and NSTEMI subgroups are incomplete and their comparison is exploratory. Reanalysis temperature on a half degree grid does not capture urban heat islands, and municipality centroids misplace residents of large municipalities. Air pollution was not modelled and can confound temperature associations. The study period is short, so year to year variation in climate cannot be separated from trend, and out of hospital deaths are not observed. MIMIC-IV is a single tertiary center in a temperate climate with high ICU use, so the sensitivity of an ICU stay for measured severity may be lower in Brazilian hospitals with fewer ICU beds; vasopressor and ventilation records in MIMIC-IV are ICU based, so part of that sensitivity is by construction, although the location independent phenotype gave a sensitivity of 93 percent. Coding validity in Boston may not transfer to Brazil.

5. Conclusion

In Brazil between 2023 and 2026, MI admissions were fewest on the hottest days, about 6.5 percent below the median, and only modestly more frequent on the coldest, about 2 percent above, and

temperature did not shift admissions toward intensive care or death. Benchmarked in MIMIC-IV, an ICU stay is a sensitive and death a specific marker of measured severity, whereas diagnosis codes are not fit for the purpose; national data can measure the volume of MI that temperature brings and, with recorded care, whether it is sicker.

Declarations

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Competing interests. The authors declare that they have no competing interests.

Ethics approval. The study used two sources of previously collected, deidentified data and involved no contact with patients. SIH/SUS microdata are anonymized public records published by the Brazilian Ministry of Health (DATASUS) and are exempt from ethics committee review under Brazilian National Health Council Resolution 510/2016. MIMIC-IV is a deidentified database released for research after approval by the institutional review boards of Beth Israel Deaconess Medical Center and the Massachusetts Institute of Technology with a waiver of informed consent; the authors completed the PhysioNet credentialing process and signed the data use agreement, and no record level data left the credentialed environment. The study complied with the Declaration of Helsinki and was reported according to the STROBE and RECORD guidelines. No additional institutional ethics approval was required.

Consent to participate. Not applicable. The study analysed only anonymized public data and a deidentified research database, and no participant was contacted.

Consent to publish. Not applicable. No identifiable information on any individual appears in the manuscript, tables, figures or supplementary material.

Data availability. SIH/SUS microdata are publicly available from DATASUS and NASA POWER data are openly available; MIMIC-IV is available to credentialed researchers through PhysioNet under a data use agreement.

Code availability. The extraction and analysis scripts (Python, DuckDB and R) are provided in Online Resource 1 and will be deposited in a public repository on acceptance.

Use of generative artificial intelligence. As stated in the Methods, a large language model (Claude, Anthropic) was used to draft the manuscript structure, the methods text, the analysis code and the reference list; the authors reviewed and edited all content and take full responsibility for it.

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Figures

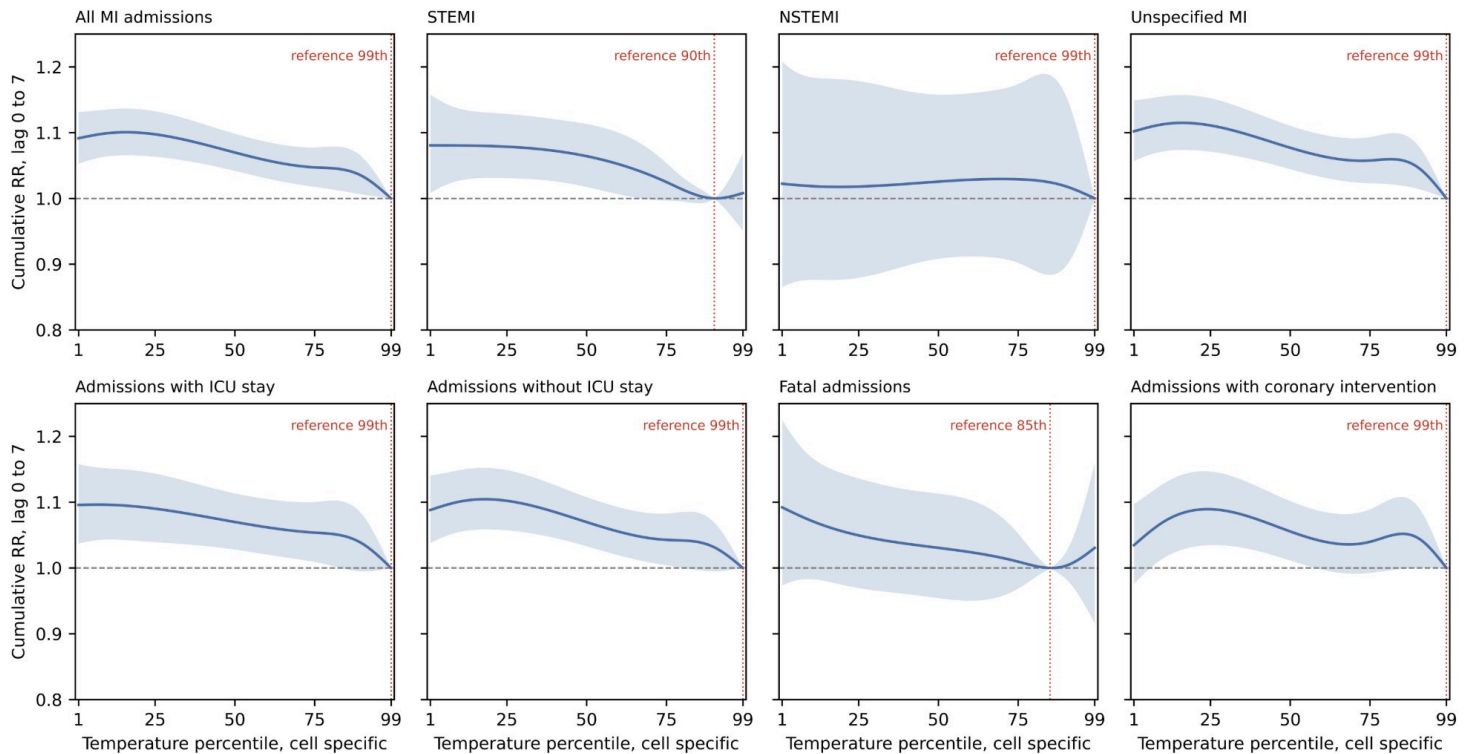


Figure 1

Cumulative exposure-response (lag 0 to 7) for MI admissions overall, by type, with and without an ICU stay, fatal, and with coronary intervention, on the cell specific temperature percentile scale, each curve centred at the percentile of minimum risk of its model (dotted line), with 95 percent confidence bands. RR, relative risk; MI, myocardial infarction; STEMI and NSTEMI, ST elevation and non ST elevation MI; ICU, intensive care unit

STEMI followed the same pattern (99th versus median 0.95, 0.90 to 1.00; 1st versus median 1.02, 0.96 to 1.07), with no evidence of a difference from NSTEMI (ratio of RR at the 1st percentile 1.02, 0.89 to 1.17, P 0.79; at the 99th 0.97, 0.85 to 1.11, P 0.67), although the NSTEMI estimates were imprecise. Unspecified MI, the largest group, gave 0.93 (0.90 to 0.96) at the 99th and 1.02 (0.99 to 1.06) at the 1st percentile. Admissions with a coronary intervention gave 0.95 (0.91 to 0.99) at the 99th and 0.98 (0.94 to 1.02) at the 1st percentile.

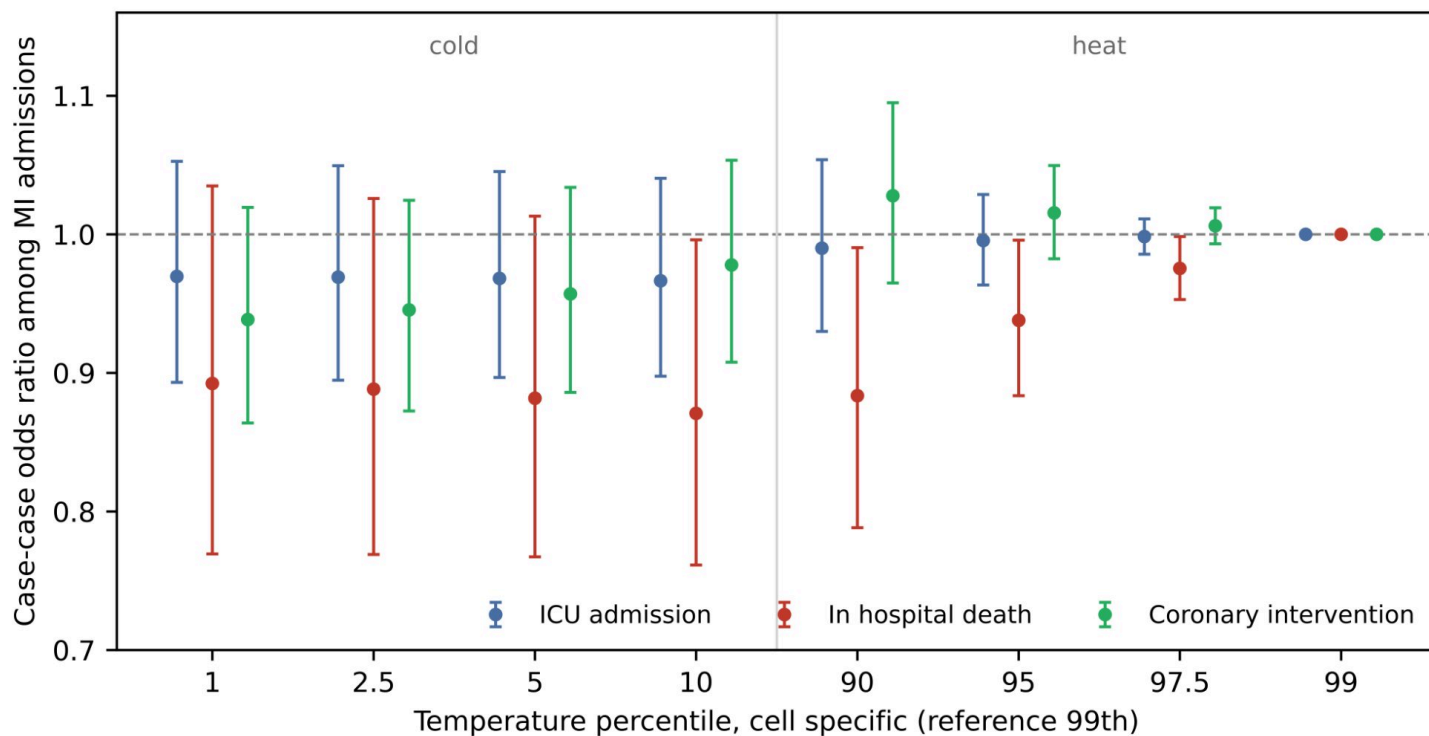


Figure 2

Case-case odds ratios among MI admissions for ICU admission, in hospital death and coronary intervention by temperature percentile, relative to the 99th percentile, with 95 percent confidence intervals. MI, myocardial infarction; ICU, intensive care unit

Supplementary Files

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