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Short-term effects of ambient temperature on preterm birth and effect modification by relative humidity across Brazilian regions: a nationwide time-series study

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Abstract

Background

Exposure to non-optimal ambient temperatures has been associated with preterm birth (PTB), a leading cause of neonatal mortality and long term morbidity. Relative humidity may modify thermal stress, but its influence on PTB risk related to temperature remains insufficiently characterized across climatically diverse settings. This study investigated the short-term association between ambient temperature and daily PTB risk across Brazilian regions from 2003 to 2023 and assessed effect modification by relative humidity.

Methods

We applied region specific generalized additive models incorporating distributed lag non linear models to daily PTB counts, using daily live births as the model offset, to estimate non-linear associations between temperature and PTB across 0 to 7 days lag. Relative humidity was modeled as a continuous effect modifier, and conditional temperature x PTB curves were estimated at the region specific 5th and 95th percentiles of relative humidity.

Results

Among 39,815,229 live births, 3,126,433 (7.85%) were preterm. In warmer regions higher risks occurred near temperatures moderately outside the regional mean and were most evident at lag 0, whereas in colder and moderate temperature regions risk exhibited U-shaped curves, with pronounced associations at lag 7. Humidity modified these associations heterogeneously, high humidity produced the clearest amplification in the Southeast, whereas low humidity was more influential in the Northeast and intensified risk associated with cold in the South.

Conclusions

Preterm Birth risk related to temperature varied substantially across Brazilian regions and it`s climatic characteristics. The direction and magnitude of humidity modification were also specific to each region. Assessments based on temperature alone may overlook relevant combined environmental stressors. Region specific temperature x humidity indicators may improve maternal health surveillance, early warning systems, and climate adaptation strategies.

BACKGROUND

Exposure to temperature extremes is known to have a wide range of adverse health effects in humans, evidence indicates that exposure to this risk factors before conception and during pregnancy can lead to serious outcomes for babies, including impaired fetal growth, stillbirth, low birth weight and preterm birth (1, 2).

Prematurity, defined as the birth less than 37 completed weeks, is one of the main causes of neonatal death worldwide and the second most common cause of death in children under five years, despite growing attention, preterm birth rates have changed little over the past decade, a barely significant decrease (3, 4). Although many preterm babies survive, they are at higher risk of developing a range of complications later in life, including cardiorespiratory, metabolic, gastrointestinal, and kidney issues, as well as significant neurodevelopmental impairments and mental health challenges (5). These lasting effects can substantially impact long-term health and quality of life.

The World Health Organization (WHO) estimates that about 13 million babies were born prematurely in 2020, and nearly 1 million newborn died due to prematurity complications in the same year (4, 6). In the Americas, about 1.2 million preterm births are registered each year, in Brazil a recent report indicated that, between 2012 and 2022, were recorded 31,351,324 births, of which 11.3% (3,530,568) were preterm (7).

Exposure to temperature extremes can contribute to prematurity by different mechanism, cold temperatures could increase blood viscosity and vascular constriction, which can induce the onset of labor. Also, cold weather may increase exposure to pathogenic agents and result in complications during pregnancy, further increasing the risk of Preterm Birth (8). On the other hand, high temperatures could trigger labor through dehydration, or cardiovascular complications. Also, physiological changes inherent to the pregnancy may influence the thermoregulation efficiency of pregnant women. During pregnancy, the increase in weight may decrease the ratio of body surface area to body mass, which may limit a woman's capacity for heat loss. In addition, heat production would increase due to fetal growth and metabolism (9).

Relative humidity may further modify these temperature related strains. High humidity reduces evaporative heat loss and can intensify physiological heat strain, whereas hot and dry conditions may increase fluid loss and dehydration. These mechanisms may differ across Brazil’s highly heterogeneous climates, which range from humid equatorial environments to semi-arid and subtropical regions humidity may further modify these temperature-related pathways (10, 11).

Climate change is increasing the frequency and intensity of temperature extremes, yet evidence on temperature, humidity, and pregnancy outcomes remains limited in South America. We therefore investigated short-term associations between daily ambient temperature and preterm birth across the five Brazilian regions from 2003 to 2023 and assessed whether relative humidity modified these associations. We used regional time-series models combining generalized additive models with distributed lag non-linear models.

METHODS

The study covered the entire Brazilian territory, comprising 5,570 municipalities distributed across 26 states and the Federal District. These 27 Federative Units (FU) are grouped into five major geographic regions: North, Northeast, Midwest, Southeast, and South (Figure S1).

Health data

We obtained individual live birth records from Brazil's Live Birth Information System (SINASC/DATASUS) for January 2003 through December 2023 (12). We included singleton live births with no reported congenital anomaly and with complete, plausible information on gestational age, mode of delivery, birth weight, maternal age, maternal municipality of residence and municipality of birth. We imposed no restrictions on maternal age or mode of delivery. We further restricted the analysis to births for which the municipality of occurrence matched the mother's municipality of residence, thereby reducing short-term exposure misclassification around delivery.

The World Health Organization defines a preterm birth as a baby born alive before 37 completed weeks of pregnancy. Based on gestational age, preterm births are categorized as extremely preterm (born at less than 28 weeks), very preterm (born at 28 to less than 32 weeks), and moderate to late preterm (born at 32 to less than 37 weeks) (6). Because extremely preterm births are often associated with intrauterine infection and congenital anomalies, we removed these records from our analyses and retained only those for very preterm and moderate to late preterm births (13).

After applying the aforementioned eligibility criteria, individual records were aggregated by date of birth and federative unit (FU), generating daily counts of eligible total births and preterm births. The resulting state specific series were retained within five regional analytical datasets. They were not collapsed into a single regional series, each regional model jointly analyzed all federative unit day observations for the states in that region.

Environmental data

We obtained daily municipal climate estimates from the publicly available dataset "Zonal statistics datasets of climate indicators for Brazilian municipalities" (14). The dataset is derived from ERA5-Land reanalysis, which combines model output with observations to provide a spatially and temporally consistent long-term record (15). Daily mean air temperature (°C) was the main exposure, and daily mean relative humidity (%) derived from dew-point temperature was included as a covariate and effect modifier.

To match the resolution of the health outcomes, municipal climate estimates were aggregated to a daylily FU level using the arithmetic mean of municipal values. These environmental estimates were then merged with the corresponding daily birth counts by FU and date.

Statistical analyses

The analytical unit was the FU day. Separate models were fitted for the North, Northeast, Midwest, Southeast, and South regions. Within each regional model, observations from all FUs in that region were analyzed jointly. We employed a time series regression using a Generalized Additive Models (GAMs) within a Distributed Lag Non-Linear Modeling (DLNM) framework to analyze the association between daily temperature exposure and preterm birth rates in each of five Brazilian regions. This approach allowed us to capture both nonlinear exposure response relationships and delayed effects across a specified lag period (16). These approaches are widely used in this type of analyses, hence chosen for this work. (17).

The response variables for each model were assumed to follow a negative binomial distribution, chosen to account for potential overdispersion in the count data for preterm births y_{mt} Let:

$$y_{ft} \mid \mu_{ft}, \kappa \sim NegBin(\mu_{ft}, \kappa)$$

where y_{ft} represents the number of preterm births in a Federation Unit *f* on day *t*, μ_{ft} is the expected number of cases. and *Kappa* (*κ*) is the dispersion parameter, which adjusts the variance to account for overdispersion.

To assess the exposure-lag-response association between temperatures and preterm births, we used a Distributed Lag Non-Linear Model (DLNM), considering a lag period ranging from zero to seven days prior to birth. For this we defined a crossbasis for temperature with a nom linear function for the exposure response relationship using a natural spline with 3 degrees of freedom, based on the assumption that the risk of preterm birth may behave nom linearly as temperature vary. For the lag response association, we also used a natural spline, but, with 2 degrees of freedom to avoid a very wiggly relationship in a such short lag spam.

We also added as co-variables, a penalized smooth function of continuous calendar time s(time) to control for broad temporal pattern, we also included the day of the week as a categorical variable to control for to weekly variations (DOW), a smooth term for relative humidity s($humidity$) and a categorical variable indicating each FU in the region.

The final model specification for each Brazilian Region was:

$$\log(E\left[y_{ft}\right] = \beta 0 + CB\left(temp_{ft}\right) + s\left(time_{ft}, K = 30\right) + DOW_{ft} + s\left(humidity_{ft},\ k = 5\right) + FU_{ft} + Log(N_{ft})$$

Where: Y_{ft} is the daily count of preterm births at day *t* and FU *f*. $\mathrm{CB}\left(\mathrm{temp}_{ft}\right)$ is the crossbasis matrix for temperature exposure. $s(\mathrm{Time}_{ft}.\, k=30)$ is a penalized smooth function of continuous calendar time with a maximum basis dimension of 30. DOW_{ft} is day of the week as a categorical variable. FU_{ft} represents Federative Unit as a fixed effect factor to account for baseline differences between states within the same region. $s(\mathrm{Humidity}_{ft}.\, k=5)$ is a smooth function of relative humidity with a maximum basis dimension of 5 and $\log\left(N_t\right)$ is the offset term (logarithm of total daily births).

The temperature cross-basis was grouped by Federative Unit, preventing lagged exposure histories from carrying over between state specific time series. We centered our the predictions at the mean temperature of each region. (18).

To assess whether relative humidity modified the temperature preterm birth association, we extended the final model using a varying coefficient DLNM parameterization. Let $CB\left(temp_{ft}\right)$ denote the crossbasis matrix for temperature and $humidity_{ft}$ the daily mean relative humidity for Federative Unit f on day t. Interaction terms were constructed by multiplying the temperature crossbasis by relative humidity centered at selected values of its region-specific distribution. For a selected percentile q. the interaction term was defined as $CB\left(temp_{ft}\right)$ × ($humidity_{ft} - \ humidity_{ft_q}$). where $humidity_{ft_q}$ corresponded to the regional 5th, or 95th percentile of relative humidity. Relative humidity was therefore retained as a continuous variable, and these terms did not represent binary indicators of dry or humid days.

$$UR.\,Ind_{ft} = CB\left(temp_{ft}\right)\ \mathrm{x}\, humidity_{ft} - \ humidity_{ft_q}$$

Under this parameterization, the coefficients of the main temperature crossbasis represent the exposure lag response association when relative humidity is equal to the selected centering value, because the interaction term equals zero at that point. Models centered at the 5th, and 95th percentiles are algebraically equivalent reparameterizations of the same continuous interaction model and therefore produce identical fitted values and model-performance statistics. The alternative parameterizations were used to derive temperature preterm birth curves directly at low, and high relative humidity levels.

The final model specification for Brazilian Region with the interaction term was:

$$\log(E\left[y_{ft}\right] = \ \beta\, 0 + CB\left(temp_{ft}\right) + s\left(time_{ft}.\ K=30\right) + DOW_{ft} + \ FU_{ft} + s\left(humidity_{ft}.\ k=5\right) + Log(N_{ft}) \ + \ UR.\,Ind_{ft}$$

Model development proceeded sequentially, beginning with the temperature crossbasis and then adding the temporal smooth, day of the week, relative humidity and Federative Unit fixed effects. The flexibility of the temporal adjustment was examined using basis dimensions k = 3, 6, 15 and 30. Candidate models were assessed jointly using the Akaike Information Criterion (AIC), explained deviance, Pearson dispersion and the stability of the exposure response curves. Lower AIC, greater explained deviance, dispersion values close to one, stable temperature estimates, and the methodological relevance of the covariates supported the final specification. Detailed results are provided in Supplementary Table S1 and Figures S4 - S8.

From the fitted DLNM. we estimated the number of preterm births attributable to non optimal temperatures using the framework proposed by Gasparrini and colleagues (18). We further decomposed this burden into components due to cold and heat by summing contributions for days with mean temperature below the 5th percentile (cold) and above the 95th percentile (heat) of the temperature distribution. Empirical 95% confidence intervals were obtained using Monte Carlo simulation (with 5000 draws), as implemented in the *attrdl* function of the dlnm package in R.

All analyses were carried out in the R environment (version 4.0) using the mgcv package for Generalized Additive Models and the dlnm package for Distributed Lag Non-linear Models.

RESULTS

A summary of total births and preterm births between 2003 and 2023 in Brazil is available in Table 1. A total of 39,815,229 eligible singleton live births were included in the analysis, of which 3,126,433 were preterm, corresponding to 7.85% of all included births (78.5 per 1,000 live births). The North had the highest proportion of preterm births (407,350 of 4,915,861; 8.29%), followed by the Southeast (1,295,169 of 15,908,613; 8.14%), the Midwest (268,132 of 3,437,826; 7.80%), the South (408,467 of 5,391,913; 7.58%), and the Northeast (747,315 of 10,161,016; 7.35%). For Brazil as a whole, daily mean temperature was 24°C, ranging from 4°C to 32°C. The North and Northeast were the warmest regions, with mean temperatures of approximately 26°C, whereas the South had the lowest mean temperature (19°C) and the greatest variability (SD: 4°C) (Table 1).

Overall and lagged effect

Estimates of the overall temperature and preterm birth associations across Brazilian regions are shown in Fig. 1. In the warmer regions (North, Northeast, and Midwest), the exposure response curves showed higher risks at moderate temperatures, with a reduction in relative risk toward the tails of the temperature distributions.

In the North, an inverted U-shaped pattern was observed. Risk increased at temperatures slightly below the regional mean (25.6°C), peaked at 24°C (RR: 1.07; 95% CI: 1.06–1.08). and attenuated toward both tails of the distribution. In the Northeast. a modest increase in risk was observed at temperatures above the regional mean (25.5°C). peaking at 27°C (RR: 1.03; CI: 1.03–1.04), with estimates losing statistical significance above 28°C. In the Midwest, a similar but weaker pattern to the North was observed, with no significant risk increase captured in our final model.

In the Southeast and South, which present wider temperature ranges, U-shaped associations were observed, with increasing risks at both high and low temperatures relative to the regional mean (21.9°C and 19.4°C, respectively). Heat related risks peaked at 32°C in the Southeast (RR: 1.13; CI: 1.07–1.18) and

at 31°C in the South (RR: 1.24; CI: 1.17–1.32). Cold related risks also increased, peaking at 10°C in the Southeast (RR: 1.14; CI: 1.09–1.21) and at 3°C in the South (RR: 1.16; 95% CI: 1.10–1.22).

Lag specific effects are shown in Fig. 2, non-cumulative relative risks estimate at lags 0 and 7. Overall. North and Northeast. exhibited more pronounced immediate effects (lag 0), with risk estimates being largely null by lag 7, suggesting predominantly short-term responses in these regions. In contrast, the Southeast and South showed clearer increases at lag 7. particularly under higher temperatures, indicating a more delayed effect in these regions.

Preterm births attributable to temperature

Table 2 presents the estimated number of preterm births attributable to non-optimal temperature overall and, where supported by the regional exposure response curve, to extreme cold and heat. The largest absolute attributable burdens were observed in the Southeast and South, with 18.520 (95% CI: 16.500–20.469) and 9.892 (95% CI: 8.412–11.117) cases, respectively. These estimates corresponded to 1.43% of all preterm births in the Southeast and 2.42% in the South. In the North. 5.940 cases (95% CI: 4.898–6.811) were attributable to temperature, representing 1.46% of preterm births, whereas in the Northeast the corresponding estimate was 4.057 cases (95% CI: 2.546–5.330), or 0.54%.

Attributable burdens due to cold and heat were estimated only for the Southeast and South, where the U-shaped associations supported a meaningful separation of the lower and upper tails of the temperature distribution. In the Southeast. 738 preterm births were attributable to cold (95% CI: 20–1.337) and 4.850 to heat (95% CI: 4.030–5.545), corresponding to 0.06% and 0.37% of all preterm births, respectively. In the South. 890 cases were attributable to cold (95% CI: 534–1.181) and 2.348 to heat (95% CI: 1.974–2.661), corresponding to 0.22% and 0.57%, respectively.

Overall effects evaluated at low and high humidity

Figure 3 shows the overall cumulative temperature preterm birth associations evaluated at the region specific 5th and 95th percentiles of relative humidity. The direction and magnitude of effect modification differed across regions. In the North, the exposure response curves at low and high humidity were broadly similar across most of the temperature range, suggesting limited effect modification. In the Northeast, lower humidity was associated with a more pronounced increase in risk at lower temperatures, with a peak at 19°C (RR: 1.22; 95% CI: 1.09–1.35), whereas the corresponding estimates at high humidity were lower.

In the Midwest, temperature-related risks were more evident when the association was evaluated at low humidity. The Southeast showed the clearest contrast between humidity levels. At 11°C, the RR was 1.18 (95% CI: 1.07–1.32) at high humidity and 1.01 (95% CI: 0.93–1.09) at low humidity. At 31°C, the corresponding RRs were 1.20 (95% CI: 1.10–1.30) and 1.15 (95% CI: 1.09–1.21). respectively. In the South, the curves were similar at higher temperatures, whereas cold-related risk was greater under low humidity, peaking at 4°C (RR: 1.20; 95% CI: 1.06–1.36).

Preterm births attributable to temperature under low and high humidity

Table 3 presents the estimated number of preterm births attributable to temperature at the region-specific 5th and 95th percentiles of relative humidity. In the North, the estimated burden was slightly higher at high humidity (5.402; 95% CI: 3.817–6.664; 1.33% of preterm births) than at low humidity (4.440; 95% CI: 1.758–6.559; 1.09%). In the Northeast, the burden was modestly higher at low humidity (4.740; 95% CI: 2.613–6.455; 0.63%) than at high humidity (4.330; 95% CI: 3.127–5.332; 0.58%). In the Midwest, an attributable burden was identified only at low humidity (1.617; 95% CI: 1.181–1.984; 0.60%).

The largest contrast occurred in the Southeast, where 6.198 preterm births (95% CI: 3.330–8.666; 0.48%) were attributable to temperature at low humidity, compared with 22.066 (95% CI: 16.018–27.002; 1.70%) at high humidity. In the South, attributable counts were somewhat higher at low humidity (10.461; 95% CI: 7.175–13.272; 2.56%) than at high humidity (9.069; 95% CI: 6.857–10.852; 2.22%). These results reinforce that the modifying role of humidity was region specific, high humidity was most influential in the Southeast, while low humidity was more relevant in the Northeast, Midwest, and for cold-related risks in the South.

DISCUSSION

In this nationwide analysis we investigate de short-term effects of temperature on preterm births and how humidity might affect these impacts over all five Brazilian regions.

We observed that in warm regions (North, Northeast), where thermal variability was narrower, risk increases at moderately non-optimal temperatures closer to the regional mean, with predominantly immediate responses. Although much of the literature emphasizes extreme heat or cold, other studies have also documented elevated preterm birth risks under moderate temperature conditions (17, 19, 20). In Nepal. Kc et al. found that exposure at the 75th centile temperature (28°C) was associated with a higher, risk of preterm birth (RR 1.29; 95% CI 1.09–1.54) compared with the median temperature (24.1°C) (21). Evidence of effects outside extremes is also reported in Xuzhou (China), where exposure to moderate cold (25th percentile) was associated with increased preterm birth risk relative to the median (22). More recently Iñiguez and colleagues (2026) evaluating only Brazil's capitals, also observed effects of temperature on preterm births mainly under moderate temperature (23).

In the Southeast and South, we observed a U-shape risk curve, patterns consistent with the broader epidemiological literature indicating that non optimal temperatures extremes, especially high temperatures and heat waves, can act as an acute trigger for birth. Lakhoo et al (2) identified in their review, a 1.26 (95% CI = 1.08–1.47; n = 10) increase odds of preterm birth during heat waves. Darrow et al. (13) found in USA higher daily rates of preterm birth following

heat waves, after 4 consecutive days of mean temperatures exceeding the local 95th percentile. the rate ratio for preterm birth was 1.02 (95% CI. 1.00–1.03). Also, in USA in a multi-city sample, Sun et al. (9) observed a 2% increased PTB risk with extreme heat in the prior 4 days.

Evidence for acute cold effects close to delivery was also found in China (24). Exposure to extreme cold events during the week before delivery was associated with increased PTB odds, specifically, weeks with higher number of days with daily mean temperature below the 5th percentile (OR = 1.07; 95% CI: 1.04–1.10) and below the 10th percentile (OR = 1.06; 95% CI: 1.04–1.09) (25). In another Chinese study with 6.850 pregnant women (4.4% PTB), using mild temperature (10th − 90th percentile) as the reference, extreme cold (< 10th percentile) was associated with increased risk when assessed over the 4 weeks preceding delivery (RR = 2.45; 95% CI: 1.11–5.40) and across the entire pregnancy (RR = 3.85; 95% CI: 1.56–9.53) (26).

However, cold effects are not universally observed and may vary by climate, exposure definition, and population adaptation (17). In a large U.S. analysis, Sun et al. (9) reported a monotonic association between ambient temperature and preterm birth, with extreme heat associated with a higher risk over the subsequent four days (RR = 1.025; 95% CI: 1.015–1.036) relative to the county-specific median temperature, whereas extreme cold was associated with a slightly lower risk (RR = 0.985; 95% CI: 0.976–0.993).

Our findings highlight not only the overall temperature and preterm birth (PTB) exposure–response curves but also their lag structure across Brazilian regions. In the North, and Northeast. the predominance of immediate responses (lag 0) is consistent with studies reporting elevated PTB risk outside extreme ranges (17, 20, 22). Conversely, the increases observed toward lag 7 in the Southeast and South may reflect more persistent multi day exposures and are consistent with evidence that heatwave and extreme heat impacts can extend over several days following exposure (2, 9, 13). While cold related vulnerability may also manifest within short but not necessarily same day windows (25, 26).

Regional differences in acclimatization and in the capacity to mitigate exposure (e.g., housing characteristics, access to cooling/heating and health care coverage) may further shift the apparent lag structure, with more constrained regions despite the narrower thermal variability showing more immediate responses and more resourced regions with broader thermal variability showing effects distributed across several days.

An important finding of this study was that relative humidity modified the temperature preterm birth association, although the direction and magnitude of this modification varied across regions. The Southeast showed the clearest amplification under high humidity at both lower and higher temperatures, this pattern is biologically plausible because high humidity impairs evaporative cooling and may increase physiological heat strain at a given air temperature [(10)].

Evidence supporting joint temperature and humidity effects on preterm birth also comes from a large cohort study in China, Wu et al. [(11)] showed that the temperature preterm relationship differed by pregnancy stage (U-shaped early in pregnancy and J-shaped near delivery) and that, close to delivery, high temperature and high humidity were risk factors, whereas low humidity tended to be protective. The strongest heat effects occurred 4 weeks before delivery, with Hazard Ratio of 1.417 (P95) and 1.627 (P99), and high humidity effects also peaked in this window (HR 1.257 for P95; 1.313 for P99).

In the Northeast and Midwest, stronger temperature related risks were observed when the association was evaluated at low humidity. Hot and dry conditions may increase sweat loss and dehydration, potentially contributing to earlier labor among susceptible women, while regional differences in climate, housing, behavior and acclimatization may influence the apparent interaction [(10)].

Taken together, these findings indicate that the relevant compound exposure is not restricted to hot humid conditions. Depending on the regional climate, temperature-related risks may be intensified by high humidity, low humidity or specific combinations such as cold and dry conditions.

Public health monitoring should therefore use region specific temperature humidity profiles rather than assuming a single direction of modification for the entire country. Interventions aimed at reducing thermal strain during pregnancy such as improving access to cooling, ventilation, hydration, and targeted prenatal guidance during high-risk periods are extremely important and will be most effective when tailored to local climate patterns and vulnerability profiles.

Some limitations should be acknowledged, alongside the strengths of this study design. First, we relied on routinely collected vital statistics and region level time-series approaches. While these methods are widely used and well suited for evaluating short-term associations at the population level, they can be affected by exposure misclassification when gridded climate estimates represent municipal averages rather than individual or indoor exposures, and by residual confounding from time-varying factors that are difficult to measure comprehensively. On the other hand, modeled gridded datasets can provide consistent long-term temporal coverage and broad spatial continuity, which are particularly valuable for nationwide time-series analyses and long study periods where sparse, localized weather stations may not offer complete or comparable coverage across regions and years.

Second, results may be sensitive to modeling decisions, including spline flexibility, lag specification, and the choice of centering temperature. However, these choices are standard in the literature and can be evaluated transparently through sensitivity analyses. Third, humidity was represented using fixed percentile scenarios, which is a practical way to illustrate potential effect modification but may not fully capture day to day joint temperature/humidity distributions or indoor microclimates.

Overall, the main strength of this approach is its broad coverage over large populations and long periods, providing high statistical power and enabling consistent regional comparisons that would be difficult to achieve with individual-level cohort designs.

CONCLUSION

This nationwide time-series study provides evidence that short term associations between ambient temperature and preterm birth differed across Brazilian regions in exposure–response shape, lag pattern, and attributable burden.

The North and Northeast showed more immediate associations near moderately non-optimal temperatures, whereas the Southeast and South showed U-shaped cumulative curves and more delayed effects. Relative humidity modified these associations heterogeneously. High humidity produced the clearest amplification in the Southeast, whereas low humidity was more influential in the Northeast and Midwest and intensified cold related risk in the South. These findings support the development of region specific temperature humidity indicators for maternal health surveillance, early-warning systems, and climate-adaptation planning.

These findings carry significant implications. They affirm that rising temperatures and changing humidity patterns due to climate change pose a tangible threat to maternal and neonatal health in Brazil. Public health adaptation strategies, including early warning systems and targeted advice for pregnant women, must move beyond a one size fits all approach. Effective intervention will require region specific risk assessments that account for local climate profiles and the compound stress of temperature and humidity.

DECLARATIONS

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

The study used publicly available, deidentified secondary data and involved no direct contact with participants or access to personally identifiable information. Thus, ethics committee approval and individual informed consent were not required.

CONSENT FOR PUBLICATION

All authors have read and approved the submitted version of the paper and agree to be accountable for their respective contributions.

COMPETING INTERESTS

Authors declare to have no conflicts of interest, as defined by BMC, nor any other interests that could be perceived as capable of influencing the results and/or discussion of this article.

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AVAILABILITY OF DATA AND MATERIALS

The datasets analyzed during the current study are available from public repositories. The derived analytical dataset and R code used in the present study are available from the corresponding author upon reasonable request.

Deidentified live birth records can be obtained from the Brazilian Live Birth Information System (Sistema de Informações sobre Nascidos Vivos - SINASC), maintained by the Brazilian Ministry of Health through DATASUS. Thise microdata are freely available from the DATASUS portal at: “https://datasus.saude.gov.br/nascidos-vivos-desde-1994”.

Daily municipality level estimates of 2-m air temperature and 2-m dew-point temperature derived from the Copernicus ERA5-Land reanalysis are freely available from the Zenodo repositories maintained by Saldanha et al. (2024; https://doi.org/10.1017/eds.2024.3).

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Author Contribution

LOC, LVJ, and SC contributed to conceptualization, data curation, formal analysis, methodology, and preparation of the original draft. MREK, FMRSJ, and SSH contributed to conceptualization, supervision, and review and editing of the manuscript. SSH was responsible for funding acquisition. All authors read and approved the final manuscript.

Data Availability

Availability of dataThe datasets analyzed during the current study are available from public repositories. Deidentified live birth records can be obtained from the Brazilian Live Birth Information System (Sistema de Informações sobre Nascidos Vivos - SINASC), maintained by the Brazilian Ministry of Health through DATASUS. Thise microdata are freely available from the DATASUS portal at: “https://datasus.saude.gov.br/nascidos-vivos-desde-1994”.Daily municipality level estimates of 2-m air temperature and 2-m dew-point temperature derived from the Copernicus ERA5-Land reanalysis are freely available from the

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TABLES

Table 1
Descriptive statistics on births, preterm births, temperature and humidity in Brazil and its regions.

Regions	Total Births	Preterm Births n (%)	Temperature Min.	Temperature Mean	Temperature Max.	Temperature - Sd	Humidity Min.	Humidity Mean	Humidity Max.	Humidity - Sd
Brazil	39,815,229	3,126,433 (7.85)	4	24	32	3	19	72	99	13
North	4,915,861	407,350 (8.29)	16	26	32	2	28	79	99	13
Northeast	10,161,016	747,315 (7.35)	19	26	32	2	27	68	96	11
Midwest	3,437,826	268,132 (7.80)	9	24	32	3	19	66	99	16
Southeast	15,908,613	1,295,169 (8.14)	10	22	31	3	31	74	96	10
South	5,391,913	408,467 (7.58)	4	19	30	4	37	77	98	9

Source: Elaborated by the authors with data from: Live birth Information System DataSUS available at: < https://datasus.saude.gov.br/nascidos-vivos-desde-1994 >; Saldanha *et al.*, 2024.

Note

Preterm birth proportion (%) was calculated as the number of preterm births divided by the total number of live births, multiplied by 100.

Table 2
Preterm births attributable to temperature by Brazilian region.

Region	Preterm Births	Preterm Birth Attributable to temperatures	Preterm Birth Attributable to cold	Preterm Birth Attributable to Heat
North	407,350	5,940 (4,898–6,811)	-	-
Northeast	747,315	4,057 (2,546–5,330)	-	-
Midwest	268,132	-	-	-
Southeast	1,295,169	18,520 (16,500–20,469)	738 (20–1,337)	4,850 (4,030–5,545)
South	408,467	9,892 (8,412–11,117)	890 (534–1,181)	2,348 (1,974–2,661)

Source: Elaborated by the authors with data from: Live birth Information System DataSUS available at: < https://datasus.saude.gov.br/nascidos-vivos-desde-1994 >; Saldanha *et al.*, 2024.

Note

Cold and heat were defined as daily mean temperatures below the region-specific 5th percentile and above the 95th percentile, respectively.

Table 3
Preterm births attributable to temperature at low and high relative humidity levels across Brazilian regions.

Region	Preterm Births	Preterm Birth Attributable to Temperature at Low Humidity	Preterm Birth Attributable to Temperature at High Humidity
North	407,350	4,440 (1,758–6,559)	5,402 (3,817–6,664)
Northeast	747,315	4,740 (2,613–6,455)	4,330 (3,127–5,332)
Midwest	268,132	1,617 (1,181–1,984)	-
Southeast	1,295,169	6,198 (3,330–8,666)	22,066 (16,018–27,002)
South	408,467	10,461 (7,175–13,272)	9,069 (6,857–10,852)

Source: Elaborated by the authors with data from: Live birth Information System DataSUS available at: < https://datasus.saude.gov.br/nascidos-vivos-desde-1994 >; Saldanha *et al.*, 2024.

Figures

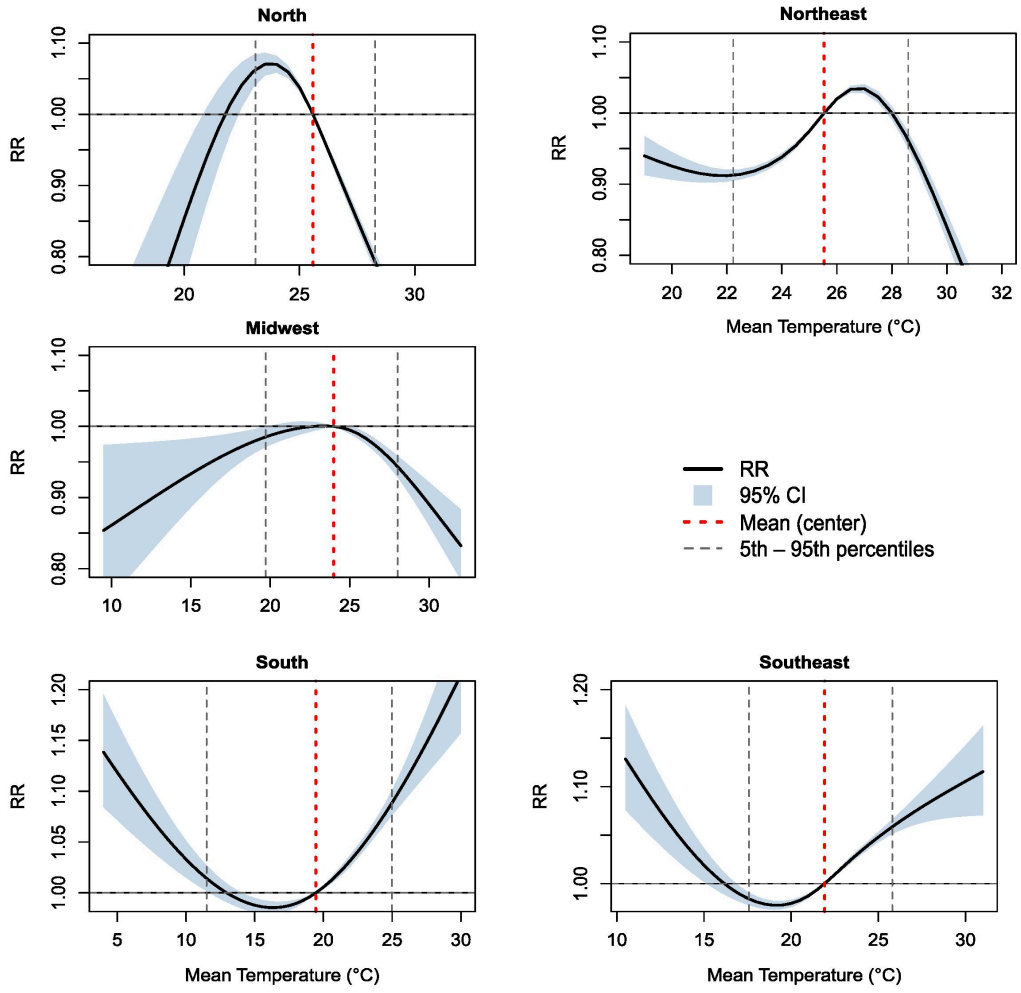


Figure 1

Overall effects of temperature on preterm births across Brazilian regions.

Source: Elaborated by the authors with data from: Live birth Information System DataSUS available at: < https://datasus.saude.gov.br/nascidos-vivos-desde-1994 >; Saldanha et al., 2024.

Figure 2A. Lagged effects of temperature on preterm births in Brazilian regions, North and Northeast.

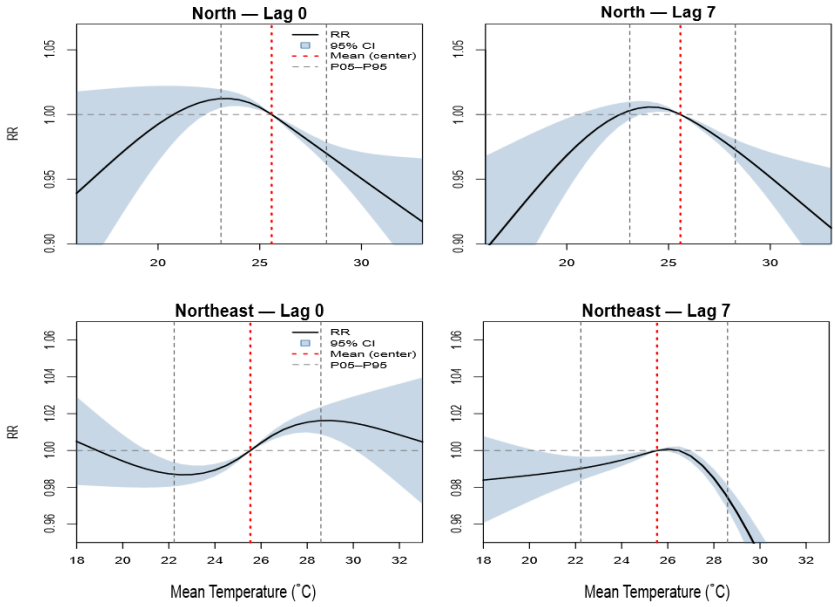


Figure 2B. Lagged effects of temperature on preterm births in Brazilian regions, Southeast and South.

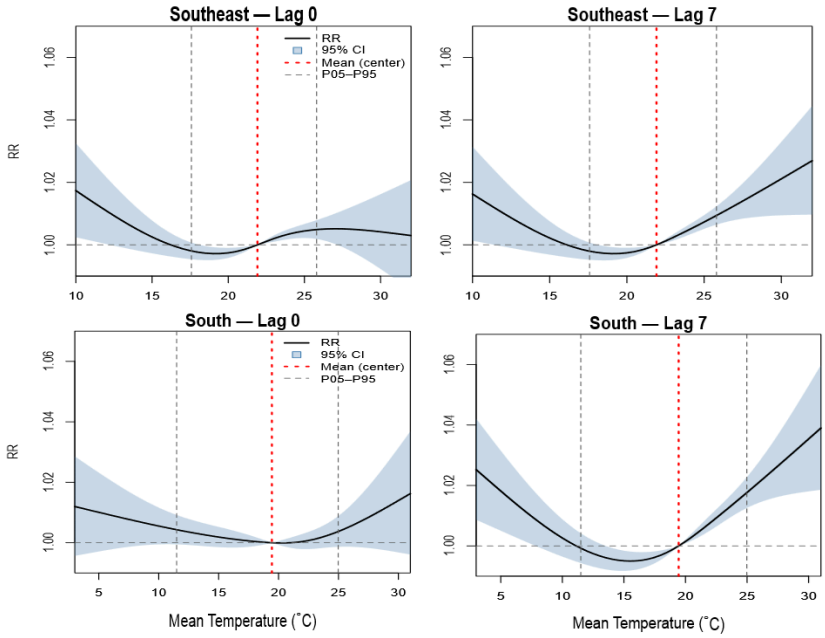


Figure 2

Source: Elaborated by the authors with data from: Live birth Information System DataSUS available at: < https://datasus.saude.gov.br/nascidos-vivos-desde-1994 >; Saldanha et al., 2024.

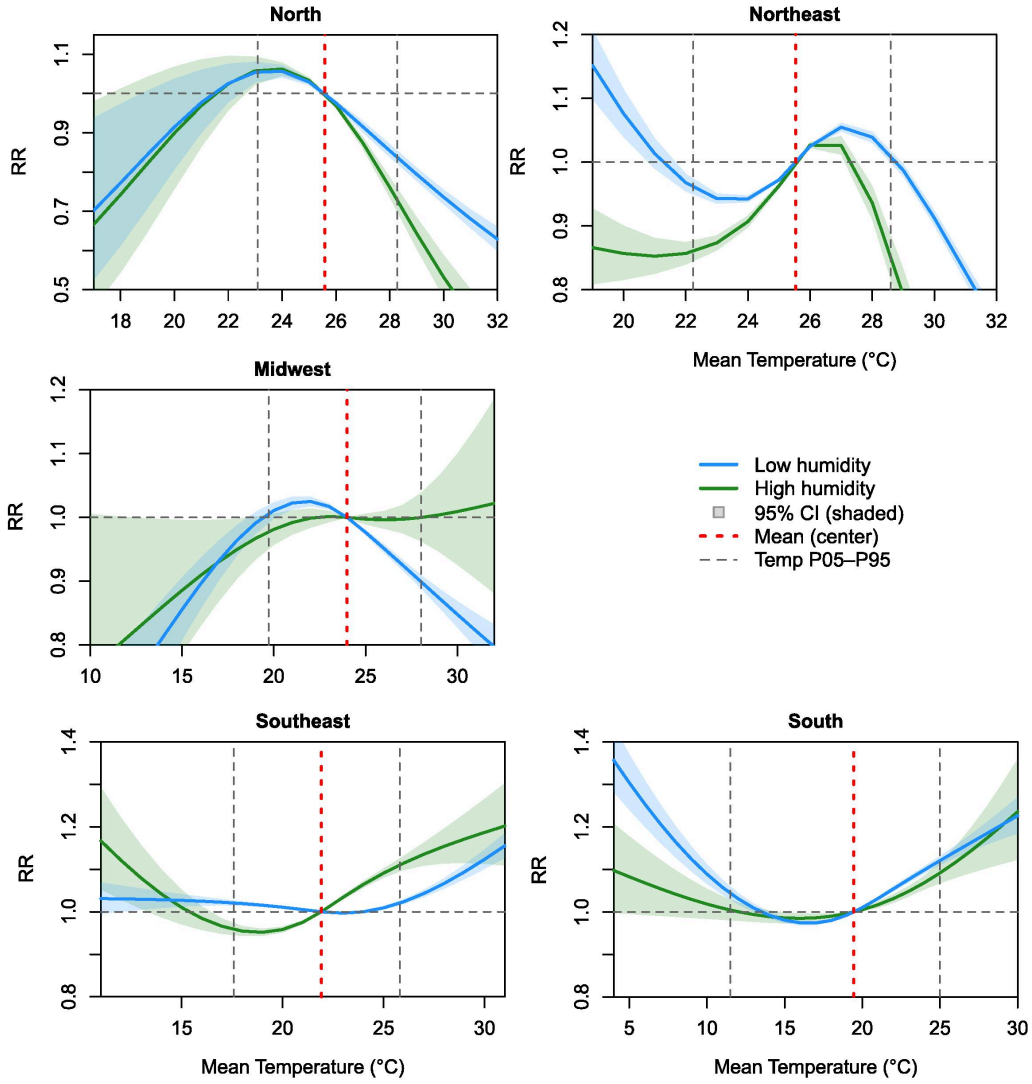


Figure 3

Overall effects of temperature on preterm birth, evaluated at low and high relative humidity levels across Brazilian regions.

Source: Elaborated by the authors with data from: Live birth Information System DataSUS available at: < https://datasus.saude.gov.br/nascidos-vivos-desde-1994 >; Saldanha et al., 2024.

Note: Curves were derived from a continuous temperature–humidity interaction model and evaluated at the region-specific 5th and 95th percentiles of daily mean relative humidity. Relative risks were centered at the regional mean temperature, and shaded areas represent 95% confidence intervals.

Supplementary Files

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- 0.4SupplementaryMaterial.docx