GeoHealth

RESEARCH ARTICLE

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Key Points:

- Health impacts of climate change should be evaluated in diverse regions
- Lower birth weight was observed for exposure to extreme temperatures
- Exposure to warmer mean temperatures related to higher birthweight

Supporting Information:

Supporting Information may be found in the online version of this article.

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From the Atacama to Patagonia: Understanding the Effects of Extreme Temperatures on Birth Weight Across Climate Regions in Chile

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Abstract Exposure to extreme temperatures during pregnancy can have adverse effects on birth weight, however, there is little evidence from Latin America. We used birth records in 2011–2020. Mean, minimum, and maximum daily temperatures were obtained from meteorological stations in 26 municipalities representing different climatic zones of Chile. We explored different windows of exposure (entire pregnancy, trimester, and gestational week) and calculated temperature percentiles based on climatic zone for each window. The 50th percentile served as the reference for comparison. General additive models and distributed lag nonlinear models (DLNM) adjusted for month and year of last menstrual cycle, maternal and paternal: age, education, and employment. Exposure to cold mean temperatures (≤10th percentile) in the total pregnancy period and each trimester was associated with a lower mean birth weight (−28.7 g for the total period, −45.9, −36.1, and −83.4 g for trimester 1, 2, and 3, respectively), whereas exposure to warm mean temperatures was associated with higher birth weight (21.3 g for >90th percentile). For extreme temperatures, exposure to both cold (≤10th percentile for minimum) and hot (>90th percentile for maximum) in the total pregnancy period related to lower birth weight: −48.7 g (95% CI −49.7; −47.6) and −17.48 g (95% CI −18.5; −16.4), respectively, with similar effects by trimester. In DLNM, consistent effects were observed later in pregnancy. Lower birthweight was observed with exposure to extreme cold and heat, while warmer mean temperatures were associated with higher birthweight. Findings from Chile underscore regional impacts of climate change on child health.

Plain Language Summary Being exposed to very cold or very hot temperatures during pregnancy can affect a baby's birth weight. However, there is little evidence from Latin America. We studied 10 years of birth records (2011–2020) from 26 areas across Chile with different climates. We matched each pregnancy to daily temperature data and looked at exposure during the entire pregnancy, each trimester, and each week of gestation. We have three primary findings. First, exposure to cold temperatures (especially in the coldest days) during pregnancy was linked to lower birth weight, especially in the third trimester. Second, exposure to warmer average temperatures was linked to slightly higher birth weight. Finally, extreme temperatures, both very cold and very hot, were also linked to lower birth weight. Our findings suggest that temperature extremes—both cold and hot—can affect fetal growth. The results show the importance of understanding how climate and weather affect pregnancy outcomes in different parts of the world, especially in the context of climate change.

1. Introduction

Climate change is the greatest threat to human health, in part because the health effects are many and varied (Pan American Health Organization, 2020). It is important to study potential health effects in a variety of climates because as has been well documented (Choudhary et al., 2024; Guirguis et al., 2018), place matters. Chile is an ideal place to study the health effects of climate change; its borders extend across 38° latitude, contain all 5 of the main climate groups (tropical, arid, temperate, continental, and polar), and have several major climatic subtypes (e.g., temperate dry with hot summer, temperate with no dry season, cold steppe) (Beck et al., 2018). In addition, it has 7 of the 9 high priority conditions determined by the UN Convention on Climate Change (e.g., low coastal areas, areas prone to natural disasters, drought and desertification) (Ministerio del Medio Ambiente, Gobierno de Chile, 2018; Rojas & Billi, 2024).

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Studies of the health effects of climate change have focused on differential risks among certain subgroups of the population, for example, older adults, people with underlying health conditions, and, to a lesser extent, pregnant women, the fetus, and the newborn (Ha, 2022; Zhang et al., 2017). Pregnancy is a period of extraordinary change and exposures during the fetal period have the potential to affect short- and long-term health (Barker, 2007; Heindel & Vandenberg, 2015). The perinatal period begins at 23 weeks of gestation and continues until 7 days after birth. It is considered a critical period for the future health of the mother and child. Despite significant global improvements in maternal mortality, maternal morbidity remains high. In many regions, adverse pregnancy and childbirth outcomes are either increasing or showing little progress in reducing prevalence (Blanco et al., 2022; Blencowe et al., 2012; Lopez-Jaramillo et al., 2018; Wallis et al., 2008; World Health Organization, 2018, 2019). One of the first markers of newborn health is birth weight, which summarizes aspects of maternal nutrition and prenatal care (UNICEF, 2004). Deviations in this indicator, whether due to underweight or excess, are associated with negative health effects.

In Latin America, the prevalence of low birth weight (birth weight <2,500 g) has been estimated to be between 7% and 10% (Blanco et al., 2022), while in Chile, despite a slight increase over the years (4.6% in 1991 vs. 6.3% in 2016), the prevalence is lower (DEIS, 2015). Low birth weight is attributed to up to 60% of neonatal deaths. In Chile, the mortality rate for children with low birth weight is 10 times higher than the mortality rate for children with normal weight (Aguilera et al., 2020). In addition, it is associated with later problems in the life cycle, such as childhood asthma, metabolic syndrome, type 2 diabetes, and cardiovascular diseases in adulthood (Risnes et al., 2011; UNICEF, 2004).

Evidence suggests that ambient temperature impacts birth weight, with more robust findings related to heat exposure (Basu et al., 2018; Jakpor et al., 2020; Molina & Saldarriaga, 2017; Yitshak-Sade et al., 2021; Zhang et al., 2017). While the exact biological mechanisms are unclear, animal models have demonstrated alterations in thermoregulation among pregnant females due to thermal stress, where low birth weight is hypothesized to be an adaptation mechanism (Wells, 2002). In addition, inflammatory responses to hypo- or hyperthermia have also been described, which would be involved in the reduction of uterine blood flow, affecting placental growth (Ding et al., 2023; Nyadanu et al., 2023). In terms of human evidence, one study identified a reduction of 16.7 g of birth weight for each increase of 8°C (Kloog et al., 2015). Regarding the risk of term low birth weight at term (tLBW), another study showed a 13% increase in risk for each increase of 5°C (Basu et al., 2018). A recent article focused on ambient temperatures in Latin American cities in Brazil, Chile and Mexico and found lower birth weight associated with exposure to higher temperatures overall, but when separated by country, only observed lower average birth weights for exposure to cold temperatures in Chile, with a positive trend for higher temperatures (Bakhtsiyarava et al., 2022). Although there is some evidence, additional research is needed from more diverse climatic zones.

Most previous studies have used absolute temperature to evaluate health effects; however, recent work has used temperature percentiles as a way to consider the potential of individual and population-level adaptation to temperature (Basagaña et al., 2021). This may be especially important using information from different climatic zones present within a geographic area. The average behavior and the number and intensity of extreme events can vary latitudinally, so for example, according to historical data from the Climate Risk Atlas for Chile (Ministerio del Medio Ambiente, Gobierno de Chile, 2020), the average maximum temperature varies between 22° Celsius in the extreme north of Chile (desert) and only 7° Celsius in the southern zone (cold steppe). Using this methodology, Basagaña and colleagues found a U-shape negative relationship between temperature and birth weight in Israel, with lower birth weights associated with exposure to both lower (−56 g for ≤10th vs. 41st–50th percentile) and higher temperatures (−65 g >90th vs. 41st–50th percentile) over the entire pregnancy period (Basagaña et al., 2021). Furthermore, questions remain about windows of vulnerability to the potential effects on birth weight from exposure to extreme temperatures during gestation. The same study from Israel (Basagaña et al., 2021) and another conducted in the US (Yitshak-Sade et al., 2021), found greater effects in the initial and final weeks of gestation for exposure to higher temperatures, with less consistency for colder temperatures. More study is needed to clarify these relationships, as understanding whether timing of exposure influences the magnitude of effect is helpful for elucidating potential biological mechanisms and, potentially, for the design of interventions.

The objective of the current study was to evaluate the relationship between exposure to both average and extreme temperatures (minimum and maximum) and birth weight using available data from government meteorological stations representing a variety of climatic zones and birth records available in Chile. We analyzed 330,118 term births between 2011 and 2020, explored windows of exposure (total pregnancy period, trimester, and gestational week), in attempt to increase evidence on the potential perinatal health effects of climate change in Chile.

2. Materials and Methods

We conducted a population-based cohort design using secondary information from births in Chile obtained from the Department of Statistics and Health Information (DEIS) and National Statistics Institute. In compliance with Article 29 of Law 17.374, all records remained anonymous and confidential. Records contain information from birth certificates including demographic characteristics of both parents and child. We evaluated births between 2011 and 2020 for the municipalities with available temperature date (described below). Infants born at term (≥37 weeks gestation), who had complete information on gestational age, birthweight and covariates were included in analyses (n = 330,118). To avoid fixed-cohort bias (Strand et al., 2011), we limited the sample to infants whose estimated first week of gestation was on or after 1-1-2011 and who were able to be born at term by 12-31-2020. A detailed summary of sample sizes associated with each inclusion criterion can be found in the (Figure S1 in Supporting Information S1).

Our main analyses focused on term birth weight (tBW), measured in grams (g). Additional analyses were conducted for term low birth weight (tLBW), defined as a birth weight <2,500 g among infants born ≥37 weeks. In Chile, gestational age is determined using reported date of last menstrual period and via ultrasound conducted in the first trimester in the primary care setting (Blanco et al., 2023).

2.1. Exposure Assessment

Daily temperature (mean, minimum, and maximum) from meteorological stations located in municipalities throughout Chile and maintained by the Meteorological Department of Chile (DMC for initials in Spanish) was obtained. We selected municipalities based on availability and completeness of data during the period of interest; data from a total of 26 municipalities representing different climatic zones of Chile was downloaded. Temperature sensors maintained by the DMC are installed at a height of 1.5 m, in accordance with the international standard. We note that 9 of the 27 DMC monitoring stations used are located at small regional airports that range between 4 and 18 kms from the center of the municipality. A map of municipalities represented (Figure S2 in Supporting Information S1) and the coordinates of each temperature monitoring station (Table S1 in Supporting Information S1) are shown in Supplemental Material.

The municipalities included in this study are distributed across continental Chile, an area that spans multiple climate zones. We used a spatially resolved map of Köppen-Geiger climate zones to identify the predominant climate in each municipality (Beck et al., 2018). Then, we classified municipalities into five distinctive climate zone categories: desert (Northern zone); temperate dry with hot summer (Center zone); temperate dry with warm summer (Center-south zone); temperate with no dry season (South-austral and insular zone); and cold steppe (Austral zone). Details of which municipalities and number of births for the study period in each climatic zone can be found in (Table S2 in Supporting Information S1).

Exposure was assigned as follows. First, the start and end date of each week of gestation was calculated using the date of birth and gestational age (e.g., start of week 1 = date of birth—gestational age; end of week 1 = start of week 1 + 6). Next, the average of mean, minimum, and maximum temperatures was calculated for each week of gestation using daily information by municipality. Temperature values for gestational week were then used to average by other exposure windows: entire pregnancy (1–36 weeks) and first (gestational weeks 1–12), second (gestational weeks 13–24), and third (24–36) trimester. We truncated exposure at 36 weeks to avoid bias arising from various lengths of the third trimester that are all considered term. Finally, we calculated temperature percentiles for each exposure window (entire pregnancy, trimester, and week of gestation) based on climatic zone. This approach allows for relative comparisons of exposure among pregnant individuals living in similar climatic contexts (e.g., Desert, Temperate dry-hot summer, etc). We conducted analyses for mean temperatures, comparing percentiles of low (≤10, 11–20, 21–30, and 31–40) and high (51–60, 61–70, 71–80, 81–90, and >90) mean temperatures to the 41–50th percentile for each exposure window. In addition, we analyzed exposure to extreme cold (≤10, 11–20, 21–30, and 31–40 of minimum temperatures) and hot (51–60, 61–70, 71–80, 81–90, and >90 of maximum temperatures) compared to the 41–50th percentile of minimum and maximum temperatures, respectively.

2.2. Statistical Analysis

We estimated Generalized Additive Models (GAM) for tBW (linear link function) and tLBW (logit link function), assessing the effects of our three temperature metrics (mean, minimum, and maximum) over the total pregnancy period and by trimester. All models were adjusted for covariates, including maternal and paternal age, education, employment status, and month and year of the last menstrual cycle (separate variables), to account for seasonal and time trends. We assessed intraclass correlation coefficients (ICCs) by municipality and found low within-climate zone variability, suggesting minimal differences in exposure assignment at the municipal level (Table S3 in Supporting Information S1). Thus, models did not include a fixed effect for muncipality.

We also fitted distributed lag nonlinear models (DLNM), using the dlnm *R* package version 2.4.7 (Gasparrini, 2011), to explore the effect of temperature by gestational week. Our DLNM models were built as an extension of the GAM, given that nonlinear relationships have been previously described (Chersich et al., 2020), maintaining the same covariate adjustments.

Formally, the DLNM approach is based on the construction of a *cross-basis* function that simultaneously defines the exposure-response and lag-response relationships across the pregnancy periods. $\boldsymbol{Y_t}$ represents the outcome at time $\boldsymbol{t}$ (tBW or tLBW). The model is specified as follows (Gasparrini et al., 2010):

$$g(E[Y_t]) = \alpha + \beta X_t + s_j(T_t) + \sum_{l=1}^{L} s_l(T_{t-l}) + Z_t\gamma$$

where $\boldsymbol{g}()$ is the link function (identity for linear model and logit for binary outcome), $\boldsymbol{T_t}$ represents temperature metric (mean, minimum, maximum) at time $\boldsymbol{t}$, $s_j(T_t)$ represents a smooth function of the temperature metric over time, and $\sum_{l=1}^{L} s_l(T_{t-l})$ is the lag structure up to lag $\boldsymbol{L}$, which captures the delayed effects of temperature exposure. $\boldsymbol{Z_t}$ represents a vector of covariates (infant sex, maternal and paternal age, education, employment status, month, and year of last menstrual cycle), and $\boldsymbol{\gamma}$ is the corresponding vector of coefficients. For DLNM models, we used a cross-basis function to simultaneously model the exposure-response and lag-response relationships for each temperature metric. To specify the lag-response function, we conducted sensitivity analyses comparing alternative functions (natural cubic splines and polynomials of degree 2 and 3) and varying the number of internal knots (Table S4 in Supporting Information S1). We selected natural cubic splines with 2 knots, which has been used in previous studies (Basagaña et al., 2021), based on goodness-of-fit criteria and biological plausibility. We considered a lag period ranging from 1 to 37 gestational weeks. This lag window was chosen to capture the cumulative and potentially delayed effects of temperature exposure throughout the gestational period (from week 1 to the first week considered full-term (37)).

We conducted additional analyses using a two-stage design to better understand the relationship between temperature and birthweight by climatic zone. First, we estimated models for each climatic zone and then pooled estimates using meta-analytic techniques (Sera & Gasparrini, 2022). We calculated best linear unbiased predictions (BLUPs) to adjust original estimates for each climatic zone. As this was an exploratory analysis only, we focused on term birth weight and exposures in the entire pregnancy period only. All models included the same adjustment variables as the GAM models. To assess whether observed heterogeneity was statistically significant across climate zones, we conducted a meta-regression analysis using the mixmeta package in *R*, incorporating the climatic zone as a moderator of the exposure-response estimates derived in the first stage of our two-stage DLNM framework (Sera & Gasparrini, 2022).

R code used to conduct all analyses is provided in Supporting Information S1. Our study was conducted in accordance with the Declaration of Helsinki and was reviewed and approved by the Institutional Review Board at Universidad Mayor.

3. Results

Average birth weight was 3,381.9 g (SD = 433.3), with 2.0% of births classified as tLBW. Table 1 provides additional descriptive information of the sample. During the total pregnancy period, median temperature for the sample was 14.9° and varied between 9.9 (10th percentile) and 18.4 (90th percentile) degrees. When considering

Table 1
Characteristics of Singleton Term Births in Chile: 2011–2020 (n = 330,118)

Variable	% (n)
Gestational age (eeks)[a]	38.7 (1.0)
Birth weight (g)[a]	3,381.9 (433.6)
Term low birth weight	2 (6,602)
Newborn sex, male	51 (167,247)
Maternal age	
≤20	14 (45,263)
20–29	45 (148,549)
30–39	37 (123,609)
≥40	4 (12,562)
Unknown	0.04 (135)
Maternal education	
No education	0.06 (212)
Primary	8 (26,132)
Secondary	52 (170,869)
College	40 (132,768)
Unknown	0.04 (137)
Mother employed	50 (164,124)
Paternal age	
≤20	6 (20,466)
20–29	35 (115,904)
30–39	38 (125,456)
0–49	10 (33,085)
≥50	1 (4,620)
Unknown	9 (30,587)
Paternal education	
No education	0.05 (149)
Primary	7 (23,664)
Secondary	47 (154,810)
College	37 (120,929)
Unknown	9 (30,566)
Father employed	75 (246,722)
Climatic zones	
Desert	29 (96,918)
Temperate dry, hot summer	20 (65,224)
Temperate dry, warm summer	29 (94,832)
Temperate, no dry season	17 (57,402)
Cold steppe	5 (15,742)

[a]Mean (standard deviation).

climatic zone, greater variability in exposure was observed. Median daily temperature in the desert climatic zone was 17.0 and varied between 14.6 (10th percentile) and 19.7 (90th percentile), while in the cold steppe climatic zone, the 50th, 10th and 90th percentile of mean daily temperatures were 6.5, 5.1 and 8.0, respectively. Table 2 provides summary statistics for the three exposure metrics for the entire sample and for each climatic zone during the entire pregnancy period; Figure S3 in Supporting Information S1 shows distribution of temperatures across climatic zones and Figure S4 in Supporting Information S1 provides the distribution of minimum, mean, and maximum temperatures by climatic zone and overall. Additional summary statistics (all temperature deciles) for exposure metrics during the entire pregnancy period and by trimester per climatic zone can be found in Tables S5–S7 in Supporting Information S1.

3.1. Birth Weight: Exposure in Total Pregnancy Period and by Trimester

Unadjusted plots showing the predicted estimated term birthweight related to exposure to mean, minimum, and maximum temperatures by climatic zone and overall can be seen in Figures S5, S6, and S7 in Supporting Information S1, respectively. Compared to exposure to the 41–50th percentile in the total pregnancy period, exposure to cold mean temperatures (≤10th percentile) was associated with a lower mean birth weight (−28.6, 95% CI −29.7; −27.6 g, see Table S8 in Supporting Information S1), whereas exposure to warmer temperatures (>90th percentile) was associated with a higher birth weight (21.3, 95% CI 20.2; 22.4 g, Table S8 in Supporting Information S1) see Figure 1, Panel A. For trimester of pregnancy (Figure 1, Panel B), exposure to the coldest mean temperatures (≤10th percentile) in the third trimester related to the lowest birth weight (−83.4, 95% CI −91.8; −74.9 g, see Table S9 in Supporting Information S1); estimates for each trimester were very similar for percentiles 21–30 and 31–40 compared to the reference group (Table S9 in Supporting Information S1). For warmer temperatures (>50th percentile), exposure in the first and third trimester were consistently related to higher birthweight. Estimates for the second trimester were less consistent (Figure 1, Panel B) and of smaller magnitude (−0.2 g, 95% CI −10.4; 10.0 g, for >90th percentile, see Table S9 in Supporting Information S1).

Exposure to both the coldest (≤10th percentile of minimum temperatures) and hottest (>90th percentile of maximum temperatures) temperatures on average during the entire pregnancy related to lower birth weight (Figure 1, Panel C and E): −48.6 g (95% CI −49.6; −47.6) and −17.4 g (95% CI −18.5; −16.4), respectively (see Table S8 in Supporting Information S1). In trimester-specific analysis, we observed similar patterns for extreme temperatures (Figure 1, Panel D and E). For the coldest minimum temperature (≤10th percentile), the strongest effect was observed for exposure in the third trimester (−63.0, 95% CI −71.0; −55.0), with first and second trimesters having similar magnitudes of effects (Table S10 in Supporting Information S1). For maximum temperatures, estimates were similar for each trimester <80th percentile, after which we observed slightly more pronounced effects in the first and third trimesters (Figure 1, panel F). For example, exposure to >90th percentile of maximum temperatures in the first and third trimester, compared to 41–50th percentile, related to the following reductions in birth weights: −51.1 (95% CI −59.3; −42.8) and −64.8 (−73.4; −56.2) *g*, respectively (Table S11 in Supporting Information S1).

Table 2
Summary Statistics of the Mean Temperatures in Every Climatic Zone During Research Period (2011–2020) and the Distribution in Mean Term Birthweight (tBW, g) and Term Low Birthweight (Birthweight <2,500 g, ≥37 Gestational Weeks)

				Daily mean temperature			Daily minimum temperature		Daily maximum temperature	
	N	tBW	tLBW	10th %ile	50th %ile	90th %ile	10th %ile	50th %ile	50th %ile	90th %ile
Overall	330,118	3,386.15	2%	9.9	14.9	18.4	1.5	6.2	22.3	27.0
Desert	96,918	3,352.20	2%	14.6	17.0	19.7	1.8	13.6	21.5	25.2
Temperate dry, hot summer	65,224	3,383.59	2%	13.5	16.0	18.6	4.4	6.5	26.6	29.1
Temperate dry, warm summer	94,832	3,395.25	2%	12.4	14.4	17.3	3.7	6.5	23.4	26.4
Temperate, no dry season	57,402	3,425.16	2%	8.9	10.9	14.1	0.7	2.8	18.1	20.8
Cold steppe	15,742	3,408.70	2%	5.1	6.5	8.0	−0.9	0.2	12.9	14.9

Note. Overall average temperature for mean: 14.6, min: 7.0 and max: 22.2. All temperature in degrees Celsius.

3.2. Birth Weight: Exposure by Week of Gestation

Using DLNMs, we observed a negative relationship with exposure to mean temperatures ≤10th percentile compared to the 41–50th percentile early in pregnancy (gestational weeks 1–10) and again starting at week 16 through the end of pregnancy (Figure 2, Panel A), with estimates for exposure starting in week 25 being very similar. For example, exposure in week 25 and 34 were −5.2 g (95%CI −7.0; −3.3) and −5.5 g (95%CI −7.5; −3.4). For exposure to mean temperatures >90th percentile, we observed a positive relationship for exposure throughout pregnancy, with the strongest effects early and late in pregnancy: 6.1 g (95% CI 2.8; 9.2) in week 1 and 6.2 g (95% CI 3.1; 9.3). Table S12 in Supporting Information S1 provides exact estimates for these comparisons for each week.

For extreme temperatures, we found a consistent negative effect for exposure to the coldest temperatures later in pregnancy between gestational weeks 28–37 (Figure 2, Panel C). For example, exposure to ≤10th percentile of minimum temperature, compared to the 41–50th percentile, in gestational week 28, related to −1.9 g birth weight (95% CI −3.5; −0.3, see Table S13 in Supporting Information S1). For maximum temperatures negative associations were observed for exposure to the >90th compared to the 41-50th percentile across all weeks of gestation (Figure 2, Panel D), with the strongest associations later in pregnancy beginning in gestational week 27 (week 27, −3.1 g, 95% CI −4.9; −1.2, Table S14 in Supporting Information S1) and increasing in magnitude until term (week 37, −11.0 g, 95% CI −14.4; −7.7, Table S13 in Supporting Information S1). The entire exposure-lag response for each exposure metric (mean, minimum, and maximum temperatures) can be visualized in Figure S8 in Supporting Information S1 (left panel).

3.3. Term Low Birth Weight (tLBW): Exposure in Total Pregnancy Period and by Trimester

The associations with tLBW and temperature percentiles during the gestational period showed similar results. Unadjusted plots showing the predicted probabilities of term low related to exposure to mean, minimum, and maximum temperatures by climatic zone and overall can be seen in Figures S9–S11 in Supporting Information S1. Compared to the reference group (41-50th percentile), exposure to cold mean temperatures (≤10th percentile) was associated with a higher likelihood of low birth weight (OR 1.10, 95% CI 1.08; 1.12), while exposure to warmer temperatures (>90th percentile) was linked to a decreased likelihood of low birth weight (OR 0.93, 95% CI 0.91; 0.95), see Figure 3 (Panel A) and Table S7 in Supporting Information S1. For analysis by trimester (Figure 3, Panel B), exposure to cold temperatures (≤10th percentile) during the third trimester was associated with the highest odds of tLWB (OR 1.45, 95% CI 1.25; 1.68). However, estimates for warmer temperatures (>90th percentile) in the first, second and third trimesters were less consistent and of smaller magnitude (e.g., first trimester OR 0.88, 95% CI 0.75; 1.04, second trimester OR 1.00, 95% CI 0.84; 1.18 and third trimester OR 1.03, 95% CI 0.88; 1.19, Table S8 in Supporting Information S1).

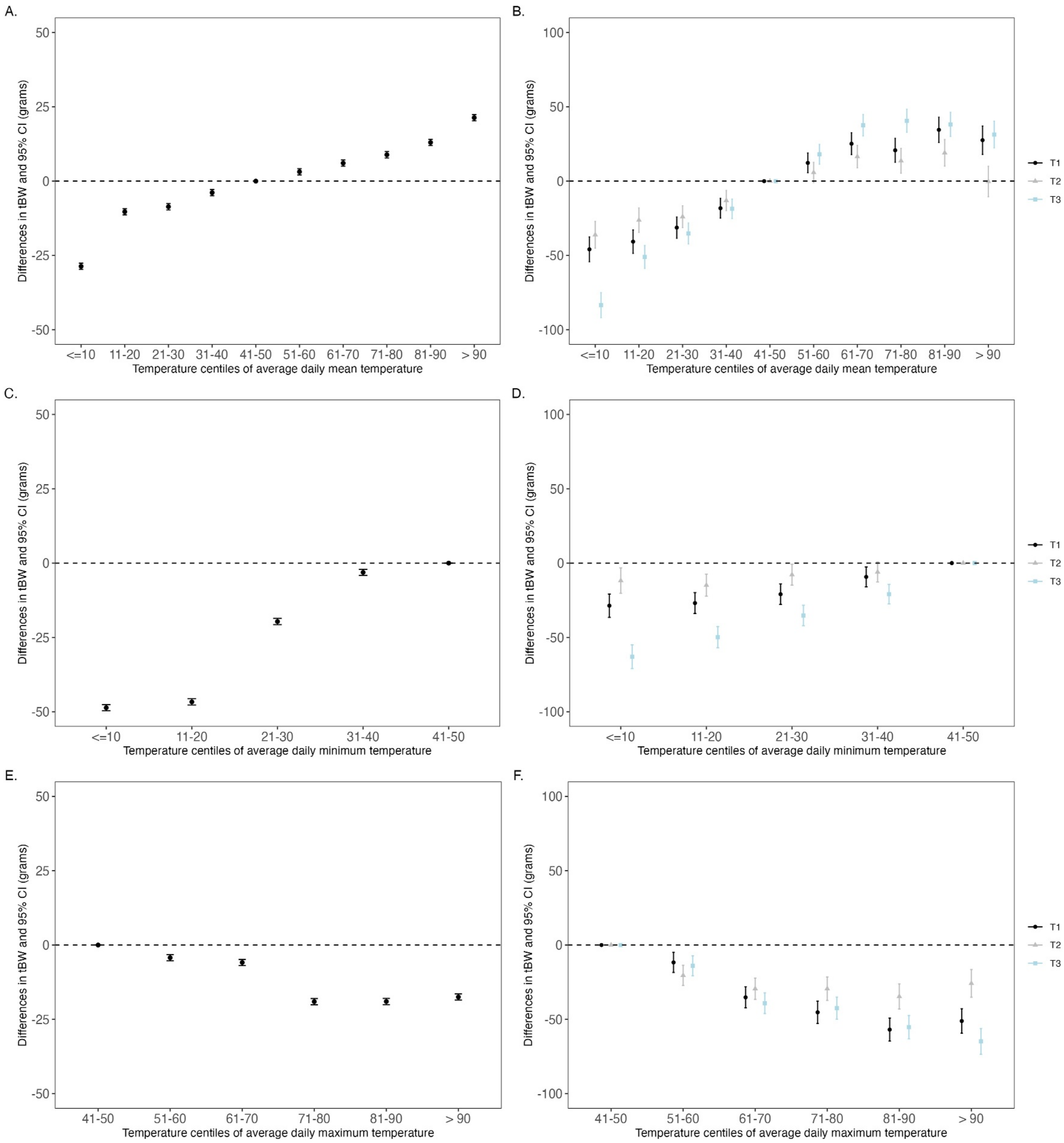

Figure 1. Estimated differences in mean term birth weight (g) and 95% confidence intervals according to climate zone-specific centiles of average daily mean, minimum and maximum temperature relative to the reference category (41st–50th centile) among singleton term live births during the entire pregnancy (panel A, C, E) and by trimester (panel B, D, F) in the period 2011–2020.

Exposure to extreme temperatures during the entire pregnancy period temperatures was associated with an increased risk of tLBW. Specifically, exposure to extremely cold temperatures (≤10th percentile of minimum temperatures) was associated with an OR of 1.26 (95% CI 1.24; 1.29), and exposure to extremely hot temperatures (>90th percentile) was associated with an OR of 1.12 (95% CI 1.09; 1.14), see Figure 3 panels C and E and Table S7 in Supporting Information S1. Results were consistent when evaluated by trimester, with the third trimester showing the strongest association for extremely cold temperatures (OR 1.49, 95% CI 1.30; 1.72, Table S9 in Supporting Information S1) and extremely hot temperatures (OR 1.58, 95% CI 1.35; 1.85, Table S10 in Supporting Information S1) (Figure 3 panels D and F).

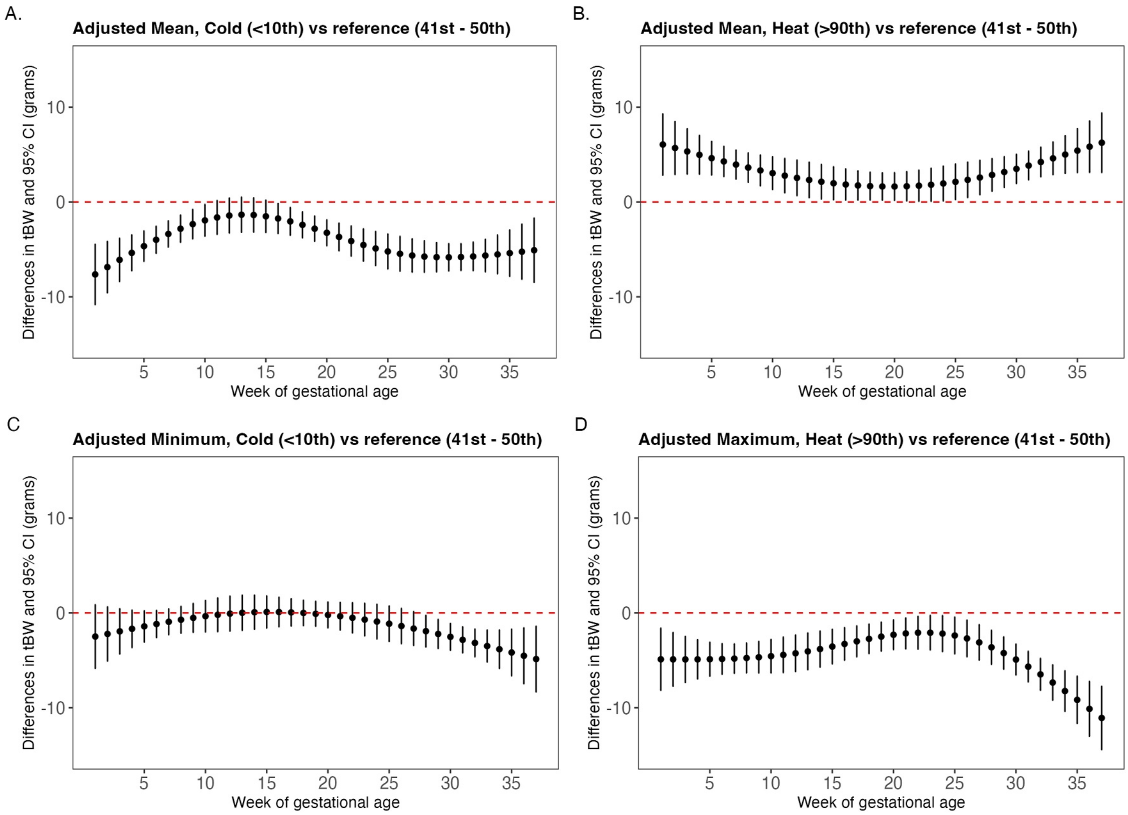

Figure 2. Estimated differences in mean term birth weight (g) and 95% confidence intervals associated with exposure to cold and hot daily mean, minimum and maximum temperatures (≤10th or >90th the percentile for each climate zone, respectively, relative to the 41st–50th centile) during each gestational age week among singleton live births in Chile during the period 2011–2020.

3.4. Term Low Birth Weight (tLBW): Exposure by Week of Gestation

The DLNMs analysis showed an inverse relationship with cold mean temperatures (≤10th percentile vs. 41-50th percentile) during early pregnancy, particularly in the first 4 weeks (Figure 4, Panel A), and between weeks 21 and 32, with similar magnitudes of effects: OR 1.06, 95% CI 1.01; 1.12 for week 1 and OR 1.04, 95% CI 1.01; 1.07 for week 28 (See Table S11 in Supporting Information S1). For hot mean temperatures (>90th percentile), no significant associations were detected (Figure 4, Panel B and Table S11 in Supporting Information S1).

For extreme temperatures, DLNMs analysis revealed that exposure to extremely cold temperatures (≤10th percentile of minimum) was associated with a non-significant slightly elevated risk of tLBW throughout the pregnancy (Figure 4, Panel C), with ORs remaining close to 1.01 for most of the gestational period (e.g., week 10: OR 1.01, 95% CI 0.98; 1.04, Table S12 in Supporting Information S1). For hot temperatures (>90th percentile of maximum), starting around week 30, a gradual increase in ORs was noted, with estimates reaching statistical significance for weeks 32–37 (Figure 4, Panel D). The highest effect observed in week 35 (OR 1.06, 95% CI 1.01; 1.11, Table S13 in Supporting Information S1), indicating a slightly higher risk of tLBW during late gestation for exposure to extreme hot temperatures (>90th percentile of maximum). Figure S8 in Supporting Information S1 (right panel) shows the entire adjusted exposure-lag response figure for tLBW.

3.5. Two-Stage Analysis

The results of our two-stage analysis, in which we analyzed the effect of exposure to average daily mean, minimum and maximum temperatures in the entire pregnancy period on tBW by climatic zone, are summarized graphically in Figure 5. Overall, lower temperatures (Panel A) were associated with reduced birth weight, particularly in desert regions (−228.1 g; 95% CI: −310.2, −146.1) and cold steppe regions (−95.8 g; 95% CI: −204.8, 13.3). Heat conditions (Panel B) were linked to greater birth weight in desert regions (350.7 g; 95% CI: 145.1, 556.4) but lower birth weight in temperate dry, hot summer regions (−265.6 g; 95% CI: −473.7, −57.5).

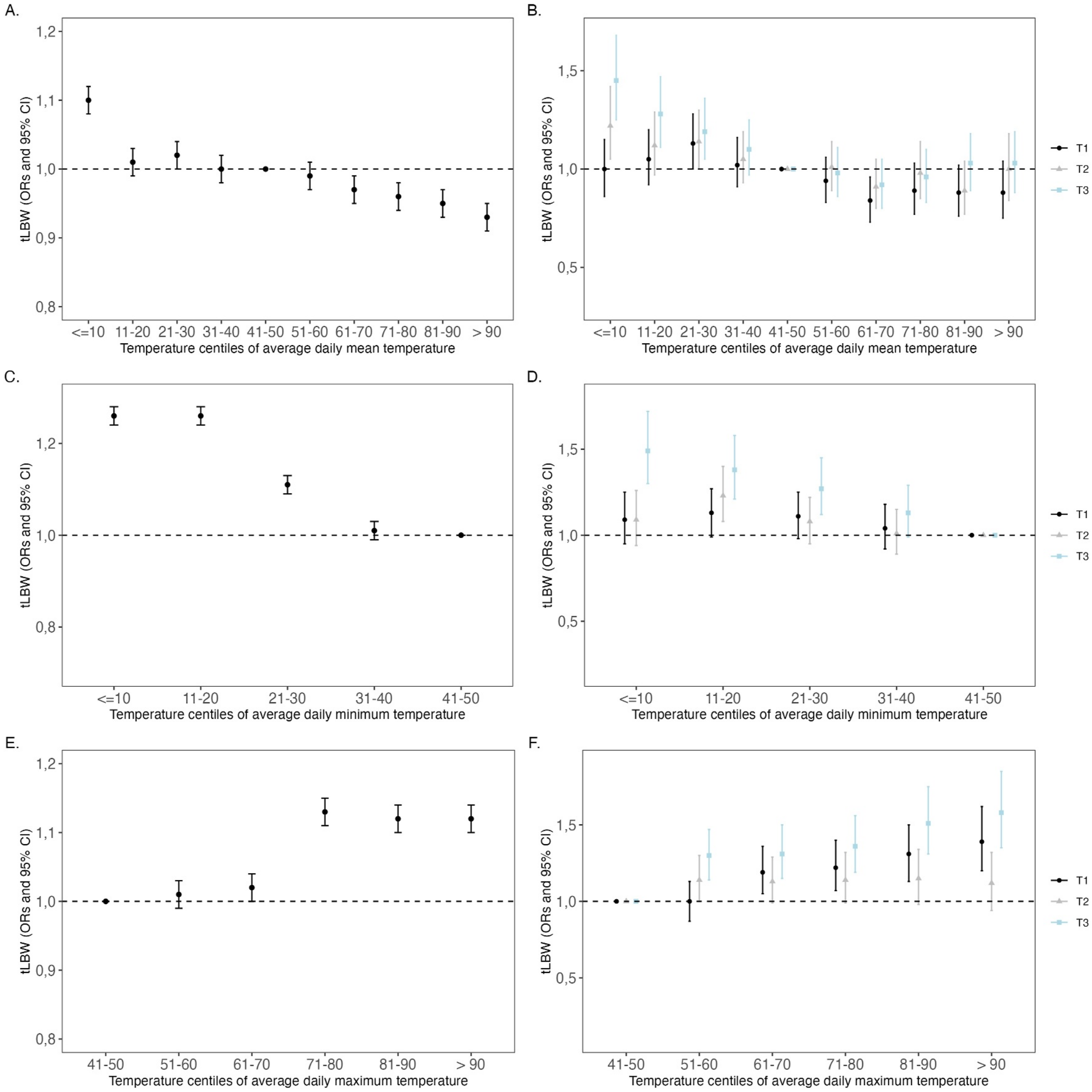

Figure 3. Adjusted ORs and 95% confidence intervals for term low birth weight according to climate zone-specific centiles of average daily mean, minimum and maximum temperature relative to the reference category (41st–50th centile) among singleton term live births during the entire pregnancy (panel A, C, E) and by trimester (panel B, D, F) in the period 2011–2020.

For extreme temperatures, pooled estimates indicate a moderate negative effect on birth weight across all climatic zones during cold and heat extremes. Effects were particularly marked for both extreme cold (minimum) and hot (maximum) temperatures in the desert zone and, for hot temperatures, for the temperate dry, hot summer climatic zone (Figure 5, Panels C and D). Significant variation in temperature effects on tBW for mean ($Q = 1{,}123.6$, $df = 36$, $p < 0.001$), minimum ($Q = 721.4$, $df = 36$, $p < 0.001$), and maximum temperatures ($Q = 1{,}458.4$, $df = 36$, $p < 0.001$) were confirmed after tests of heterogeneity across climatic zones.

4. Discussion

In our study of nearly 300,000 births from 26 municipalities and 5 climatic zones in Chile, we found consistent associations between exposure to low temperatures (<10th percentile) during gestation and lower birth weight. Our cold temperature results were consistent using both daily mean temperatures and extreme cold temperatures, estimated using daily minimum temperatures. Associations for exposures to warmer temperatures were more nuanced. When evaluating daily mean temperatures, exposure to temperatures above the 50th percentile in the entire pregnancy period related to slightly higher birth weights. However, when maximum temperatures were

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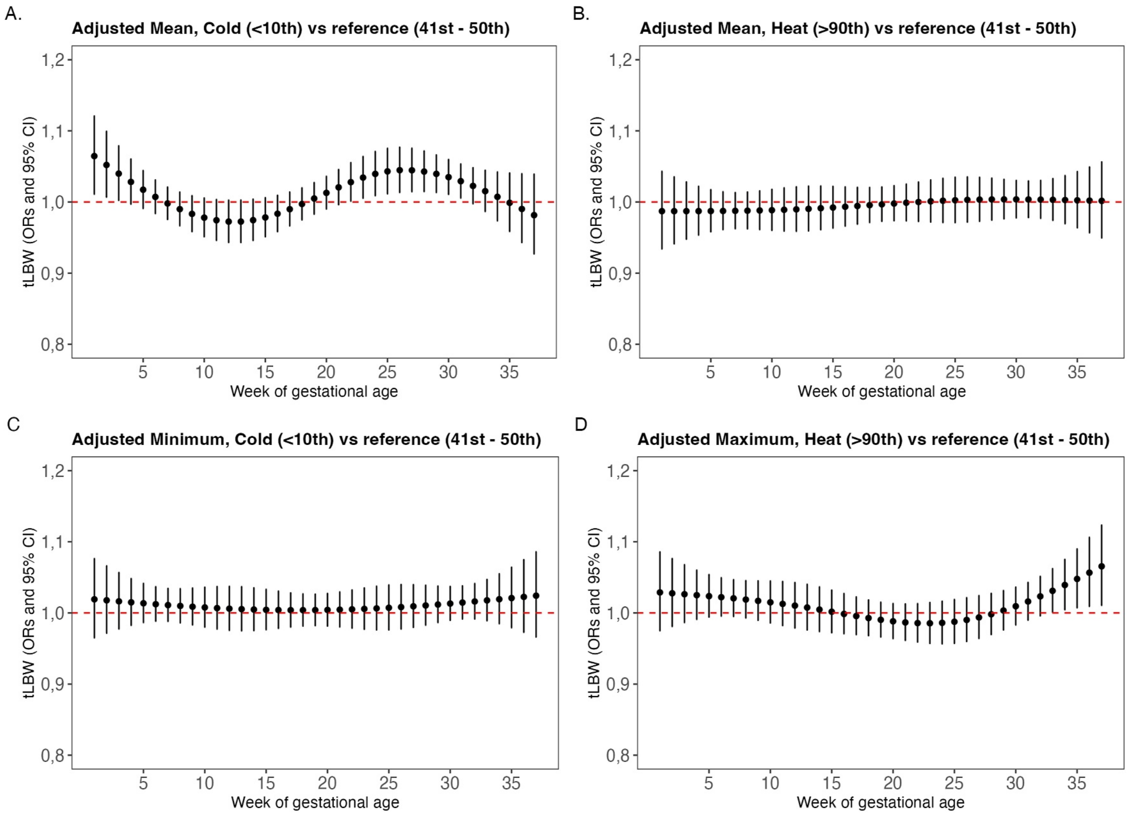

Figure 4. Adjusted ORs and 95% CI for tLBW in association with extreme cold and hot daily mean, minimum and maximum temperatures (≤10th or >90th the percentile for each climate zone, respectively, relative to the 41st–50th centile) during each gestational age week among singleton live births in Chile during the period 2011–2020.

used as the metric of interest, exposure to temperatures above the 50th percentile were associated with lower birth weights.

Our cold temperature results are in agreement with recent work from Israel (Basagaña et al., 2021), however at least two main differences can be appreciated. First, we found more modest effects (−28 vs. −56 g). A large study focused on births in the U.S. found an even smaller (6 g) decrement in birth weight, associated with exposure to low temperatures (≤10th percentile) during the total pregnancy period (Sun et al., 2019). A modest reduction in birth weight may not have any clinical importance on the individual level, however, at the population level it signifies an environmental problem in a vulnerable population group, where prevention can reduce the population mean risk involved in avoiding the public health consequences of low birth weight (Rose, 2001). Moreover, the impact takes on greater importance when temperature extremes (both cold and hot) are common and escalating (Chersich et al., 2020; Hajdu & Hajdu, 2021). Second, while we also found the strongest associations for exposures to colder temperatures in the later weeks of pregnancy (starting in gestational week 16), our results suggested additional susceptibility in the early weeks of pregnancy. Specifically, using mean temperature, we observed a lower birth weight for exposures to cold mean temperatures in gestational weeks 1–10. Direct comparisons with other studies are difficult considering differences in methodologies, nevertheless, another study from the U.S., did not find a relationship with exposure to colder temperatures in early pregnancy and risk of tLBW (Ha et al., 2017). Another study using data from cities in Mexico, Brazil and Chile, did not identify any cold-temperature effects for tBW (Bakhtsiyarava et al., 2022). While we caution against over-interpretation of our results, these differences make clear that additional studies are needed from a variety of climatic regions, as identifying windows of increased risk is important for thinking about public health interventions.

Several previous studies have identified an inverse relationship between exposures to warmer temperatures during gestation and birth weight (Bakhtsiyarava et al., 2022; Basagaña et al., 2021; Sun et al., 2019; Yitshak-Sade et al., 2021). For exposure to extreme heat, using maximum daily temperatures, we found an inverse relationship in our large sample from a variety of climatic zones in Chile. On the other hand, we found a positive

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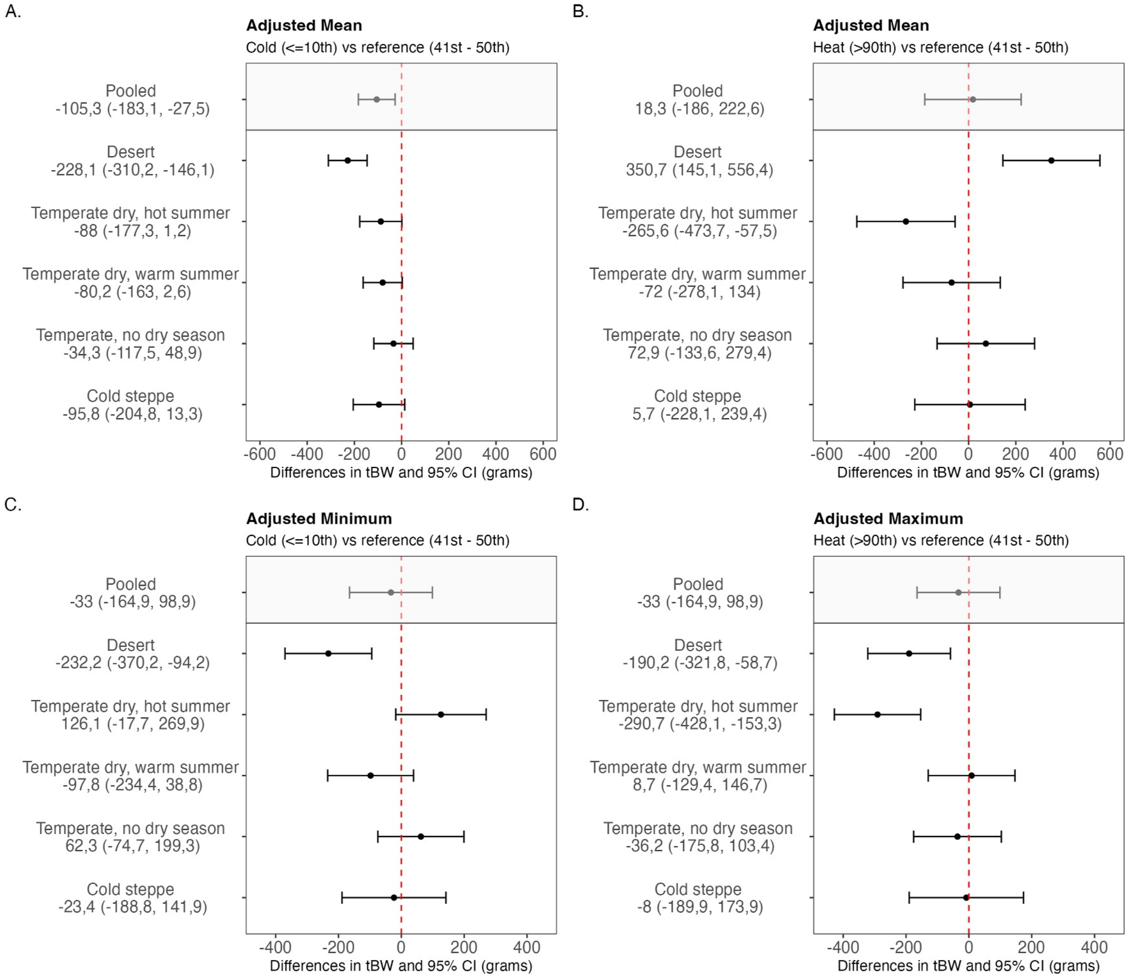

Figure 5. Two Stage estimated differences in mean term birth weight (g) and 95% confidence intervals according to climate zone-specific centiles of average daily mean (Panels A and B), minimum (Panel C), and maximum (Panel D) temperature relative to the reference category (41st–50th centile) among singleton term live births in Chile 2011–2020. Estimates were calculated for exposure in the entire pregnancy period.

association between exposure to greater mean temperatures (>50th percentile) and tBW. This result was especially apparent for exposures in the first and third trimester of pregnancy. Other studies have found modest positive relationships between exposure to warmer temperatures and tBW, however these associations were observed for later pregnancy only (Ding et al., 2023; Lawlor et al., 2005). We hypothesize that the reason we see the inverse relationship when only using maximum temperatures relates to a potential threshold of effect. For example, the 90th percentile of daily mean temperatures for the study conducted in Israel ranged between 23 and 28 degrees Celsius (Basagaña et al., 2021), compared to 16 and 18° in our study. By comparison, the 90th percentile of daily maximum temperatures in our study were between 27 and 34°. While far from resolving this quandary, our two-stage analysis helped to identify that the positive association between warmer mean temperatures and tBW was present for the desert climatic zone only. These results suggest that a more specific analysis using smaller geographic areas may be warranted. Our two-stage approach was implemented to explore region-specific heterogeneity in the association between temperature and birth outcomes. Given the large sample size and the use of flexible adjustments for region, climate zone, and time trends in the main models, although we observed that differences between climate zones were significant, our primary pooled analysis remains appropriate and informative.

For our exposure metrics we used data from government maintained meteorological stations. Meteorological monitoring networks provide reliable, continuous measurements of temperature usually over large periods of time. However, monitoring stations have limited spatial coverage as they are scarce and are spread throughout large geographic areas, limiting the study to 26 Chilean communes. Future studies might benefit from using non-traditional sources of temperature data with more complete spatial coverage, including satellite-derived land surface temperature or modeled temperature. Nevertheless, there are important tradeoffs between these data in terms of granularity, coverage, and accuracy that need to be evaluated and considered for its use in exposure assessment of ambient temperature. e.g., land surface temperature data have continuous global coverage at high spatial resolution over large periods of time. However, land surface temperature measures the temperature at the surface canopy (i.e., tree tops, roofs, bare ground), and while its spatial behavior correlates well with that of daytime air temperature (measured two m above the ground), the two exhibit important data differences, as surface temperature can exceed 50° even when air temperature is below 30° (Smith et al., 2021). On the other hand, modeled temperature data might have good spatial and temporal granularity, but the accuracy of predictions will depend on the quality of training data, modeling decisions, and statistical approaches used. Future studies should explore the potential of these alternative data sources, evaluating strengths and limitations and the implications of its use in environmental health research. This is particularly relevant in regions like Latin America, where monitoring stations are sparse.

Our study had several limitations. First, there are several potential points for exposure misclassification. We assigned exposure based on maternal residence reported on birth certificates. While mobility during pregnancy has been reported to be high in the U.S. and Canada (Brauer et al., 2008; Pereira et al., 2016), there are no similar published reports of the phenomenon in Chile. Local evidence, not specific to the pregnancy population, shows that internal migration is uncommon in Chile (6.2%) and is most prevalent among men aged 25–54 with no children (Instituto Nacional de Estadística Chile, 2020). Nevertheless, we expect that this bias, if present, to be non-differential. In addition, we assigned exposure at the level of municipality using temperature records from meteorological monitoring stations that were not necessarily located in the urban center, where the largest proportion of the population is located. In fact, 9 of the 27 stations used in the current analysis were located at small regional airports. Studies from Chile (Sarricolea et al., 2022) and around the world (Estoque et al., 2017; Hsu et al., 2021) have illustrated the urban heat island effect, in which higher temperatures are experienced in densely populated areas compared to rural areas outside of urban centers. Along these lines, there may be important differences between areas within the same city or commune, which cannot be represented by a single registry, representing a potential for future studies. Thus, our results, especially for higher temperatures, may be attenuated. Furthermore, while we did have some information on variables known to influence adverse birth outcomes, such as maternal and paternal age (Goisis et al., 2018; Khandwala et al., 2018), parental education level (Boardman, 2008), and social vulnerability (Alves de Moura et al., 2022; Crequit et al., 2023), many individual-level variables were not available (e.g., maternal morbidities). Additionally, the lack of data on indoor exposures and air conditioning use may have led to greater imprecision in our findings. Another potential limitation is spatial autocorrelation, specifically that temperature exposure might not be independent across regions. Ignoring spatial autocorrelation in models could lead to biased standard errors and invalid inference. Two final limitations should be noted. We were unable to adjust for air pollution in our models, as reliable measures were not available for all municipalities used in the analysis, a common reality in the Global South (Quinteros et al., 2019). Finally, we were unable to account for pregnancy loss in our analysis, which may have attenuated results (Bruckner & Catalano, 2018; Raz et al., 2018).

Several strengths should also be noted. We used data from 5 different climatic zones. Chile is an extremely diverse country in terms of climatic zones (Sarricolea et al., 2017), making it necessary to consider zone in analysis. In addition, relative measures of temperature were used, which may better relate to biological mechanisms of health effects and individual and population-level adaptation to temperature (Masiero et al., 2022; Molina & Saldarriaga, 2017). That is, we may expect greater health effects when temperatures deviate from common levels (50th percentile). Finally, we took advantage of large administrative data sets. In particular, birth data is highly standardized, with nearly all births in Chile occurring in hospitals using a standard of care birth protocol (Castro Santoro et al., 2008). This enabled us to assess how differences in temperature exposure during pregnancy may be related to birth weight, using data from over 300,000 births across 26 municipalities and multiple climatic zones over a 10-year period.

5. Conclusions

Although there is evidence reporting associations between temperature and newborn health, additional research is needed from more diverse climatic zones. To our knowledge, this is only the third published report from South

America. One study focused on the Andean regions of Peru, Bolivia, and Colombia and found a negative relationship between exposure to increased relative temperature and birth weight (Molina & Saldarriaga, 2017). The only other study with information from Chile, focused on cities in Mexico, Brazil and Chile and, while authors concluded that exposure to warmer temperatures in pregnancy related to lower birth weight overall, results were inconclusive for Chile (Bakhtsiyarava et al., 2022). In our analysis, we were able to include additional municipalities and climatic zones, as we used a different source for exposure assignment and evaluated exposure based on percentile of temperature for each climatic zone, which may better adjust for adaptation. Clearly, more studies from Latin America and the Global South are needed. From a scientific perspective, it is important to test whether a relationship described in other countries and regions is maintained, after considering local conditions, health habits, underlying risk factors and resilience of the population, among other aspects. Having locally produced evidence also serves to raise national awareness. In Chile, several branches of the government have taken on the task of understanding the potential threats of climate change (Ministerio de Salud, Gobierno de Chile, 2015; Ministerio del Medio Ambiente, Gobierno de Chile, 2018) with mention of rising temperatures, but nowhere is the health of the newborn mentioned.

Our findings have important implications for both the public and policymakers. Exposure to both cold and hot temperatures during pregnancy across diverse climatic regions of Chile was associated with lower birth weight, a key indicator of newborn health (UNICEF, 2004). Given the established links between low birth weight and increased risk of neonatal mortality, childhood illness, and chronic disease in adulthood (Risnes et al., 2011; UNICEF, 2004), these results highlight an often-overlooked consequence of climate variability and climate change. Importantly, the observed effects occurred even within the range of local climatic conditions, suggesting that communities are vulnerable to deviations from typical temperature patterns. For the public, our results underscore the importance of awareness and protective behaviors during periods of unusual cold or heat in pregnancy, such as staying in thermally regulated environments. For policymakers, the evidence supports integrating maternal and newborn health considerations into climate adaptation strategies, including improving thermal comfort in housing, expanding access to cooling and heating resources, and strengthening early warning systems for temperature extremes. Addressing these exposures now can help safeguard maternal and child health in the face of a warming and increasingly variable climate.

Our analysis of nearly 300,000 births from 5 climatic zones in Chile between 2011 and 2020 showed that exposure to cold and hot temperatures were related to lower birth weight among infants born at term. Exposure to warmer mean temperatures, however, related to slightly higher birthweight. Differing results from our sample of births from Chile highlight the importance of understanding regional impacts of climate change on maternal and child health.

Conflict of Interest

The authors declare no conflicts of interest relevant to this study.

Data Availability Statement

Original data resources and codes are listed in the repository: https://github.com/ClimChange-NewbornHealth/CIIIA-ClimateBirthWeightAnalysis (Conejeros & Blanco, 2025).

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