Temperature Extremes Exposure and Children’s Health: Extreme Heat- and Cold-Related Impacts in Edmonton, Alberta

by

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Abstract

In the current context of escalating climate change effects on public health, Canada's distinctive geographic position causes it to warm at double the global average rate. This phenomenon leads to potentially heightened health risks for its residents through direct and indirect mechanisms. Particularly at risk are the most vulnerable age groups, such as children aged 0-5 years. Extreme temperature events—both hot and cold—pose latent health threats, especially to this demographic. It is imperative to note that while all children within this age range are at risk, certain age-specific and sex-specific factors may exacerbate or mitigate their vulnerability. Given the transformative developmental stages within these early years and the pronounced physiological differences between sexes, these factors are crucial to understand. This study, focusing on Edmonton, AB, aims to explore the health ramifications of such temperature extremes on children aged 0-5. To achieve a comprehensive analysis, the research segments its investigation based on age brackets (0-1, 2-3, 4-5 years) and sex (male and female). The objective is to examine the association between outdoor exposure to extreme temperature conditions and the incidence rate of hospital admissions and emergency visits for children in this age group. It utilizes health data from Alberta Health Services (AHS) and environmental data from the Alberta Climate Information Service (ACIS) from 2015 to 2018, focusing on age- and sex-specific trends. Time-series analysis, including Poisson and negative binomial regression, were applied to examine the correlation between temperature extremes—quantified by the 95th and 5th percentiles of weekly average temperatures—and pediatric hospital admissions and emergency visits. The analyses were stratified by age and sex and adjusted for confounding variables such as air pollution, relative humidity, seasonality, and long-term trends. During the study period, we recorded 5,970 hospital admissions and emergency visits for the 0-5 age group, with a notable majority (92.2%) for respiratory diseases. A significant increase in health service utilization was found in the 2–3-year age group during extreme heat (IRR= 1.36, 95% CI 1.03-1.80, p=0.03) and cold (IRR= 1.30, 95% CI 1.01-1.67, p=0.05) events. No significant associations were found in the 0-1- and 4-5-year age brackets, nor were there sex-based differences in health outcomes. The study revealed that pediatric respiratory diseases, such as asthma, bronchiolitis, and pneumonia, were significantly associated with extreme temperature events in the 2–3-year age group. The effects of cold temperatures persisted up to four weeks post-exposure (IRR= 1.30, 95% CI 1.00-1.69, p=0.05), while the impact of heat was more immediate (IRR= 1.36, 95% CI 1.01-1.83, p=0.04), suggesting different temporal patterns of risk. These findings demonstrate a rising trend in the risk of negative respiratory health effects in young children linked to extreme hot and cold temperatures, highlighting the need for a more thorough assessment across various health outcomes. Additionally, they emphasize the need for ongoing research to refine our understanding of how these events affect pediatric health and develop comprehensive mitigation and adaptation strategies. Future studies should investigate more precise and direct methods for assessing the health impacts of such events, explore the contributing factors of these temperature extremes, including the role of climate change, and explore preventative strategies to mitigate their effects. This research is crucial for developing robust measures to protect our youngest and most vulnerable residents from the health hazards of extreme climate variability.

Preface

This thesis is an original work by Sara Alsunaidi under the supervision of Drs. Allyson Jones, Shelby Yamamoto, and Alvaro Osornio-Vargas. The research project of which this thesis is a part received ethics approval from the University of Alberta Health Research Ethics Board (PRO00106985).

Dedication

Written in dedication to my two precious children, both under the age of 4, who serve as my daily motivation and reminder of why this research into children's health is crucial. As a mother, I hope to create a world where you and all children can thrive. Your laughter, curiosity, and resilience inspire every word I pen. I write this not only as a researcher but as a mother who dreams of a healthier future for you.

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Chapter 1: INTRODUCTION

1.1 Background

The ongoing global climate crisis, primarily driven by human activities, signifies a pressing challenge. Projections indicate a rise of 1.5°C in global warming within the next two decades [1], a warming trajectory predominantly attributable to industrialization, urbanization, and high-energy consumption lifestyles [2]. These climatic changes amplify extreme weather events, such as heat waves, thereby escalating threats to public health. Particularly susceptible are vulnerable populations, including children, older adults, pregnant women, and individuals with chronic illnesses [3]. In addition, the surge in greenhouse gas emissions, specifically carbon dioxide and methane, from industrial activities contributes significantly to global warming [4]. Deviations in average temperatures, a critical climate change indicator, pose serious risks to human health [5, 6].

Thermoregulation plays a crucial role in maintaining human health, which necessitates keeping core body temperature within a 3-degree window around the standard 36 to 37.5°C. Extrinsic temperatures outside this range can impair this regulation, potentially leading to severe health consequences [7, 8]. This risk is especially heightened in young children 0-5 years due to their physiological immaturity and comparatively higher intake of air, food, and water relative to their body weight [9, 10]. Factors contributing to children's distinct vulnerability include their limited thermoregulation capacity, developmental stage, and socio-physiological characteristics [11, 12, 13]. Furthermore, socio-economically disadvantaged children and those afflicted with chronic diseases encounter amplified risks due to high infection prevalence, malnutrition, restricted healthcare access, and inadequate housing conditions [14, 15, 16].

Canada experienced a significant increase in average temperatures in the 21st century, surpassing the standard period of 1961-1990 by 2.1°C. This temperature rise ranks 2016 as the fourth warmest year since 1948 [17]. This warming trend has been observed nationwide, including regions such as Edmonton, Alberta. Forecasts indicate that this trend is expected to continue and amplify in the coming years [18].

In 2018, Edmonton's demographic data indicated that children aged five years and younger represented 6.6% of the population, marking a slight decrease of 0.4% from 2016 [19]. Given that young children form a significant and high-risk demographic, and considering their heightened vulnerability, enhancing the limited research on how temperature extremes affect their health outcomes is of paramount importance, especially in light of the evident gap in comprehensive studies dedicated to this association [20, 21, 22].

1.2 Impacts of Climate Change on Extreme Temperature Events

Ambient temperature is the most common and influential climate factor affecting human health compared to other factors, such as precipitation, wind speed, and humidity. For this reason, multiple studies have been conducted on climate change and health-related outcomes using temperature as a climate factor [23, 24, 25, 26]. Anthropogenic climate change exacerbates temperature extremes worldwide, leading to severe repercussions for ecosystems and public health. These changes encompass an increase in the intensity and duration of heat waves, potentially doubling the probability of certain heat events [27]. Furthermore, should global temperatures continue to rise, extreme heat events are expected to become more frequent, with increasing and more persistent impacts on human health and agriculture [28]. Climate change does not just amplify heat extremes; it also affects cold extremes, albeit in a more complex and region-specific manner. Despite the overall trend of decreasing cold extremes due to global warming, some areas might experience colder winters due to disturbances in atmospheric circulation patterns, such as those impacting the polar vortex [29].

Temperature extremes exacerbated by climate change are already visible across the world. For instance, the 2003 European heatwave, linked partially to climate change, resulted in an estimated 70,000 deaths [30]. In Australia, the "angry summer" of 2018-2019 brought about extreme heat events that led to significant loss of life and property damage and witnessed environmental catastrophes, such as the severe coral bleaching of the Great Barrier Reef, highlighting the farreaching impacts of these temperature fluctuations [31]. In contrast, the United States experienced a frigid winter in 2014, referred to as a polar vortex event, a phenomenon connected to climate-induced atmospheric changes [29]. The regions affected by these temperature extremes are often ill-equipped to handle such severe weather events due to their rarity and the local infrastructure and health systems being unprepared for such conditions [32, 33]. In Europe, for example, the infrastructure and the majority of homes, particularly in urban areas, are designed to conserve heat rather than for cooling, leaving populations vulnerable during heatwaves [30, 32]. Australia's "angry summer" similarly confronted communities and ecosystems unprepared for relentless heat, leading to widespread damage and loss [30, 33]. In the United States, the polar vortex event brought temperatures far below what is typical, causing energy systems to fail and significantly impacting those without adequate housing or emergency resources [29, 34]. The impacts of these changing temperature extremes are profound, endangering biodiversity, raising wildfire risks, worsening drought conditions, and presenting considerable challenges to human health and infrastructure [35, 36, 37].

Given the gravity of these consequences, developing, and implementing effective mitigation and adaptation strategies becomes critical [38]. Mitigation strategies encompass transitioning towards renewable energy sources, promoting sustainable practices like reforestation and carbon capture, and incorporating energy-efficient infrastructures. A circular economy model and sustainable consumption habits, however, can contribute significantly to reducing our global carbon footprint [38]. In contrast, adaptation strategies emphasize resilience building against temperature extremes. They include improving infrastructure to withstand these extremes, enhancing early warning systems for prompt disaster response, implementing heat health action plans, improving housing insulation, and conserving natural ecosystems [39].

Overall, an integrated approach to climate action is imperative with the escalating impacts of temperature extremes. This involves a combination of rigorous scientific research, public engagement, informed policymaking, and cross-sector collaborations. Such concerted efforts will equip us to confront climate change and foster a more sustainable future effectively. [40] The findings from this research will likely contribute to this collective effort, highlighting the importance of considering young children's health in our response to the climate crisis.

1.3 Health Risk of Extreme Temperature on Young Children

Extreme temperatures can pose significant direct and indirect health risks to young children, particularly those between 0-5 years of age. These risks span across a range of physical, developmental, and psychological health domains, presenting complex challenges for public health and healthcare delivery.

1.3.1 Direct Health Risks

Direct health risks refer to the immediate physiological ramifications of extreme temperature exposures. During periods of excessive heat, children under the age of 0-5 are susceptible to a range of heat-related health complications, including but not limited to heat exhaustion, heatstroke, and dehydration. This heightened predisposition can be primarily attributed to their less mature thermoregulation capabilities compared to adults [41]. As a case in point, during the 2003 European heatwave, a notable surge in emergency hospital admissions was observed for young children and infants, with severe dehydration and heatstroke being the primary diagnoses [42].

On the other hand, extreme cold temperatures can expose children to conditions such as hypothermia and frostbite. For example, a study conducted in Russia indicated a spike in pediatric hospital admissions for frostbite and hypothermia during frigid periods [43].

1.3.2 Indirect Health Risks

Indirect health risks emerge from broader environmental and social impacts of extreme temperatures. For instance, air pollution, which often intensifies during heat waves, can trigger or exacerbate respiratory problems, like asthma, in young children [44]. An ecological regional study in Southern California found an increased hospitalization for asthma in children due to high ambient ozone (O_3) during the warm season in California's South Coast Air Basin using a case-crossover analysis [45]. Similarly, a study in the Central Valley, California, looked at the association between pediatric asthma emergency department visits during heatwaves due to heightened ozone levels using a time-stratified cross-over analysis [46]. Another study from Edmonton, AB, concluded that emergency department visits for asthma are linked to increased O_3 and nitrogen dioxide (NO_2) levels during the warmer months [47].

Additionally, air quality can deteriorate during extreme cold events due to thermal inversion and increased emissions from heating sources [48, 49]. A study investigating winter indoor air quality in primary schools in China's extreme cold weather areas found that the average daily CO_2 levels in three occupied classrooms ranged from 1,500 to 3,863 parts per million (ppm). These levels significantly exceeded the standard threshold of 1,000 ppm, with the highest concentrations recorded during class hours, potentially impacting the health and well-being of the students and staff [50]. A separate study conducted in Argentina indicated that during the colder months, there was a significant increase in hospital admissions for children, primarily due to viral acute lower respiratory infections [51].

Climate change also impacts food and water security, which indirectly affects children's nutrition and hydration status. For instance, drought conditions associated with high temperatures can cause local food shortages, disproportionately impacting children's nutrition, as seen in sub-Saharan Africa [52]. Displacement due to climate-related disasters associated with extreme temperatures can lead to acute stress and long-term psychological impacts. For example, children displaced by the Australian wildfires in 2019-2020 showed increased signs of post-traumatic stress disorder and other mental health issues [53].

In summary, the health risks of extreme temperatures to young children are multifaceted and necessitate a coordinated response encompassing research, healthcare, and policy interventions to protect this vulnerable age group effectively. The research is of great significance, particularly for public health planning and policy-making, to mitigate these risks and protect public health.

1.4 Thesis Research Main Aim and Objectives

The overall aim of this thesis is to explore whether exposure to extreme high and low ambient temperatures is associated with changes in weekly hospital admissions and emergency visits in children aged 0-5 years in Edmonton, Alberta, using health and environmental data from 2015 to 2018.

The specific objectives are:

1- To estimate the degree to which weekly fluctuations in the number of hospital admissions and emergency visits for children aged 0-5 years in Edmonton, AB, are associated with shifts in the average weekly temperatures.
2- Define extreme heat and cold events, assess the impacts of those events on children ≤ 5 yrs., and analyze whether specific demographic factors, such as age and sex, are associated with hospital admissions and emergency visits during periods of extreme temperatures.
3- To identify the specific health events related to exposure to extreme heat and cold in children aged 0-5 years in Edmonton.

1.5 Research Question

Does exposure to extreme high and low ambient temperatures contribute to the number of hospital admissions and emergency visits among children aged 0-5 years in Edmonton, Alberta, between 2015 and 2018, and if so, which specific health events are most associated with these extreme temperature exposures? Additionally, do demographic factors like age and sex influence the likelihood of hospital admissions and emergency visits during these periods of extreme temperature?

1.6 Significance

Climate change poses numerous risks to the health of Canadians, including extreme weather events [54, 55]. Our research findings will be instrumental in forecasting hospital needs, optimizing the allocation of medical resources, and ensuring that healthcare systems are equipped to respond efficiently during periods of significant temperature deviation. Moreover, by identifying the specific health events most associated with these temperature extremes, health authorities in Edmonton and beyond can devise targeted preventive measures, support community education efforts, and establish early warning systems to mitigate the impact of severe weather conditions. Understanding how age and sex impact health outcomes during extreme temperature events can help inform interventions to address health disparities, ensuring that the most vulnerable segments of the population receive the necessary care and attention. Edmonton, Alberta, has been selected as the focus for this study not only due to its unique climatic challenges but also because it serves as an example with lessons and strategies that may apply to other regions sharing comparable climates and facing similar risks associated with extreme temperatures. While the study is centered on Edmonton, the methodologies and insights gained aim to provide a framework for analogous research in diverse geographical and climatic regions.

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Chapter 2: LITERATURE REVIEW

2.1 Introduction

Climate change has emerged as one of the most pressing global challenges in the 21st century, posing significant threats to ecosystems, human health, and socioeconomic stability [1, 2]. Climate change-related risks, such as extreme temperatures, have become increasingly common in recent years, significantly impacting human health [3, 4, 5]. These risks particularly affect vulnerable groups such as infants and young children, with social isolation and low socioeconomic status being additional risk factors [3, 6, 7, 8]. Physical health issues range from short-term outcomes (dehydration, heat exhaustion, and cold injury) to longer-term consequences, including impacts on food, water, housing, and mental health [9, 10]. Because of its immediate and long-term impacts on human health, climate change has become a focus of medical and public health research. Research varies in focus, objectives, methodologies, target populations, health outcomes, and geographical and climatic specificities. Predictions for the future consistently indicate a rise in global temperatures, with severe heat waves becoming more frequent and lasting longer due to climate change and sustained urbanization [9]. Although the overall frequency of cold days is anticipated to decline, the occurrence of cold spells is expected to remain, presenting challenges in their unpredictability and severity [9]. Existing epidemiological studies increasingly emphasize that exposure to extreme high and low temperatures is a significant risk factor for morbidity and mortality [11, 12, 13, 14].

This descriptive review explores the vulnerabilities of young children exposed to extreme temperatures, considering the most prominent health outcomes across ages and between sexes in this demographic. Beyond the health risks, the review also tackles the challenges of creating a standard definition for extreme hot and cold temperatures and the primary modeling methodologies used in assessing the implications of climate change on human health. Finally, this review will outline the preventative measures employed to mitigate the effect of climate change on young children's health.

2.2 Young Children's Vulnerability to Extreme Temperatures at Various Age or Developmental Stage

This section discusses the vulnerability of young children to extreme temperatures, a vulnerability that varies across different ages and developmental stages. Each developmental stage for infants, toddlers, and preschoolers is marked by distinct physiological, anatomical, and cognitive characteristics that influence their ability to cope with and adapt to their surroundings. Of particular interest are the ways in which motor and cognitive development, dependency on adults, and limited communication skills heighten vulnerability, particularly at earlier developmental stages.

Infants (0-1 year): During the first year of life, infants undergo a phase of rapid growth that paradoxically coincides with a period of heightened vulnerability to extreme temperatures. This susceptibility arises from a combination of physiological, anatomical, and behavioral factors. For instance, the process of thermoregulation, which allows the body to maintain a stable internal temperature, is influenced by several variables, including body surface area to volume ratio, sweat production, cardiovascular responses, and hydration status. However, this process becomes more complex in infants due to their still-developing thermoregulatory systems, higher metabolic rate, increased threshold for sweating, and faster heart rate resulting from a smaller blood volume [15, 16, 17, 18, 19]. Moreover, the larger surface area-to-volume ratio, particularly in preterm neonates, predisposes infants to a greater risk from external temperature variations [15, 20]. This physiological susceptibility is compounded by their limited communication ability and their absolute dependence on caregivers for environmental regulation [15, 21]. Cognitive factors further augment infants' vulnerability to extreme temperatures. Their limited awareness of discomfort and undeveloped language skills make it challenging for them to signal their discomfort due to extreme hot or cold conditions to their caregivers. The inability to signal specific problems may cause delays in identifying and addressing their needs, increasing their risk during periods of temperature extremes. Therefore, the complex interplay of physiological, anatomical, and cognitive factors contributes to infants' increased vulnerability to extreme temperatures.

Toddlers (2-3 years): Children undergo notable developmental changes during their toddler years. This stage is characterized by increased mobility, shifts in metabolic functions, evolving thermoregulatory capacity, and behavioral changes. With the increase in physical activity and continual development of their thermoregulatory systems, toddlers become increasingly susceptible to heat-related illnesses, particularly under extreme environmental conditions [15]. Their motor skills develop to become more complex, allowing for increased physical activity and active exploration of their surroundings, which, along with their inherent curiosity and emerging exploratory behaviors, expose them to a wider range of environmental conditions [22, 23]. Despite these advancements, their verbal communication skills and cognitive abilities are still early in developmental, leaving them unable to effectively comprehend or communicate their discomfort or sense of danger [22]. The combination of their curiosity, limited risk awareness, and underdeveloped communication skills can place them in perilous situations, such as straying into unsafe areas or inadequately dressing for adverse weather conditions. Thus, both their physiological and cognitive developments during this stage interplay to shape their vulnerability to extreme temperatures.

Preschoolers (4-5 years): Preschoolers present different vulnerabilities to extreme temperatures. Although their thermoregulatory abilities, cognitive and motor development are more advanced than infants and toddlers, they remain at an increased risk of heat- and cold-related illnesses [22]. This increased risk is due to their engagement in a broader range of activities and exposure to various environments as they grow more independent. The interaction between growth, physical activity, the maturation process, and environmental exposure significantly shapes preschoolers' metabolic rates and thermoregulation capabilities [15]. Adding to these complexities, global climate change and other environmental stressors, such as pollution and ultraviolet radiation, might further strain their thermoregulatory systems [7, 16]. Therefore, understanding age-related differences in thermoregulation and the health impacts of extreme temperatures is an important consideration in safeguarding children from potential health risks associated with climate change [16, 24]. Despite the significant cognitive and motor developments at this stage, preschoolers might lack the cognitive maturity needed to fully comprehend the potential risks of extreme temperature exposure. While they can communicate discomfort more effectively than younger children, articulating the nature or severity of discomfort may still be challenging. Though important for development, their growing sense of independence can occasionally result in dismissing adult guidance in favor of their preferences, such as choosing not to wear a jacket when cold, thus increasing their exposure risk to extreme temperatures.

Most studies often generalize the effects of extreme temperatures on children, typically treating them as a single age group without considering differences in age, developmental stages, and behaviors across the broad age range of 0 to 18 years [25, 26, 27]. Each developmental stage, however, carries unique vulnerabilities affecting children’s ability to cope with and adapt to extreme temperatures. Recognizing these differences is critical for future research to pinpoint the specific risk factors at each age and developmental stage. A detailed understanding of these age-related vulnerabilities is essential for developing targeted protective measures to address the effects of temperature extremes.

It is important to recognize children's dependence on their caregivers for protection against such environmental hazards. Parental awareness and proactive measures are vital, especially since the risk may not always be apparent. For example, the dangers of leaving children unattended in vehicles during extreme temperature events, which leads to a risk of morbidity and mortality, are often underestimated [28]. Improving parental awareness and developing age-appropriate interventions are essential targets to ensure children's safety across all environments.

During the early 2010s, multiple peer-reviewed articles and systematic reviews were published that scrutinized the influence of extreme temperatures on the morbidity and mortality rates among children [10, 16, 19, 25, 29]. This body of research suggested a pronounced susceptibility to extreme hot and cold temperatures among children between the ages of 0 and 5 years [16, 19, 20, 27, 29]. The research attributed this susceptibility to a range of physiological, anatomical, and social factors. The impacts of these risk factors became significantly more severe during extended periods of high temperatures [26, 30, 31, 32]. Among physiological and anatomical factors, the underdevelopment of certain bodily systems in children, including inadequate thermoregulation, puts them at heightened risk during an extended heatwave or extremely cold weather [23, 25]. Social factors are also contributory. For instance, children with low socioeconomic status may lack access to essential resources like air conditioning and healthcare, exacerbating their vulnerability to extreme temperatures. Children from urban areas and lower socioeconomic backgrounds often live in warmer neighborhoods with high population density, sparse vegetation, and the absence of green spaces, which further limits their capacity to adapt to temperature extremes [23, 25].

Nevertheless, these conclusions primarily stemmed from a limited set of studies [16, 25, 26, 32]. Although research exploring the impact of extreme temperatures on children's health has been conducted globally, the studies included in the systematic reviews predominantly involved higher-income countries. It is noted that only five studies were carried out in low- or middle-income countries [23, 25]. Hence, there is a pressing need for additional research across various geographical and socioeconomic contexts to gain a holistic understanding of how extreme temperatures impact children globally.

2.3 Extreme Temperatures Impacts on Young Children's Mortality and Morbidity

2.3.1 The Impact of Extreme Heat on Young Children

Due to their less efficient thermoregulation, heightened susceptibility linked to cognitive and behavioral factors, and reliance on adults for recognizing and responding to heat risks, young children face a greater risk of adverse health outcomes from extreme heat events. Higher temperatures have been associated with increased childhood morbidity and mortality [18, 31]. For instance, a case-crossover study in Montreal, Canada, concluded that high temperatures may be a novel risk factor for sudden infant death, especially at ≥ 3 months of age [33]. Young children are at higher risk of dehydration, heat stroke, kidney disease, fever, and electrolyte imbalance, with these conditions reported to rise significantly among children during heat waves and other periods of extreme heat [2, 26, 27]. Furthermore, extreme heat could lead to other health concerns, such as respiratory problems and exacerbation of underlying medical conditions, such as asthma and neurodevelopmental disorders [29, 30]. In some cases, the effects of extreme heat could have long-term consequences on a child's health and development [34]. The studies indicated that extreme temperature exposure predominantly affected the transmission of infectious diseases among children, like gastrointestinal diseases, malaria, hand-foot-and-mouth disease, and respiratory diseases [35, 36, 37, 38, 39].

2.3.2 The Impact of Extreme Cold on Young Children

Extreme cold temperatures also negatively impact young children's health, including lower respiratory tract infections and an increased risk of hypothermia [31]. The colder months demonstrate a surge in viral infections, further compounding these health risks. Seasonal viral illnesses such as the flu are more prevalent and can be particularly severe for the developing immune systems of young children [40, 41]. The increased surface area to body mass ratio in young children can compound the difficulty of maintaining body temperature in cold environments, leaving them particularly susceptible to the adverse effects of frigid climates [18]. These conditions can also adversely affect a child's nutritional status and growth [24]. Besides, conditions such as atopic dermatitis, commonly known as eczema, have been observed to worsen with exposure to cold and decreased humidity, often accompanying colder temperatures [42]. Notably, cold weather has been associated with higher mortality rates; a comprehensive international study found that cold-related deaths accounted for 7.29% of total mortality, significantly higher than the 0.42% attributed to heat [8]. In Canada, these figures were 4.46% for cold and 0.54% for heat, emphasizing the importance of considering regional variations in temperature and their specific impacts on health [8]. Similarly, a study in South Africa reported higher mortality attributable to cold 3.0% compared to heat 0.4% [43]. While these studies broadly did not account for the age factor, a focused retrospective study in Madrid, Spain, found that cold-related infant mortality during cold waves was notably high, with a 17.4% increase in mortality at a relative risk of 1.21 (95%CI= 1.10, 1.32) for each 1 °C drop below 6 °C, at a lag of 4 days [44].

2.4 Defining Extreme Temperature Exposures

Defining extreme temperatures is often based on a series of indicators that may include, such as ambient temperature, heat index (a fusion of temperature and humidity), or wind chill (a combination of temperature and wind speed), that surpass predetermined thresholds for several days [45, 46, 47, 48, 49, 50, 51]. These temperature extremes can be identified using various metrics: the daily averages, minimums, or maximums, by nighttime or daytime temperatures. Additionally, the diurnal temperature range, which is the difference between the daily maximum and minimum temperatures, can also serve as a critical metric, particularly in assessing the intensity and health impact of temperature fluctuations within a single day [52]. The concept of extreme temperatures is multi-faceted, relying on many factors that make pinning down a single definition a complex task, contributing to the lack of a universal approach for defining a heat or cold wave [45, 53]. The observed links between temperature, morbidity, and mortality can significantly vary across different regions and seasons. An event classified as extreme in one location might be typical in another due to local climatological patterns. For instance, a day with a temperature of 35°C in Helsinki, Finland, could have different health implications compared to a day with the same temperature in Riyadh, Saudi Arabia. Likewise, such a day in June might not have the same impact as it would in December [45, 54, 55, 56].

The measurement techniques employed by scientists also influence the definition of extreme temperatures. Some researchers categorize extreme events based on the highest or lowest 5% or 10% of historical measurements, while others measure these events by their deviation from the mean, recurrence interval, or probability [2, 38]. These differing methods lead to varying definitions of extreme temperature events that can be broadly grouped into relative and absolute approaches. Relative approaches define extreme temperature events based on local weather patterns where metrics are typically defined in relative, not absolute, terms, such as using percentile-based temperature extreme indices of the local temperature distribution to account for the variability across different climate zones [2, 5, 10, 57, 58]. This approach allows for comparing results across geographical areas with different climates and seasons of the year [58]. On the other hand, absolute methods set a fixed temperature threshold. For instance, studies investigating the trends in temperature extremes defined a 'Frost Day' as a day with a minimum temperature lower than 0 °C and a maximum temperature higher than 0 °C [57], and a 'Hot Day' is defined when the maximum temperature exceeds 35°C [39]. These absolute extremes, however, do not account for variations in climate conditions from region to region or season to season.

Temperature extremes are typically ascertained using weather station records, but their specific locations influence individuals' actual exposure. Factors such as urban heat islands, microclimates, and the difference between indoor and outdoor temperatures can lead to discrepancies between weather station data and actual exposure [46, 58]. The variability in defining heat waves makes it challenging to compare findings across various studies or to determine the most suitable public health warning systems [51, 58]. The associations between mortality, morbidity, and extreme temperature conditions can vary based on the methodologies used to characterize these extreme conditions [45, 59, 60]. There is a pressing need for a standardized strategy to define and measure severe temperature events, aiming to better prepare and defend communities from potential health impacts [45, 46, 53].

2.5 Modelling Approaches in Temperature-Related Health Research

Various modeling approaches have been employed in epidemiologic studies on the health impacts of climate change. Most studies generally involve health outcomes (such as disease incidence, morbidity or mortality rates, and hospital admissions) as dependent variables and climate variables as independent variables [26, 27, 35, 36]. Primarily, this review explores three modeling approaches frequently utilized in understanding the health impacts associated with temperature exposure: time-series models, case-crossover designs, and distributed lag non-linear models (DLNMs). The choice of the modeling approach in temperature-related health impact studies depends on the specific research question, available data, and resources.

2.5.1 Time-Series Models

Time-series models are extensively applied in climate change research. They analyze data points collected consecutively over time, usually employed to predict future values based on historical data [61]. For instance, time-series models were used to explore the association between temperature variability and mortality in the US over two decades [62]. Similarly, advanced time series analysis methods with Poisson regression and penalized regression spline were utilized to re-examine the effects of the 1995 Chicago heat wave on all-cause, cause-specific mortality, and mortality displacement [63]. These models effectively manage large datasets, control for long-term and seasonal trends, and incorporate lag effects [64]. However, time-series models presume that exposure-response relationships are immediate and consistent across lags, an assumption that may not hold in all circumstances [65].

2.5.2 Case-Crossover Designs

Case-crossover designs are akin to matched case-control studies, where cases serve as their own control, thereby nullifying the confounding effect of time-independent factors such as age, sex, and race [66]. A case-crossover design was employed to examine the short-term effects of high ambient temperature on daily mortality in California [67]. Case-crossover designs inherently control for time-invariant confounding factors and are particularly effective in assessing the acute effects of short exposures [68]. Despite their strengths, these designs may be susceptible to biases from time-varying confounding factors and overfitting, particularly with sparse data [68].

2.5.3 Distributed Lag Non-Linear Models

DLNMs model non-linear and delayed effects across time lags, thus accommodating more complex exposure-response relationships such as temperature variations leading to children's morbidity and mortality [26, 30, 34, 35, 69]. Notably, DLNMs were utilized to model temperature's non-linear and delayed effects on mortality across 13 countries [70]. DLNMs can capture non-linear and delayed associations and consider varying exposure-response relationships across different lags [69]. However, these models require larger sample sizes and more computational resources than simpler models, and interpretation of their results can be more challenging [65].

2.6 Preventive Measures, Policies, and Recommendations for Child Safety

Children's vulnerability to extreme temperature events, both hot and cold, is a matter of considerable concern [7, 17, 18]. Literature reveals a host of preventive strategies and policy recommendations aimed at safeguarding children from the health impacts of such events [18, 56, 71, 72]. Essential preventive measures include indoor air conditioning, maintaining adequate hydration and rest during heat waves [73], dressing appropriately, and maintaining sufficient indoor heating during cold spells [25]. Heat Health Warning Systems (HHWS) are used to forecast extreme heat events, enabling the timely initiation of public health interventions such as informing schools to limit children's outdoor activities during high-temperature hours [71].

In line with these strategies, the Government of Canada has taken proactive steps to adapt children's playspaces to the changing climate. The Standards Council of Canada and Health Canada, in collaboration with the National Program for Playground Safety (NPPS), have developed guidance to improve the climate resilience of playgrounds, which has been incorporated into the Canadian Standard Association Children's Playspaces and Equipment Standard [74]. This updated standard is a practical application of the preventive measures mentioned, supporting evidence-based options for climate mainstreaming by municipalities, affordable housing providers, and schools when new playgrounds are built or existing ones are renovated. The recommended changes in design include planting shade trees, selecting cooler materials for structures and surfaces, adding water features, promoting urban green spaces to mitigate the heat island effect, and providing cooler areas for children [74].

At the policy level, various guidelines and strategies have been devised. Educational policies advocate for suspending outdoor activities or providing climate-controlled school environments during extreme temperature events, thereby protecting children's health [75]. Building regulations ensure that homes, schools, and other buildings frequented by children are designed to withstand extreme temperatures [76]. The guidance for playgrounds applies to all seasons of play, emphasizing keeping playgrounds cooler and comfortable for children and caregivers in the summer to help prevent overheating and injuries such as burns from metal slides. These public health policies encompass heat-health action plans and cold weather plans, incorporating specific protective strategies for vulnerable populations like children [77]. These measures, when properly implemented, can play a significant role in reducing children's health risks from extreme temperature events [77].

2.7 Conclusion

Existing evidence on the correlation between extreme temperatures and adverse health outcomes is limited, specifically regarding the exposure of young children to extreme temperature conditions. Young children have significant physiological vulnerabilities, such as their limited ability to regulate body temperature and their developing immune systems, which are particularly sensitive to fluctuations in temperature.

Considering the international and regional studies reviewed, which detailed the adverse effects of extreme temperatures on children's health outcomes, our approach used a detailed, age-segmented, and sex-specific analysis of hospital admission and emergency visit data from Edmonton, which will allow for the assessment of health risks associated with both heat and cold in a localized context, offering a more customized perspective that considers Edmonton's unique climatic challenges.

In light of these findings, the literature review prioritized the development of targeted public health interventions and preventive strategies to protect the vulnerable age group of 0-5 years. The evidence gathered from the literature review has been instrumental in shaping the methodology of our study, ensuring a robust and comprehensive examination of the effects of extreme temperature exposure on the health of young children in Edmonton.

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Chapter 3: Exploring the Extreme Heat- and Cold-Related Impacts on Young Children Residing in Edmonton, AB.

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Abstract

Background: One of the most significant impacts of climate change is the alteration in temperature patterns, including the projected increase in ambient temperatures and the occurrence of extreme cold events. These temperature fluctuations are expected to have widespread environmental and human health effects. Children, in particular, have increased vulnerability to temperature extremes due to physiological, anatomical, and social factors. **Objective:** To explore the association between extreme heat and cold exposure and children ≤ 5 yrs., age- and sex-specific hospital admission and emergency visits in Edmonton, AB, during 2015-2018. **Methods:** Time-series analysis was conducted using Poisson and negative binomial regression methods to explore the association between the 95^{th} and the 5^{th} percentile of the weekly average temperature and hospital admissions and emergency visits for children aged ≤ 5 years. The analysis was age- and sex-specific, incorporating constrained distributed lags nonlinear models to account for potential delayed effects while controlling for air pollution, relative humidity, seasonality, and long-term trends. **Results:** During the study period, 5,970 hospital admissions and emergency visits for children aged 0-5, with 92.2% attributed to respiratory disease. The analysis revealed that both extreme heat and cold were significantly associated with increased hospital admissions and emergency visits for children aged 2-3 years in Edmonton, AB, IRRs= 1.36 (95% CI 1.03-1.80, p=0.03) for heat and 1.30 (95% CI 1.01-1.67, p=0.05) for cold. The data also showed no significant difference in the impact of extreme temperatures on hospital visits between male and female children. Pediatric respiratory conditions were significantly correlated with extreme temperature events in the toddlers group. The influence of cold temperatures remained notable (IRR= 1.30, 95% CI 1.00-1.69, p=0.05) up to four weeks post-exposure, whereas the impact of heat was more immediate (IRR= 1.36, 95% CI 1.01-1.83, p=0.04), occurring within the week of exposure. **Conclusion:** As the effects of climate change intensify, children are at heightened risk from diseases induced by extreme temperatures. Findings indicate that toddlers with respiratory diseases were more likely to be seen in emergency rooms and hospitals when exposed to both extreme heat and extreme cold temperatures. Addressing these exposures could potentially decrease the number of hospital admissions and emergency visits.

Keywords: Environmental epidemiology; Climate change; Extreme temperature; Children; Infants; Toddlers; Preschoolers.

1 Introduction

As the global community confronts climate change, one of its most alarming consequences is the increasing prevalence of temperature extremes [1, 2]. With the Earth's average surface temperature projected to rise significantly by the end of the century, regions worldwide are experiencing intensified and frequent episodes of both hot and cold temperatures [3, 4]. While these temperature fluctuations are a concern for all, specific population groups, especially those that experience vulnerability and lower resilience, are at a heightened risk. Of these, the very essence of our future, children are undeniably among the most susceptible [5, 6, 7, 8].

Earlier studies reporting the impact of temperature on morbidity have focused predominantly on adults, particularly older adults [9, 10]. Children, by virtue of their developmental stage, possess unique physiological and metabolic characteristics that distinguish them from adults [11]. The age group of ≤ 5 years, in particular, is of significant concern [12, 13]. These early years of life are characterized by rapid growth and development, making them critically sensitive to environmental stressors, including temperature extremes [14, 15, 16]. Their still-evolving thermoregulatory systems, combined with a limited ability to readily communicate discomfort or adopt self-care measures, create unique vulnerability [17, 18]. It has been emphasized in some public health publications that persistent extreme temperatures may raise the incidence of pediatric diseases [12, 16]. While previous studies have examined associations between meteorological variables, air pollution, and adverse health outcomes using an explanatory approach [19, 20, 21, 22, 23], no study in a metropolitan center with a humid continental climate zone has separately quantified the effects of weekly extreme temperatures on infants and young children ≤ 5 years, stratified by age and sex.

This time-series regression study aims to explore the association between temperature, particularly extreme heat- and cold-related exposures, and hospital admissions and emergency visits of infants and children ≤ 5 years in Edmonton, Alberta.

2 Methodology

2.1 Study design, setting, and population

This time-series regression study used meteorological, air quality, and health services data for hospital admissions and emergency visits from January 1, 2015, to December 31, 2018. The main aim was to explore whether week-to-week changes in the number of respiratory diseases, potentially heat-related illnesses, and injury presentations are explained by changes in the weekly average maximum and minimum temperatures.

Edmonton is situated on the North Saskatchewan River, with a land area of 765.61 square kilometers (km^2) and a population density of 1,320.4/km^2 [24]. In 2016, Edmonton had a total population of 932,546, with an average age of 37.7 [25], of which children aged ≤ 5 years comprised 6.1% [24]. Edmonton has a humid continental climate with freezing, dry winters lasting from November to March and warm, sunny summers that last from late June until early September [26]. According to the Canadian Climate Normals 1981-2010 Station Data, Edmonton's average daily temperatures range from −10.4 °C in January to 17.7 °C in July, with an extreme minimum of -48.3 °C recorded in December 1938 and an extreme maximum of 34.9 °C recorded in June 2002 [26]. In the metropolitan center of Edmonton, local air quality is notably influenced by factors such as major petrochemical industrial operations and air pollutants from wildfires within Alberta and neighboring provinces and states [27]. These contributing factors result in Edmonton's atmospheric conditions often having higher levels of specific pollutants when compared to other regions within the province. Among these pollutants, the concentrations of fine particulate matter ($PM_{2.5}$), ozone (O_3), and nitrogen dioxide (NO_2) are prominently elevated [27].

Within Canada, residents have access to a universal healthcare system funded through taxes covering emergency department visits, physician visits, and hospital care [28]. Edmonton has four main hospitals with emergency departments that see children, one of which is a primary children’s tertiary care center.

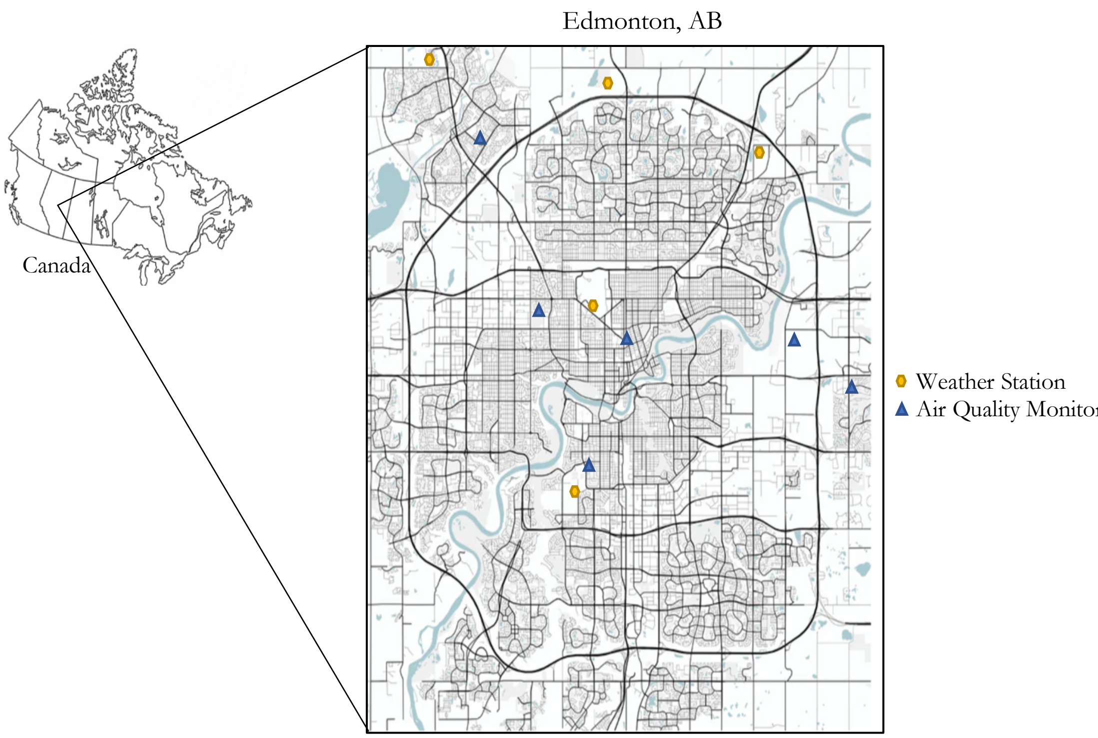

Figure 1- A map outlining the city of Edmonton, Alberta, features the positions of local weather stations and air quality monitoring devices. Additional stations positioned beyond the city boundaries were also integrated into the analysis.

Reference: weather monitors map: https://acis.alberta.ca/weather-data-viewer.jsp (accessed on July 27, 2023); air monitors map: https://capitalairshed.ca/monitoring-data/live-air-data-map/ + https://airquality.alberta.ca/map/ (accessed on July 27, 2023) Edmonton map: https://as2.ftcdn.net/v2/jpg/05/11/57/07/1000_F_511570778_dwcZ2gX5j7jUL9L6qalLPDf5QsYuYgXN.jpg (accessed on July 26, 2023); Canada map: https://www.theblog.ca/wp-content/uploads/2006/11/mapofcanada.jpg (accessed on July 26, 2023)

2.2 Health Outcomes Data

Healthcare data were gathered from two Canadian health administrative databases: the Alberta Health Services (AHS) discharge abstract database (DAD) for inpatient hospital discharge data and the National Ambulatory Care Reporting System (NACRS) for the emergency department, day surgery, and outpatient facilities data [29, 30]. The 9th and 10th International Classification of Diseases revisions (ICD-9 and ICD-10, respectively) were used to identify the adverse health outcomes of heat- and cold-related exposure among children residing in Edmonton, AB, for the study period from January 1, 2015, to December 31, 2018, by linking the physician claims data in the DAD and NACRS databases from January 1, 2015, to December 31, 2018 (Appendix 1). Reported adverse health outcomes of extreme heat- and cold-related exposure captured by healthcare service use in Edmonton included cause-specific respiratory diseases, heatstroke, and hypothermia (ICD-9: 992.0, 991.6; ICD-10: T67, T68), and injuries (ICD-9: 800-999; ICD-10:

S00-T98) [31, 32]. Respiratory diseases include acute bronchitis (ICD-9: 466.0; ICD-10: J20.9), acute respiratory disease (ICD-9: 460-519; ICD-10: J06.9, J98.9), asthma (ICD-9: 493; ICD-10: J45), bronchiolitis (ICD-9: 466.1; ICD-10: J21.0), chronic obstructive pulmonary disease (COPD)(ICD-9: 491-496; ICD-10: J44), pneumonia (ICD-9: 480-488; ICD-10: J12-J18), shortness of breath (ICD-9: 786.05; ICD-10: R06.02), and wheezing (ICD-9: 786.07; ICD-10: R06.2) [31, 32]. The health data from the AHS included information about the date of visit, age (years), sex (male/female), zone of residence of the patient (RCPT_ZONE) and scrambled unique identifier (ULI). The data were linked to the outcome data from DAD and NACRS based on the date of the visit and the associated ULI number. Duplicates on date, ULI, age, sex, and data source were eliminated. The health data were aggregated to weekly levels to ensure statistical robustness and a comprehensive view of health outcomes. This approach addresses the challenge posed by the lower frequency of visits in our daily dataset.

2.3 Meteorological and Air Quality Data

Meteorological data from January 1, 2015, to December 31, 2018, was acquired from the Alberta Climate Information Service (ACIS), including daily average temperature and relative humidity [31]. $PM_{2.5}$ and O_3 are critical indicators in studies exploring the health impacts of extreme temperatures [16, 32, 33] because they represent airborne particles that are small enough to be inhaled into the lungs and enter the bloodstream, causing adverse health effects, particularly respiratory and cardiovascular diseases [34, 35]. O_3 is also known to exacerbate existing respiratory conditions and increase susceptibility to respiratory infections [36, 37]. Data from ACIS was also utilized to gather information on the air quality, specifically on hourly average units [38]. To account for sample size considerations and gain a clearer insight into the health impacts of temperature extremes on children aged 0 to 5, we shifted our analysis from daily to weekly averages, encompassing temperature, humidity, $PM_{2.5}$, and O_3 measurements. The study focuses on the effects of temperature on this age group, and it uses meteorological data from nearby weather and air quality stations (five stations) around Edmonton for the same period to highlight the connection between these variables and children's health (Figure 1). Although the city had three weather stations within its limits, data from 14 surrounding stations strategically located across all sections of Edmonton were included to improve precision in spatial interpolation.

2.4 Defining Extreme Temperatures

The definition of extreme temperature and its threshold varies across different regions or countries and can depend on various factors such as climate, geography, and local weather patterns owing to variations in population characteristics and adaptation [39, 40, 41, 42, 43, 44]. In other words, an extreme value in one location may be within the normal range in a different location. In our study, we employed a weekly dataset to assess the aggregated impact of extreme temperature conditions. To define the thresholds for what we considered extremely high temperatures (leading to extreme heat events) and extremely low temperatures (leading to extreme cold events) in Edmonton, we referred to statistical percentiles: the 95th percentile was used to set the upper-temperature limit based on the average of weekly maximum temperatures, and the 5th percentile set the lower limit based on the average of weekly minimum temperatures [26]. These particular percentile thresholds were selected because they indicate temperature values that are markedly higher or lower than the typical temperature range, thereby providing a reliable measure of extreme temperature events [45, 46, 47].

2.5 Statistical Analysis

Time series regression analysis was used to quantify the main impact of temperature, particularly extreme temperatures, on the outcome, hospital admissions, and emergency visits. The data covers January 1, 2015, to December 31, 2018, representing 209 data points based on a weekly dataset. Health outcomes data were stratified by age and sex with distributed lag nonlinear models while controlling for long-trend and seasonality, relative humidity, $PM_{2.5}$, and O_3. The extreme heat and cold impact on cause-specific respiratory disease analysis stratified by age controlled for other variables were separately performed. Monitoring data were utilized to determine the weekly mean measurements and concentrations and the maximum weekly moving average concentrations, which were subsequently employed in the analysis.

The initial statistical analysis involved a comprehensive descriptive analysis of the weekly assembled data. Weekly average temperatures and relative humidity were calculated based on the daily mean measurements. Whereas weekly average concentrations of $PM_{2.5}$ were calculated based on the hourly average concentration of each day, and the 8-hour weekly maximum average concentrations of O_3 were calculated based on the estimated 8-hour daily maximum concentration.

The mean and standard deviation (SD). Additionally, the minimum and maximum values, the 5th, 25th, 50th (median), 75th, and 95th percentiles, were evaluated and calculated for each meteorological and air quality variable under consideration to provide an extensive view of our data distribution, which offered a broader understanding of the variability and spread of the dataset.

Missing data were analyzed. Generally, a 4-year period would have 35,064 hours, considering it includes a leap year. One data point was one hourly mean value of daily air pollutant concentrations from 2015 to 2018. A day with more than 10% missing data points was considered missing. The calculation of missing data points and missing days did not include pollutants that were not regularly measured at stations. $PM_{2.5}$ was measured at all stations except Edmonton East and Edmonton South, and O_3 included all stations except for Edmonton McIntyre.

Step I: Estimating the main effects of temperature on hospital admissions and emergency visits for children ages 0 to 5.

There were five phases to estimate the main effects of extreme temperature on hospital admissions and emergency visits. Firstly, a Poisson regression analysis was used for the count data of hospital admissions and emergency visits while acknowledging its underlying assumptions. Negative binomial regression models were incorporated to account for over-dispersion in the event of significant likelihood ratio tests for the alpha parameter (λ) in Poisson regression models pointing to over-dispersion [48]. The second phase included generating distributed lag nonlinear models to consider lagged effects and different lag structures; lag 0 (effects happening within the same week) and lag 1 (effects observed after a week), which were assessed for both temperature and covariates. Overloading the model with numerous lags could raise the error margin, and on the contrary, having too few lags might leave out important pertinent information [48]. Of three popular criteria used to determine the optimal number of lags, Akaike's information criterion (AIC), which is usually applied to monthly datasets, was selected over Hannan and Quinn's information criterion (HQ) or Schwarz's Bayesian information criterion (SBIC) [49], which are often preferred for quarterly datasets [49]. These lagged exposure effects were also adjusted for collinearity using constrained distributed lag nonlinear models [48]. Unconstrained models showed that the individual lag effects were highly correlated and confounded, hence the implementation of constrained models to handle the collinearity [48]. These constrained lags were determined by the patterns shown in the unconstrained model, and those with similar values were treated as equivalent [48]. Long-term trends and seasonality were controlled using flexible spline functions, where different reference points were selected based on distribution characteristics (i.e., knots were placed based on specific data distribution characteristics, such as areas with high variability) using the formula [= (the number of calendar years x 7)- 1] [48, 49]. The analysis also controlled for other time-varying factors, such as relative humidity, $PM_{2.5}$, and O_3, as potential confounding factors. The linearity assumption of continuous variables (temperature, humidity, air pollutant concentrations) was analyzed by generating a scatter plot and observing the pattern of each variable. Lastly, model fit was examined for all included steps by generating diagnostic plots based on deviance residuals.

Step II: Estimating the impact of extreme heat on total, age- and sex-specific hospital admissions and emergency visits.

In Step II, the focus is on estimating the impact of extreme heat on hospital admissions and emergency visits, factoring in age and sex variations, using the 95th percentile of the weekly average temperature to classify a week of extreme heat event. Stratified analyses were conducted by age and sex. Effect estimates were obtained for sex (male and female) and three age groups (0–1, 2–3, and 4–5 years) to enable the differentiation of extreme heat temperature effects across these demographic strata, ensuring a comprehensive understanding of the varying susceptibilities. As in Step I, the models in the analysis of Step II incorporated constrained lags and controlled for seasonality and other potential confounding factors, including relative humidity, $PM_{2.5}$, and O_3, to ensure the observed effects are primarily attributed to extreme heat events.

Step III: Estimating the impact of extreme cold on total, age- and sex-specific hospital admissions and emergency visits.

Using the same approach as Step II, Step III emphasizes assessing the impact of extreme cold on hospital admissions and emergency visits, considering age and sex differences. To this end, any week where the average temperature falls below the 5th percentile is designated as a week of extreme cold.

Stata/SE 18.0 (Stata Corp LLC, College Station, TX) was employed for statistical analysis in this study. Ethics approval for the research project was obtained from the University of Alberta Health Research Ethics Board. The project ID is PRO00106985, and the research ID is RES0051992.

3 Results

Of the 5,970 included events, (30.4%) were hospital admissions, and (69.6%) were emergency visits for children under five. Between 2015 and 2018, infants (0-1 years old) had the highest hospital admissions and emergency visits rate at 40%, followed by toddlers (2-3 years old) at 31% and preschoolers (4-5 years old) at 29% (Table 1). The majority were male (60.5%). The leading causes for all encounters were respiratory diseases (92.1%), of which asthma (48.3%) and bronchiolitis (16.2%) were the most common respiratory diagnoses. Among the reported cases, injuries constituted over (7.8%), while instances of heat exhaustion (0.03%) and hypothermia (0.02%) were notably rarer. The prevalence of weekly hospital admissions and emergency visits among children was used in this study rather than incident cases.

The average weekly temperature was 3.95 °C, ranging from -19.73 to 21.06 °C. Relative humidity averaged 70.48%, with values between 37.75% and 95.33%. $PM_{2.5}$ and O_3 had weekly averages of 8.29 μg/m^3 (3.31–59.65) and 29.80 ppb (8.15–53.27), respectively (Table 2). The recorded average temperatures indicate a marked seasonal variation, with summer exhibiting an average temperature of 16.31 °C, which contrasts sharply with the winter season, where the average temperature is -7.52 °C (Table 3). Generally, the proportion of encounters was higher during the spring (27.2%) and winter seasons (41.4%), while fewer encounters were seen during the fall (13.9%) and summer seasons (17.4%) (Table 4). "Extreme heat" was defined as temperatures exceeding the 95th percentile, averaging 18.14 °C. Conversely, "extreme cold" was identified as temperatures below the 5th percentile, with an average of -14.88 °C.

Table 1- Summary statistics for hospital admissions and emergency visits of children aged 0-5 by age group in Edmonton, Alberta, from 2015-2018.

	Overall (0-5 yrs.) N (%) (Mean, SD)	Infant (0-1 yrs.) N (%) (Mean, SD)	Toddler (2-3 yrs.) N (%) (Mean, SD)	Preschool (4-5 yrs.) N (%) (Mean, SD)
All-cause hospital admission	1,816 (30.4)	1,032 (17.3)	451 (7.6)	333 (5.6)
All-cause emergency visits	4,154 (69.6)	1,360 (22.8)	1,399 (23.4)	1,395 (23.4)
	(1.69, 0.46)	(0.63, 0.83)	(0.54, 0.85)	(0.52, 0.85)
Sex				
Male	3,610 (60.5)	1,456 (24.4)	1,076 (18.0)	1,078 (18.1)
Female	2,360 (39.5)	936 (15.7)	774 (12.9)	650 (10.9)
	(1.60, 0.49)	(0.64, 0.85)	(0.49, 0.78)	(0.47, 0.78)
Cause-specific hospital admission and emergency visits				
Respiratory diseases	5,500 (92.2)	2,244 (37.6)	1,697 (28.4)	1,559 (26.1)
Injuries	467 (7.8)	147 (2.5)	151 (2.5)	169 (2.8)
Hypothermia	1 (0.02)	1 (0.02)	0	0
Heat exhaustion	2 (0.03)	0	2 (0.03)	0
	(4.08, 2.57)	(4.33, 2.56)	(3.95, 2.62)	(3.88, 2.47)
Total	5970	2,392	1,850	1,728

The distribution of average temperature, relative humidity, O_3, and $PM_{2.5}$ levels are presented in Figure 2A-D. The weekly distribution of total hospital admissions and emergency visits is plotted against the weekly average temperature, demonstrating that hospital admissions and emergency visits for children aged 0-5 years increased during high and low temperatures (Figure 3A). Notable patterns emerged when analyzing extreme temperature events. During our study, we observed 11 weeks that met the criteria for extreme heat events during summer and 11 weeks of extreme cold incidents during winter (Table 5) and (Figure 3B). Based on the AIC results, the findings decisively converged on the selection of different lag periods for variables included in the analysis (Appendix 2), all of which suggest a model that captures the key patterns in the data while resisting overfitting. The underlying seasonal patterns unrelated to temperature and any trends in the admissions data were controlled for using the cubic spline functions of time used for all models in all steps of the analysis, using 27 knots (Figure 4).

Table 2- Summary of weekly mean temperature, diurnal temperature change, humidity, and air pollution (O_3, $PM_{2.5}$) in Edmonton, Alberta, from 2015-2018.

					Percentiles (%)					
Environmental variables	N	Mean	SD	Min	5	25	50	75	95	Max
Air temperatures (°C)	-	3.95	10.75	-19.73	-14.88	-3.82	4.92	14.29	18.14	21.06
Diurnal temp (°C)	-	11.44	2.96	2.25	6.75	9.28	11.74	13.66	16.15	17.53
Relative humidity (%)	-	70.48	11.31	37.75	47.17	65.40	71.43	78.79	86.13	95.33
O_3 (ppb)	-	29.80	9.63	8.15	15.42	22.93	28.45	37.23	46.81	53.27
$PM_{2.5}$ (μg/m^3)	-	8.29	5.94	3.31	4.28	5.46	6.90	8.97	15.49	59.65

Table 3- Summary of weekly mean temperature data in Edmonton, Alberta, from 2015-2018 by season.

					Percentiles (%)					
Season	N	Mean	SD	Min	5	25	50	75	95	Max
Fall (Sep-Oct)	-	6.24	4.02	-1.44	-0.43	2.89	5.83	9.36	11.38	14.29
Spring (Mar-May)	-	5.21	7.86	-12.84	-11.90	1.07	6.31	11.26	15.81	17.61
Summer (Jun-Aug)	-	16.31	2.10	10.47	12.62	14.97	16.48	17.89	19.28	21.06
Winter (Nov-Feb)	-	-7.52	6.24	-19.73	-18.58	-11.83	-5.97	-3.10	2.48	7.58

Table 4- Number of hospital admissions and emergency visits for 0-5-year-old children per season.

Events by season	Total N (%)	Infant N (%)	Toddler N (%)	Preschool N (%)	Female N (%)	Male N (%)
Fall (Sep-Oct)	830 (13.9)	273 (11.4)	271(14.7)	286 (16.6)	320 (13.6)	510 (14.1)
Spring (Mar-May)	1626 (27.2)	661(27.6)	479 (25.9)	486 (28.1)	634 (26.9)	992 (27.5)
Summer (Jun-Aug)	1041 (17.4)	293 (12.3)	373 (20.2)	375 (21.7)	398 (16.9)	643 (17.8)
Winter (Nov-Feb)	2473 (41.4)	1165 (48.7)	727 (39.3)	581 (33.6)	1008 (42.7)	1465 (40.6)
Total	5,970	2,392	1,850	1,728	2,360	3,610

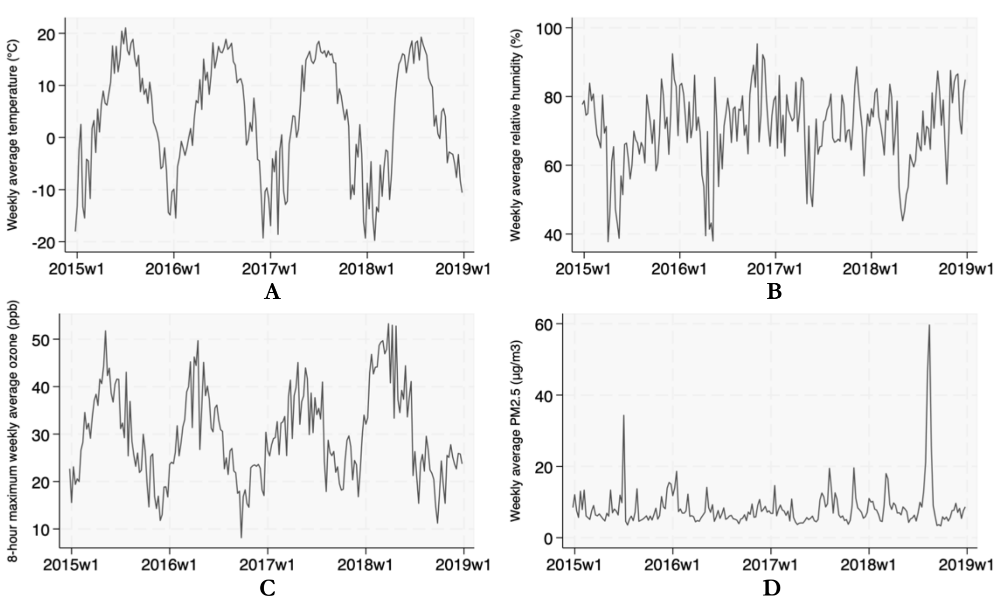

Figure 2- (A) The weekly distribution of weekly average temperature (°C), (B) The weekly distribution of relative humidity (%), (C) The weekly distribution of 8-hour maximum ozone or O_3 (ppb), and (D) The weekly distribution of fine particulate matter or $PM_{2.5}$ (μg/m^3).

A

B

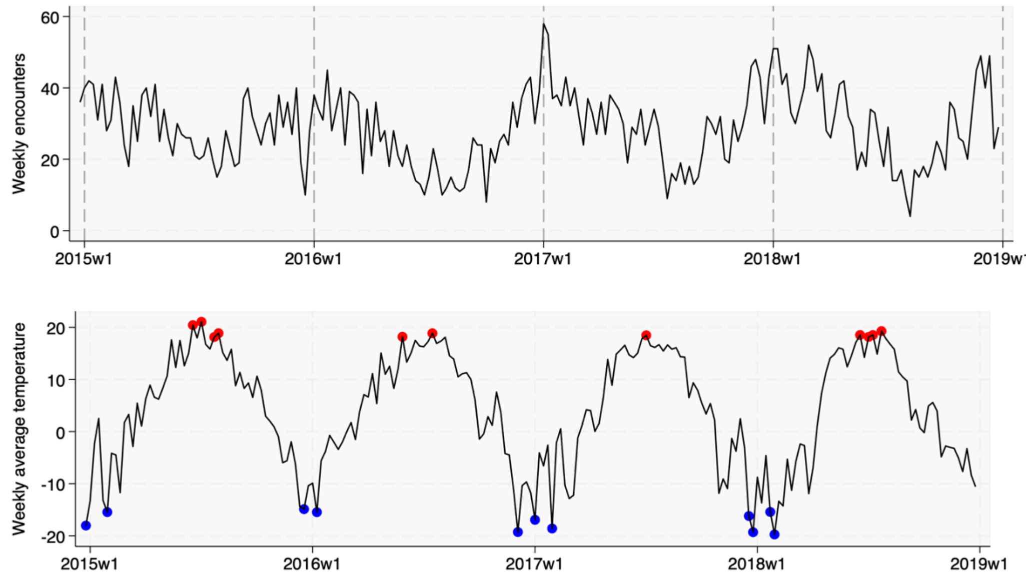

Figure 3- (A) Weekly hospital admission and emergency visits and weekly average temperature in Edmonton, AB, from 2015 to 2018. (B) Temporal distribution of temperatures. Red markers denote days with extreme hot temperatures, identified as temperatures above 18.1 °C. In contrast, blue markers indicate days with extreme cold temperatures, classified as temperatures below -14.8 °C.

Table 5- Summary of extreme temperature events according to the 5th and 95th percentile of weekly temperature measurements in Edmonton, Alberta, from 2015-2018.

Extreme event variable	Date	Week	Average temperature (°C)
Extreme heat events	25-Jun-15	2015w25	20.43
95th percentile (18.14 °C)	09-Jul-15	2015w27	21.06
	30-Jul-15	2015w30	18.14
	06-Aug-15	2015w31	18.87
	02-Jun-16	2016w22	18.19
	21-Jul-16	2016w29	18.87
	06-Jul-17	2017w27	18.48
	21-Jun-18	2018w25	18.53
	05-Jul-18	2018w27	18.16
	12-Jul-18	2018w28	18.53
	26-Jul-18	2018w30	19.28
Extreme cold events	01-Jan-15	2014w52	-18.03
5th percentile (-14.88 °C)	05-Feb-15	2015w5	-15.44
	24-Dec-15	2015w51	-14.88
	14-Jan-16	2016w2	-15.46
	08-Dec-16	2016w49	-19.27
	05-Jan-17	2017w1	-16.92
	02-Feb-17	2017w5	-18.58
	21-Dec-17	2017w51	-16.19
	28-Dec-17	2017w52	-19.3
	25-Jan-18	2018w4	-15.41
	01-Feb-18	2018w5	-19.73

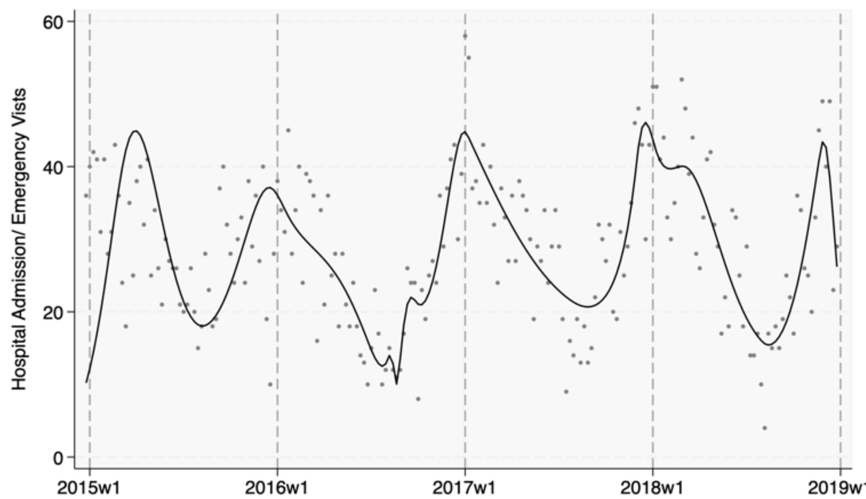

Figure 4- Modeling flexible spline functions to control for long-term trends and seasonality effect. The black solid line summarizes the seasonal pattern using a cubic spline of time. A total of 27 knots were applied [= (the number of calendar years x 7)- 1].

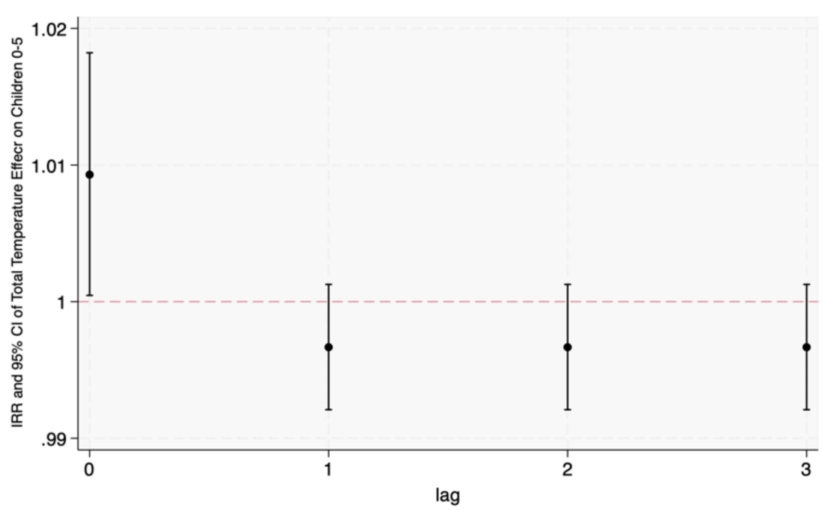

Figure 5- The estimated weekly lagged effects of average temperature on all encounters over time. A modest yet significant 1% increase in children aged five and under encounters at lag 0. Lags 1 and 2 were the same because they were defined as the same in the constrained lag model.

In our study, the average temperature lagged effects showed a slight but significant 1% increase in hospital admissions and emergency visits for children aged 5 and under during the week of exposure (IRR= 1.01, 95% CI 1.00-1.02, p=0.05) (Figure 5). However, when focusing on the exposure to extreme heat events (at the 95th percentile), children aged 2-3 appeared more susceptible to the exposure than children aged 1-2 and 4-5 years. For this age group, the increase in health events was evident (IRR= 1.36, 95% CI 1.03-1.80, p=0.03) during the same week of exposure (refer to Figure 6B-D). However, there was no observable effect on total hospital encounters for children aged 0-5 (Figure 6A) or based on their sex during the week of extreme heat (Figure 6E-F), but a significant negative association was found in total and children 0-3 encounters one week after the exposure (Figure 6A-C) and (Appendix 3).

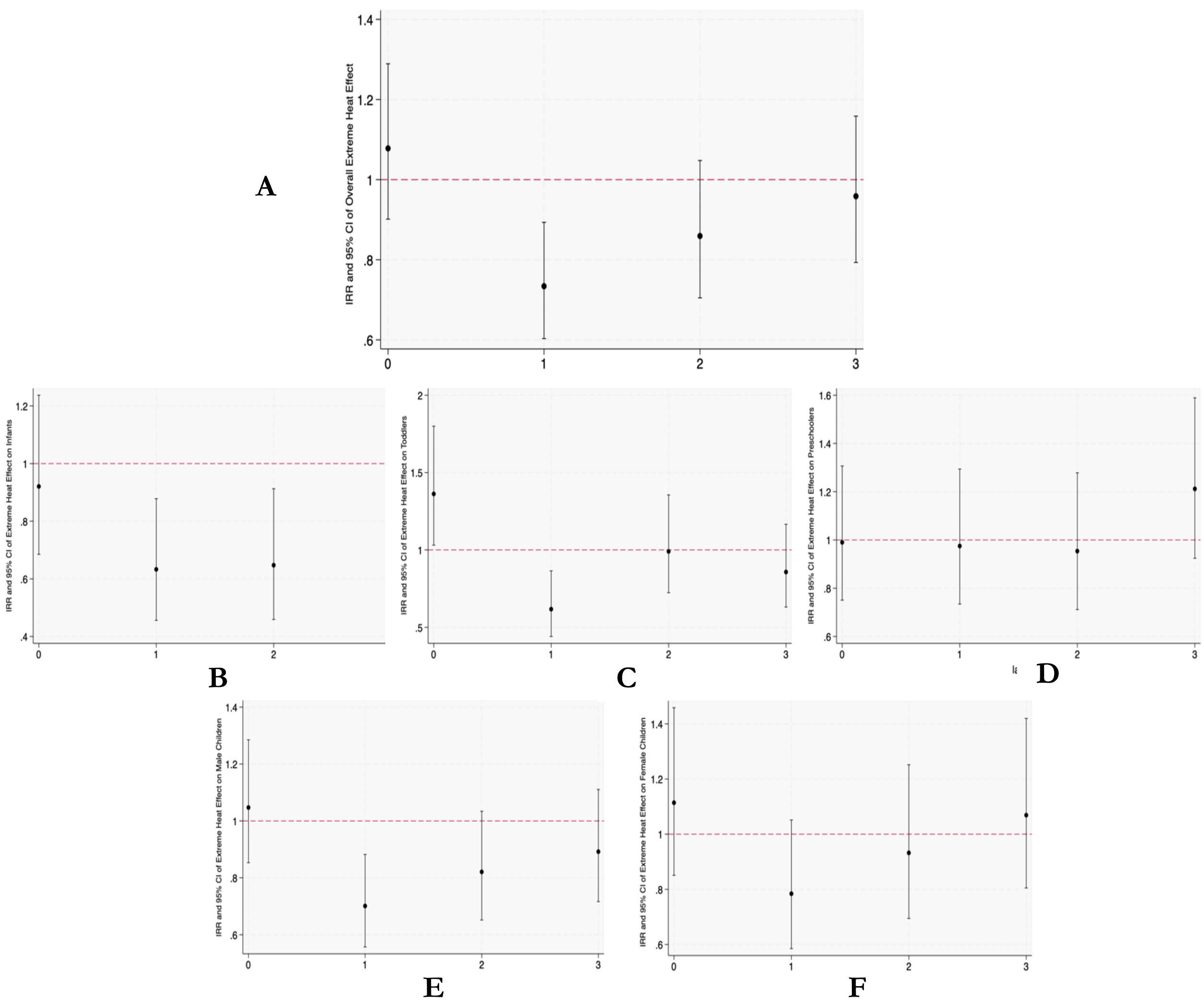

Figure 6- (A) The estimated weekly lagged effects of extreme heat on children ≤ 5 encounters, (B) The estimated weekly lagged effects of extreme heat on infants (0-1 yrs.) encounters, (C) The estimated weekly lagged effects of extreme heat on toddlers (2-3 yrs.) encounters, (D) The estimated weekly lagged effects of extreme heat on preschoolers (4-5 yrs.) encounters, (E) The estimated weekly lagged effects of extreme heat on male children encounters, and (F) The estimated weekly lagged effects of extreme heat on female children encounters. Children aged 2-3 years appeared more susceptible to the exposure than children aged 1-2 and 4-5 years at the same week of exposure.

When evaluating the effects of extreme cold events (at the 5th percentile) on pediatric encounters, toddlers aged 2-3 had a notable 30% increase in weekly hospital admissions and emergency visits occurring 4 weeks after the exposure (IRR= 1.30, 95% CI 1.01-1.67, p=0.05) (Figure 7C). In contrast, a positive correlation was observed for total pediatric hospital admissions and emergency visits, both age-specific (infant and preschool) and sex-specific, but this association was not statistically significant (Figure 7). Moreover, in children (2-3), extreme heat and cold temperatures were significantly associated with pediatric respiratory disease (acute bronchitis, acute respiratory disease, asthma, bronchiolitis, chronic obstructive pulmonary disease, pneumonia, shortness of breath, and wheezing). The cold effect persisted (IRR= 1.30, 95% CI 1.00-1.69, p=0.05) 4 weeks after the exposure, and the heat effects were relatively more acute (IRR= 1.36, 95% CI 1.01-1.83, p=0.04) during the same week of exposure (Appendix 3).

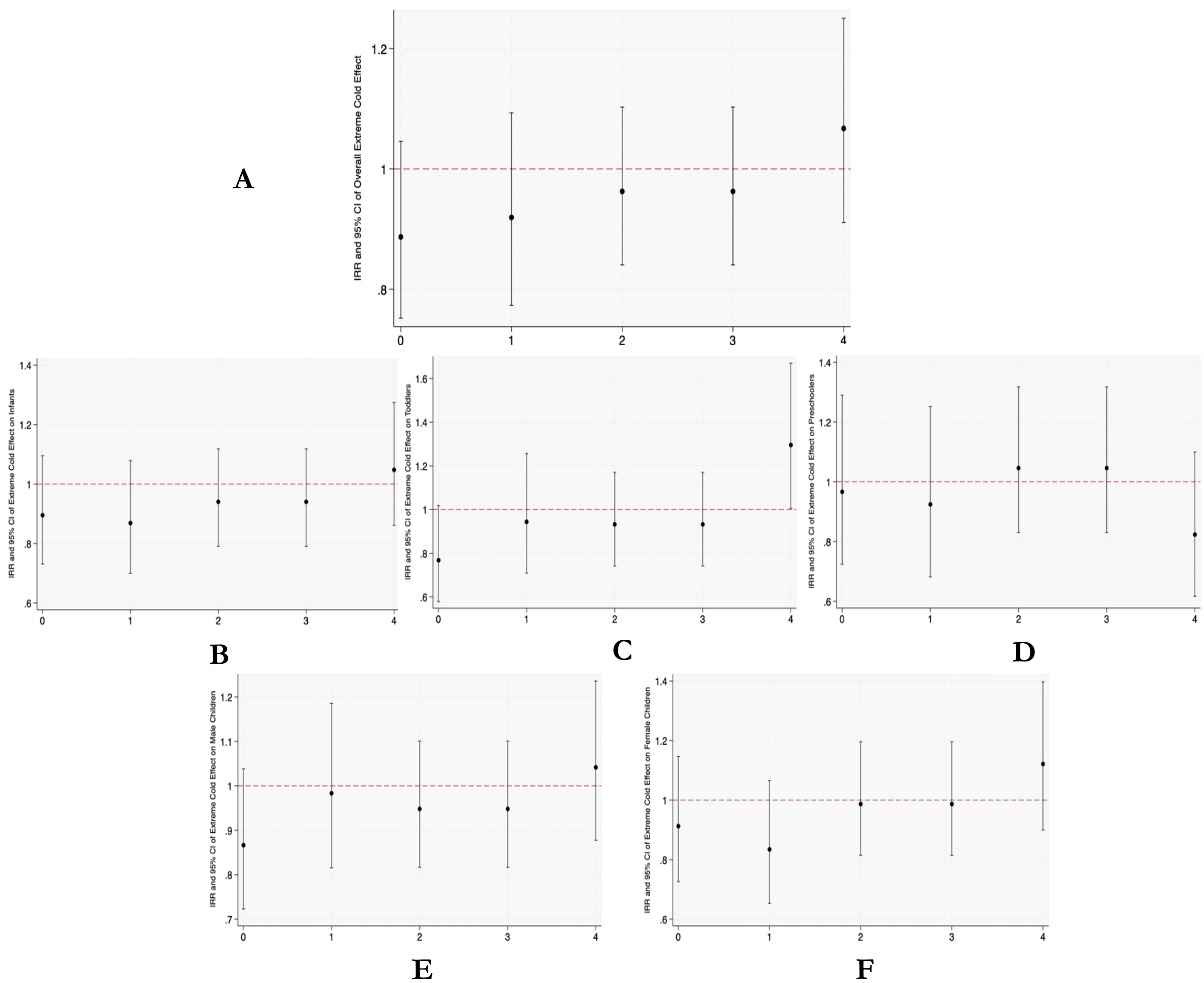

Figure 7- (A) The estimated weekly lagged effects of extreme cold on children ≤ 5 encounters, (B) The estimated weekly lagged effects of extreme cold on infants (0-1 yrs.) encounters, (C) The estimated weekly lagged effects of extreme cold on toddlers (2-3 yrs.) encounters, (D) The estimated weekly lagged effects

of extreme cold on preschoolers (4-5 yrs.) encounters, (E) The estimated weekly lagged effects of extreme cold on male children encounters, and (F) The estimated weekly lagged effects of extreme cold on female children encounters. Lags 2 and 3 were the same because they were defined as the same in the constrained lag model. Children 2-3 had a notable 30% increase in weekly hospital admissions and emergency visits occurring 4 weeks after the exposure.

Lag results are detailed in Appendix 2. Standardized residual deviations were used to visually assess the fit of the final models from Steps I, II, and III, including the model assumptions, identification of outliers, and influential points, as presented in Appendix 4. A separate analysis was performed to assess the unadjusted impact of normal warm and cold seasons on children aged 0-5. After adjusting for $PM_{2.5}$, O_3, and relative humidity, results indicated a 5% increase in hospital encounters for respiratory diseases among toddlers during the week of warm season exposure. Details of the lag results, estimated effects, and model fit evaluation are provided in Appendices 2, 3, and 4, respectively. Further information regarding variable definitions and the statistical methods used in this study is available in Appendix 5.

4 Discussion

In examining the effects of extreme temperatures on pediatric hospital admissions and emergency visits from 2015 to 2018 in Edmonton, it was found that both high and low temperatures significantly influenced these rates. Specifically, toddlers aged 2-3 years exhibited greater vulnerability to extreme heat and cold effects than children from infant and preschool age groups.

A modest yet significant 1% increase in children aged five and under encounters at lag 0 supports evidence about the immediate impacts of temperature fluctuation on health [50]. The aggregation of data on a weekly basis, while beneficial for statistical robustness and clarity of trends, may limit our ability to detect more immediate responses to temperature changes. While the immediate health effects of extreme heat exposure—specifically, those related to respiratory diseases, injury, heat exhaustion, and hypothermia—were prominently seen in the form of increased hospital admissions and emergency visits in the toddler group by 36%, the subsequent week revealed a notable decline, evidence referred to this phenomenon as the harvesting effect, where an event that causes an increase in mortality or morbidity in a population leads to a temporary reduction in the number of events in the following period [51, 52]. This negative association at a 1-week lag after extreme heat exposure was also evident across the infant and male groups. The absence of a significant association during the same week based on sex implies that both male and female children are equivalently vulnerable. This aligns with the findings from studies that children 0–4 years of age have been found to be vulnerable to hot and cold [53, 54, 55], mainly to persistent hot episodes [56, 57]. Nevertheless, other studies conducted in Singapore, Greece, and Malta, indicated a negative correlation between temperature and pediatric asthma admissions. Specifically, a Singaporean study observed that higher maximum temperatures were linked to fewer pediatric asthma admissions [58]. Similarly, research from Greece showed a decrease in hospital admissions for asthma in children aged 0–4 years with rising monthly air temperatures [53]. In Malta, a study found that mean monthly temperatures had an inverse relationship with monthly asthma admissions for various age groups, including children aged ≤1, 1-4, 5-9, and 10-14 years [59].

The substantial increase in hospital admissions and emergency visits 4 weeks post extreme cold events signals the chronic health effects of such climatic adversities. Analyzing the data by age group reveals differential vulnerabilities. Specifically, at 4 weeks after extreme cold events exposure, toddlers had a 30% increase in weekly hospital admissions and emergency visits due to respiratory diseases, injury, and hypothermia, with other variables held constant. No significant extreme cold impacts were noted in the infant or preschool age groups or by sex. This age-specific vulnerability emphasizes the need for targeted health interventions. During the cold months, pediatric hospitalizations had a notable rise due to viral acute lower respiratory infections as reported by Viegas and colleagues in Buenos Aires, Argentina [60]. Tchidjou and colleagues observed a direct correlation between low temperatures and an uptick in hospitalizations for acute respiratory infections in Yaoundé, Cameroon [61]. Similarly, in Santiago, low temperatures were linked with an increased pediatric respiratory consultation [62].

Sex-specific models showed no association between weekly hospital admissions and emergency visits during both extreme heat and cold events. However, other findings imply that variations in anthropometry, body composition (such as sexual dimorphism), and social behavior or daily activity may be the main reasons for the observed sex differences in vulnerability to extreme temperatures [57, 63]. During cold exposure, female children have a reduced thermal gradient for metabolic heat removal, which indicates that female children might retain heat more efficiently than male children, as a higher gradient would indicate faster heat loss [64]. Furthermore, female children have lower cardiovascular and metabolic responses, suggesting that the physiological reactions in female children, involving heart rate and metabolism response to cold, may be less intense than in male children when exposed to cold [64]. Our study's lack of observed sex-specific differences could be attributed to age group specificity, where physiological and behavioral differences between sexes may not be as pronounced or influential in determining vulnerability to temperature extremes in children aged 0-5 compared to older children or adults. It can also be due to our sample size and statistical power, which might not have been sufficient to detect sex-specific differences.

Human bodies automatically adjust to temperature changes to ensure comfort, facilitating mental and physical activities without detriment to health. Temperatures surpassing these limits increase the risk of adverse health outcomes. In this study, the effects of extreme heat events on toddlers' hospital admissions and emergency visits occurred during the same week of the exposure, a figure comparable with previous studies that reported shorter lag effects [65, 66]. We found that the extreme cold effects on toddlers lasted 4 weeks, which is consistent with the lag duration of cold effects on health outcomes [67]. The distinct lag times observed in toddlers' hospital admissions and emergency visits following extreme temperature events—immediate for heat and up to four weeks for cold—may be attributed to physiological and behavioral factors. Toddlers' limited thermoregulatory capabilities lead to a rapid onset of heat-related illnesses, prompting swift medical attention, while the more insidious nature of cold-related effects, like the gradual weakening of immune defenses and the subsequent development of respiratory infections, might result in delayed healthcare-seeking [66, 67]. While some results are consistent across different climates, the temperature thresholds leading to increased health issues differ regionally. This research also found associations for some commonly reported diseases in children, such as respiratory diseases [Appendix 3].

In this study, admissions for respiratory disease were found to increase due to extreme heat and cold events. Evidence shows that high temperatures lead to the formation of ground-level ozone, a primary component of smog, which, when inhaled, can irritate the respiratory system, and exacerbate conditions like asthma and chronic bronchitis [68, 69, 70]. Concurrently, warmer temperatures boost pollen production, triggering allergies and asthma symptoms in many children [68, 69, 70]. The air can become denser with airborne particles due to the increased evaporation rates that keep particles airborne longer, combined with thermal inversions that trap pollutants close to the ground, leading to higher exposure and potential respiratory problems [68, 70, 71]. The intense heat and humidity also make breathing more strenuous, especially for those with pre-existing respiratory issues [68, 70, 72]. Furthermore, warmer climates foster the growth and spread of respiratory infection-causing pathogens [68, 69]. In comparison, the effect of extreme cold temperatures on respiratory diseases may be partially due to cross-infection from indoor crowding; this, coupled with increased indoor heating that leads to more emissions, can exacerbate respiratory issues [73]. Cold temperatures aid the survival of bacteria in water droplets [74]. Similarly, cold temperatures may increase the incidence of pediatric influenza and, consequently, increase pediatric respiratory diseases [75]. Due to restrictions on available data, the fact that seasonal viral infections vary by year, and that viral diagnosis is not the standard of care for most respiratory presentations, this study did not address viral seasons, which might have included more exposure factors for modelling.

Addressing children's susceptibility to low and high temperatures is crucial and necessitates the development of proactive intervention measures. A foundational approach to managing the risks associated with extreme temperatures involves primary prevention, which can be achieved through comprehensive health education initiatives that equip parents and caregivers with the knowledge to protect their children [76]. Additionally, the implementation of an early warning system for heat events is particularly beneficial for parents of children with a history of chronic respiratory conditions, ensuring timely actions to reduce potential health risks.

This study enhances our understanding of the dynamics between temperature extremes and health by utilizing weekly average temperature data, which provides a detailed insight into short-term temperature fluctuations and their effects on hospital admissions and emergency visits for young children, a demographic particularly sensitive to such variations. This granularity, complemented by our use of lagged temperature variables, enables a comprehensive understanding of both immediate and delayed health responses to temperature variations. Given the single healthcare system where almost all health data is captured in a universal provincial system, most healthcare outcomes of interest were likely captured by our dataset. The detailed nature of this data, alongside the use of lagged temperature variables, affords a thorough comprehension of the immediate and delayed health responses to changes in temperature. Given the single healthcare system where almost all health data is captured in a universal provincial system, most healthcare outcomes of interest were likely captured by our dataset. It should be noted, however, that hospital admissions and emergency visits might represent the same child on different occasions, which could affect the perceived frequency of these occurrences. Events were linked to the visit date, and any duplicates were removed to address this issue. Nevertheless, it is important to acknowledge the limitations of our study. Our exposure measures were based on population averages, and the results must be viewed as group-level outcomes rather than individual occurrences. The generalizability of these findings is limited to similar climates and healthcare jurisdictions; however, our findings may encourage further research in different populations. As with many observational studies, deducing causality from the observed relationships remains challenging due to potential unaccounted time-varying factors.

5 Conclusion

The study highlights the effects of temperature extremes on young children's health. The findings also spotlight delayed health repercussions, suggesting that both immediate and extended health consequences should be considered. Importantly, toddlers aged 2-3 were particularly susceptible to cold and hot weather extremes, mainly presenting as a respiratory disease after adjusting for $PM_{2.5}$, O_3, relative humidity, seasonality, and long-term trend, underscoring their need for enhanced protective measures. Parents and caregivers must be acutely aware of health threats caused by extreme temperatures and utilize preventive measures, including adjusting the time children spend exposed, dressing them appropriately, and ensuring they stay hydrated. Considering these findings, there is a pressing need for further research focusing on the specific health challenges children face, especially the enduring impacts of exposure to extreme heat events, and identifying particularly at-risk groups, such as children with pre-existing conditions. A closer look at caregivers' reactions to severe weather alerts is also essential. Through a holistic research approach, we can devise strategies that robustly protect our youngest from the health impacts of extreme weather conditions.

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Chapter 4: DISCUSSION AND CONCLUSION

Extreme temperatures, a significant consequence of climate change, are becoming increasingly prevalent and threaten public health, especially in regions where the rate of warming exceeds global averages, such as Canada [1, 2, 3]. The doubling of warming rates in Canada has led its residents to confront the health repercussions of these severe temperature shifts [4, 5]. Particularly, young children are at a heightened risk due to factors that amplify their vulnerability and restrict their ability to adapt [6, 7]. As the frequency and intensity of extreme temperature events rise, there is a pressing need for targeted adaptation strategies [7]. These strategies should prioritize safeguarding the health of the most vulnerable communities by addressing specific regional hazards [8]. A deep understanding of young children's unique challenges and needs is paramount to tailor these interventions effectively. This thesis examined the relationship between extreme temperatures and health impacts on children ≤5 in Edmonton, AB, from 2015-2018.

4.1 Summary of Thesis Findings

When defining "extreme" temperatures using regional percentiles (5^{th} and 95^{th} percentiles), Edmonton experienced significant climatic variations, with 11 weeks that included extreme heat during summer and 11 of extreme cold in winter over the 4-year study period. A variety of measurement techniques have been employed to evaluate temperature impacts on human health. A relative approach makes it easier to compare different geographic climates because it is based on percentile-based indices of the local temperature distribution [9, 10, 11, 12, 13, 14, 15], while an absolute approach, designating temperature extremes with predetermined values (e.g., designate a day as "hot" if the temperature rises above 35°C [16] or define a frost day as a day with a minimum temperature lower than 0°C and a maximum temperature higher than 0°C), which may not always account for variations in local climate [17]. The methodological choice will impact the results, which could be amplified in sensitive subjects such as infants, toddlers, and preschoolers [18, 19]. The impact of a specific temperature event on human health can vary depending on where and when it occurs [20]. Cities with generally cooler climates show greater increases in mortality and hospitalizations from elevated temperatures than warmer cities [21, 22, 23, 24]. This implies that people can somewhat adapt to their usual climate conditions. Differences in infrastructure, such as more prevalent air conditioning in hotter regions like the Middle East, can partly explain this. Physiological acclimatization also plays a role. Over weeks to months in a hot environment, the body changes sweat production, blood flow, heat transfer to the skin, and kidney function, enhancing heat adaptability [25, 26]. Thus, heat events later in summer tend to cause fewer deaths compared to those early in the season, partly because of the deaths of some of the most vulnerable earlier in the season [27]. Children are at elevated risk due to their limited temperature regulation (i.e., body surface area to volume ratio, sweat rate, cardiovascular responses, and hydration status) and adaptation abilities [24, 28].

The study's findings that children aged 2–3 are more vulnerable to extreme heat and cold temperatures than children aged 0-1 and 4-5 highlight the significant impact of developmental and physiological changes during the toddler years on their sensitivity to extreme temperature events. This stage of childhood is characterized by a multitude of transformations that influence their overall well-being.

Firstly, toddlers experience increased mobility, which exposes them to a wider range of environmental conditions. Their ability to explore their surroundings grows, leading to a higher likelihood of encountering extreme temperatures [29, 30]. Toddlers, therefore, are likely to encounter extreme temperatures in both indoor and outdoor settings. Indoors, inadequate heating or cooling systems can expose them to extreme temperatures [30]. Outdoors, increased mobility, and exploration without constant supervision can lead to more direct exposure to environmental conditions [29]. Secondly, there are shifts in metabolic functions and the ongoing development of their thermoregulatory systems [25]. While these systems are evolving, toddlers may not regulate their body temperature efficiently, making them more susceptible to temperature-related illnesses, especially in extreme environmental conditions [31]. Additionally, toddlers undergo complex motor skill development, allowing for increased physical activity and active exploration [32]. However, their verbal communication skills and cognitive abilities may still be in the developmental phase [29, 33, 34]. This limitation can hinder their capacity to understand or effectively communicate their discomfort or sense of danger when exposed to extreme temperatures [33, 34]. Their natural curiosity, limited risk awareness, and evolving communication skills can place toddlers in perilous situations, such as straying into unsafe areas or inadequately dressing for adverse weather conditions [35]. Therefore, physiological and cognitive developments during this stage interplay to shape their vulnerability to extreme temperatures [36, 18]. In contrast, infants are less mobile, and preschoolers have already advanced their motor skills and cognitive abilities, affecting their response to temperature extremes [32, 33, 34]. Lastly, infants benefit from greater caregiver supervision, with parents and caregivers taking proactive measures to ensure their safety during extreme weather, while preschool-aged children possess more advanced verbal communication skills than toddlers, enabling them to express discomfort or distress related to extreme temperatures and allowing caregivers to respond promptly [32, 33, 34].

The role of parents and caregivers is crucial in mediating the exposure of toddlers to extreme temperatures. They are responsible for regulating the environments that toddlers access, both indoors and outdoors, and for ensuring that children are appropriately prepared for the weather conditions. Parents and caregivers also serve as the primary interpreters of a toddler's nonverbal cues of discomfort due to their underdeveloped communication skills.

While our study did not present different impacts on sex-specific analysis, other research has hinted at the role of anthropometry, body composition, and even daily social behavior in explaining the differences between male and female responses to extreme temperatures [28, 37]. During episodes of cold exposure, female children appear to have a unique physiological response by exhibiting a reduced thermal gradient for metabolic heat removal. In simpler terms, this suggests that female children might have a better ability to retain heat compared to males. A higher gradient in this context would typically mean that heat is being lost more rapidly from the body [38]. Female children also demonstrate lower cardiovascular and metabolic reactions when exposed to cold temperatures. This implies that when exposed to cold, the physiological changes related to heart rate and metabolism in female children are not as pronounced as in male children [38].

When comparing the results from the normal warm and cold seasons to the main model examining the impact of extreme temperatures on young children, toddlers were also at a higher risk of adverse respiratory outcomes compared to infants and preschoolers during warm seasons (Appendix 3, Table A3.7-8).

4.2 Contributions and Gaps

The investigation into the impacts of extreme temperatures on the health of children aged 0-5 in Edmonton, AB, offers valuable contributions to our understanding of pediatric environmental health and the specific challenges this age group faces. This study provides a granular, region-specific assessment of temperature extremes' health impacts, addressing a gap in location-targeted research. By concentrating on the 0-5 age cohort, the research offers insights into the unique vulnerabilities of early childhood, highlighting physiological, behavioral, and environmental factors that exacerbate health risks. The findings serve as an empirical foundation for public health initiatives and policy formulations tailored to protect children in Edmonton from temperature-related health challenges. While the study zeroes in on the 0-5 age group, comparisons with older children could further elucidate age-specific risks. Future studies could explore the interaction between socioeconomic factors (including immigration status) and temperature-related health outcomes in greater depth. This research focuses on immediate health repercussions, leaving the longer-term health implications of early life exposure to extreme temperatures as an important area for exploration.

4.3 Insights, Implications, and Recommendations

Given the current global conditions, the health effects of climate change are anticipated to increase. In the domain of clinical implications, several considerations emerge. Firstly, it is imperative for pediatricians and healthcare professionals in Edmonton to be adept at recognizing the early indicators of heat or cold-related diseases in children, especially during periods of extreme temperatures. In addition, parents and caregivers of young children should consistently receive advice on preventive care, which could include guidance on appropriate clothing, the importance of hydration, and the management of indoor environments (ensuring adequate ventilation, air-conditioning, and heating systems). From an infrastructure standpoint, hospitals and clinics in the region should anticipate and be prepared for a surge in temperature-related healthcare systems utilization among children during certain times of the year. Moreover, education and outreach are paramount. There is significant value in public health initiatives targeting parents and caregivers, with the potential to considerably reduce risks. Workshops, informational pamphlets, and community meetings on this issue can serve as effective tools.

On the research side, there is a need for long-term studies on the health impacts of extreme temperatures during early childhood. Investigating the intersection of socioeconomic factors with temperature vulnerabilities can also offer targeted intervention insights. Furthermore, interdisciplinary collaborations offer promise. By uniting the expertise of climate scientists, pediatricians, and public health professionals, a more holistic understanding of the problem and effective solutions can be achieved. Lastly, given Canada's distinct position — experiencing a rate of warming double the global average — it would be enlightening to carry out comparative research with other regions, offering a more expansive view of potential health outcomes and the strategies to counteract them.

4.4 Conclusion

This thesis contributes to the growing body of evidence that climate change, specifically in terms of extreme temperature events, is not a distant threat but a present reality with immediate health consequences for the most vulnerable populations, including young children in Edmonton, AB. While our findings add to the evidence that temperature extremes pose a significant health risk, they also reveal gaps in our understanding that necessitate further investigation, particularly in the context of our local community. Future research should focus on detailed impact assessments and the development of localized adaptation strategies tailored to the unique climate challenges faced by Edmonton. We must take decisive steps to ensure that our communities, especially our children, are not just surviving but thriving in the face of climate challenges, with strategies that reflect our region's specific needs and circumstances.

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APPENDICES

Appendix 1: Health outcome variables and ICD-9 and ICD-10 codes data dictionary

Table A1- Health outcome variables and ICD-9 and ICD-10 codes data dictionary

Health outcome condition	Category	ICD codes		Reference
		ICD- 9	ICD-10	
Acute upper respiratory infections	**Respiratory**			[1], [2]
Acute nasopharyngitis (common cold)		460	J00	
Acute sinusitis		461	J01	
Acute pharyngitis		462	J02	
Acute tonsillitis		463	J03	
Acute laryngitis		464.0	J04.0	
Acute obstructive laryngitis (croup) and epiglottitis		464.3, 464.4	J05	
Acute upper respiratory infections of multiple and unspecified sites		465	J06	
Pneumonia		487.8	J18	
Acute lower respiratory infections				
Acute bronchitis		466.0	J20	
Acute bronchiolitis		466.1	J21	
Other respiratory diseases				
Asthma		493	J45	
Shortness of breath		786.05	R06.0	
Wheezing		786.07	R06.2	
Chronic obstructive pulmonary disease (COPD)		496	J44.9	
Effect of heat and light	**Exposure to forces of nature**			[1], [2]
Heat exhaustion		992.3	T67.3	
Hypothermia		991.6	T68	
Fall related injury- exposure codes	**Injury**	E880- E888	W00-W19	[1], [2]
Fall related injury- outcome codes		920- 924	S00- T14	

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Appendix 2: Lag Selection Results

Table A2.1 Results of lag selection of the main effects of temperature model for ambient temperature

Lag	LL	LR	df	p	FPE	AIC	HQIC	SBIC
0	-775.684				114.38	7.57741	7.58396	7.59362
1	-616.618	318.13	1	0.000	24.4692	6.03529	6.04841	6.06771
2	-612.943	7.3481	1	0.007	23.8392	6.0092	6.02887	6.05783*
3	-610.918	4.0505*	1	0.044	23.602*	5.9992*	6.02543*	6.06404
4	-610.253	1.3304	1	0.249	23.6793	6.00247	6.03525	6.08352

Table A2.2 Results of lag selection of the main effects of temperature model for relative humidity

Lag	LL	LR	df	p	FPE	AIC	HQIC	SBIC
0	-788.982				130.226	7.70714	7.7137	7.72335
1	-752.384	73.198	1	0.000	92.016	7.35984	7.37295*	7.39226*
2	-751.38	2.0067	1	0.157	92.0132	7.35981	7.37948	7.40844
3	-750.899	.96317	1	0.326	92.48	7.36486	7.39109	7.4297
4	-748.131	5.5357*	1	0.019	90.8991*	7.34762*	7.3804	7.42867

Table A2.3 Results of lag selection of the main effects of temperature model for $PM_{2.5}$

Lag	LL	LR	df	p	FPE	AIC	HQIC	SBIC
0	-657.466				36.096	6.42406	6.43062	6.44027
1	-610.814	93.305*	1	0.000	23.1222	5.97867	5.99178*	6.01109*
2	-609.229	3.1706	1	0.075	22.9906*	5.97296*	5.99263	6.02159
3	-609.084	.2899	1	0.590	23.1833	5.9813	6.00753	6.04614
4	-609.045	.07807	1	0.780	23.4018	5.99068	6.02346	6.07173

Table A2.4 Results of lag selection of the main effects of temperature model for O_3

Lag	LL	LR	df	p	FPE	AIC	HQIC	SBIC
0	-754.489				93.0134	7.37062	7.37718	7.38683
1	-659.94	189.1	1	0.000	37.3404	6.45795	6.47107	6.49037
2	-645.268	29.344*	1	0.000	32.6776	6.32457	6.34424	6.3732*
3	-643.442	3.6525	1	0.056	32.4154	6.3165	6.34273*	6.38134
4	-642.174	2.5355	1	0.111	32.331*	6.31389*	6.34667	6.39494

Table A2.5 Results of lag selection of the main effects of temperature model for extreme heat temperature

Lag	LL	LR	df	p	FPE	AIC	HQIC	SBIC
0	14.5949				.051277	-.132633	-.126077	-.116424
1	16.4923	3.7947	1	0.051	.05083	-.141388	-.128275	-.108968
2	21.4424	9.9003	1	0.002	.048909	-.179926	-.160256	-.131296
3	25.2033	7.5218*	1	0.006	.047609*	-.206862*	-.180636*	-.142022*
4	25.4816	.55656	1	0.456	.047946	-.19982	-.167038	-.118771

Table A2.6 Results of lag selection of the main effects of temperature model for extreme cold temperature

Lag	LL	LR	df	p	FPE	AIC	HQIC	SBIC
0	23.8372				.046856	-.222802	-.216246	-.206592*
1	26.461	5.2475	1	0.022	.046119	-.238644	-.225531	-.206224
2	27.0952	1.2685	1	0.260	.046284	-.235075	-.215406	-.186446
3	27.7135	1.2366	1	0.266	.046457	-.231351	-.205126	-.166512
4	33.3326	11.238*	1	0.001	.04441*	-.276416*	-.243633*	-.195367

Table A2.7 Results of lag selection of the main effects of warm season models for ambient temperature

Lag	LL	LR	df	p	FPE	AIC	HQIC	SBIC
0	-228.971				38.0989	6.47806	6.49073	6.50993
1	-172.827	112.29	1	0.000	8.05947	4.92471	4.95006	4.98845
2	-170.202	5.2511*	1	0.022	7.69902*	4.87892*	4.91694*	4.97453*
3	-170.057	.28877	1	0.591	7.88738	4.90302	4.95371	5.0305
4	-169.709	.69666	1	0.404	8.03442	4.92138	4.98474	5.08072

Table A2.8 Results of lag selection of the main effects of warm season models for relative humidity

Lag	LL	LR	df	p	FPE	AIC	HQIC	SBIC
0	-247.878				64.8947	7.01064	7.02331	7.04251
1	-239.579	16.598*	1	0.000	52.8351*	6.80504*	6.83038*	6.86877*
2	-239.47	.2186	1	0.640	54.1794	6.83013	6.86815	6.92573
3	-239.411	.11777	1	0.731	55.6387	6.85664	6.90733	6.98411
4	-239.41	.00026	1	0.987	57.2346	6.8848	6.94817	7.04415

Table A2.9 Results of lag selection of the main effects of warm season models for $PM_{2.5}$

Lag	LL	LR	df	p	FPE	AIC	HQIC	SBIC
0	-258.075				86.4878	7.29788	7.31055	7.32975
1	-239.575	37*	1	0.000	52.8289	6.80492	6.83027*	6.86866*
2	-238.292	2.5654	1	0.109	52.4118*	6.79696*	6.83498	6.89256
3	-238.237	.10974	1	0.740	53.8296	6.82358	6.87427	6.95106
4	-238.22	.03467	1	0.852	55.3468	6.85126	6.91463	7.01061

Table A2.10 Results of lag selection of the main effects of warm season models for O_3

Lag	LL	LR	df	p	FPE	AIC	HQIC	SBIC
0	-239.996				51.9739	6.78862	6.80129	6.82049
1	-219.873	40.245	1	0.000	30.3286	6.24995	6.2753	6.31369
2	-216.509	6.7289*	1	0.009	28.3754*	6.18335*	6.22137*	6.27895*
3	-216.139	.73983	1	0.390	28.8855	6.2011	6.25179	6.32857
4	-215.064	2.1505	1	0.143	28.8276	6.19898	6.26234	6.35832

Table A2.11 Results of lag selection of the main effects of cold season models for ambient temperature

Lag	LL	LR	df	p	FPE	AIC	HQIC	SBIC
0	-378.003				98.8448	7.43143	7.44185	7.45716
1	-326.517	102.97	1	0.000	36.7316	6.44151	6.46235	6.49298*
2	-324.705	3.6244	1	0.057	36.1518	6.42559	6.45685	6.50279
3	-322.57	4.2701*	1	0.039	35.3569	6.40333	6.44501*	6.50627
4	-321.219	2.7026	1	0.100	35.1155*	6.39644*	6.44855	6.52512

Table A2.12 Results of lag selection of the main effects of cold season models for relative humidity

Lag	LL	LR	df	p	FPE	AIC	HQIC	SBIC
0	-407.643				176.75	8.01261	8.02304	8.03835
1	-388.094	39.099	1	0.000	122.857	7.64889	7.66974	7.70036*
2	-387.139	1.9094	1	0.167	122.968	7.64978	7.68105	7.72699
3	-387.139	.00035	1	0.985	125.405	7.66939	7.71107	7.77233
4	-382.822	8.6333*	1	0.003	117.514*	7.60436*	7.65646*	7.73303

Table A2.13 Results of lag selection of the main effects of cold season models for $PM_{2.5}$

Lag	LL	LR	df	p	FPE	AIC	HQIC	SBIC
0	-261.252				10.0174	5.1422	5.15262	5.16793
1	-249.694	23.116*	1	0.000	8.14419*	4.93518*	4.95602*	4.98665*
2	-249.163	1.0629	1	0.303	8.21945	4.94436	4.97563	5.02157
3	-249.158	.00875	1	0.925	8.38169	4.96389	5.00557	5.06683
4	-249.102	.1119	1	0.738	8.53861	4.9824	5.0345	5.11107

Table A2.14 Results of lag selection of the main effects of cold season models for O_3

Lag	LL	LR	df	p	FPE	AIC	HQIC	SBIC
0	-377.538				97.9484	7.42232	7.43274	7.44805
1	-331.451	92.174	1	0.000	40.4631	6.53826	6.5591	6.58973
2	-319.556	23.791	1	0.000	32.68	6.32462	6.35589	6.40183*
3	-317.529	4.0544	1	0.044	32.0291	6.30448	6.34617	6.40742
4	-314.976	5.1044*	1	0.024	31.0702*	6.27405*	6.32615*	6.40272

Appendix 3: Summary Tables of Estimated Cumulative Effects

Table A3.1 The estimated cumulative effect of weekly average temperature on total encounters for children under five in Edmonton, Alberta, from 2015-2018.

	Average weekly temperature effect (IRR (95% CI))			
	Lag 0	Lag 1 §	Lag 2 §	Lag 3
Total hospital admissions and emergency visits	1.01 ** (1.00-1.02)	1.00 (0.99-1.00)	1.00 (0.99-1.00)	1.00 (0.98-1.00)

§ Constrained lags were determined by the patterns shown in the unconstrained model, and those with similar values were treated as equivalent: lag 1 = lag 2.
* p-value = 0.05
** p-value = 0.01

Table A3.2 The estimated cumulative effect of extreme heat on total, age- and sex-specific hospital admissions and emergency visits of children aged 0-5 in Edmonton, Alberta, from 2015-2018.

	Extreme heat effect (IRR (95% CI))			
	Lag 0	Lag 1	Lag 2	Lag 3
Total hospital admissions and emergency visits	1.08 (0.90-1.29)	0.73 ** (0.60-0.89)	0.86 (0.70-1.12)	0.96 (0.79-1.16)
Age-specific hospital admissions and emergency visits				
Infant (0-1 yrs.)	0.92 (0.69-1.24)	0.63 ** (0.46-0.88)	0.65 ** (0.46-0.91)	0.82 (0.59-1.14)
Toddler (2-3 yrs.)	1.36 ** (1.03-1.80)	0.62 ** (0.44-0.86)	1.00 (0.72-1.36)	0.86 (0.63-1.17)
Preschool (4-5 yrs.)	1.00 (0.75-1.31)	0.97 (0.73-1.29)	0.95 (0.71-1.28)	1.21 (0.92-1.59)
Sex-specific hospital admission and emergency visits				
Male	1.05 (0.85-1.28)	0.70 (0.56-0.88)	0.82 (0.65-1.03)	0.89 (0.72-1.11)
Female	1.11 (0.85-1.46)	0.78 (0.58-1.05)	0.93 (0.69-1.25)	1.07 (0.80-1.42)

* p-value = 0.05
** p-value = 0.01

Table A3.3 The estimated cumulative effect of extreme cold on total, age- and sex-specific hospital admissions and emergency visits of children aged 0-5 in Edmonton, Alberta, from 2015-2018.

	Extreme cold effect (IRR (95% CI))				
	Lag 0	Lag 1	Lag 2 §	Lag 3 §	Lag 4
Total hospital admissions and emergency visits	0.89 (0.75-1.05)	0.92 (0.77-1.09)	0.96 (0.84-1.10)	0.96 (0.84-1.10)	1.07 (0.91-1.25)
Age-specific hospital admissions and emergency visits					
Infant (0-1 yrs.)	0.90 (0.73-1.10)	0.87 (0.70-1.08)	0.94 (0.79-1.12)	0.94 (0.79-1.12)	1.05 (0.86-1.27)
Toddler (2-3 yrs.)	0.77 (0.58-1.02)	0.94 (0.71-1.26)	0.93 (0.74-1.17)	0.93 (0.74-1.17)	1.30 * (1.01-1.67)
Preschool (4-5 yrs.)	0.97 (0.72-1.29)	0.92 (0.68-1.25)	1.05 (0.83-1.32)	1.05 (0.83-1.32)	0.82 (0.62-1.10)
Sex-specific hospital admission and emergency visits					
Male	0.87 (0.72-1.04)	0.98 (0.82-1.19)	0.95 (0.82-1.10)	0.95 (0.82-1.10)	1.04 (0.88-1.24)
Female	0.91 (0.73-1.15)	0.83 (0.65-1.07)	0.99 (0.81-1.19)	0.99 (0.81-1.19)	1.12 (0.90-1.40)

§ Constrained lags were determined by the patterns shown in the unconstrained model, and those with similar values were treated as equivalent: lag 2 = lag 3.
* p-value = 0.05
** p-value = 0.01

Table A3.4 The estimated cumulative effect of extreme heat on respiratory hospital admissions and emergency visits of children aged 0-5 in Edmonton, Alberta, from 2015-2018.

	Extreme heat effect (IRR (95% CI))			
	Lag 0	Lag 1	Lag 2	Lag 3
Total respiratory hospital admissions and emergency visits	1.05 (0.88-1.25)	0.70 ** (0.58-0.85)	0.81 ** (0.67-0.98)	0.94 (0.78-1.13)
Infant (0-1 yrs.)	0.86 (0.63-1.20)	0.63 ** (0.44-0.89)	0.55 ** (0.38-0.81)	0.81 (0.57-1.15)
Toddler (2-3 yrs.)	1.36 ** (1.01-1.83)	0.52 ** (0.36-0.76)	0.94 (0.67-1.32)	0.86 (0.62-1.19)
Preschool (4-5 yrs.)	0.96 (0.72-1.29)	1.00 (0.74-1.34)	0.93 (0.68-1.28)	1.19 (0.89-1.59)

* p-value = 0.05
** p-value = 0.01

Table A3.6 The estimated cumulative effect of extreme cold on respiratory hospital admissions and emergency visits of children aged 0-5 in Edmonton, Alberta, from 2015-2018.

	Extreme cold effect (IRR (95% CI))				
	Lag 0 §	Lag 1	Lag 2 §	Lag 3 §	Lag 4
Total respiratory hospital admissions and emergency visits	0.88 (0.74-1.05)	0.94 (0.78-1.13)	0.98 (0.85-1.13)	0.98 (0.85-1.13)	1.04 (0.88-1.24)
Infant (0-1 yrs.)	0.89 (0.72-1.10)	0.87 (0.69-1.09)	0.95 (0.79-1.14)	0.95 (0.79-1.14)	0.99 (0.81-1.22)
Toddler (2-3 yrs.)	0.81 (0.61-1.08)	1.00 (0.75-1.35)	0.96 (0.76-1.22)	0.96 (0.76-1.22)	1.30 * (1.00-1.69)
Preschool (4-5 yrs.)	0.89 (0.66-1.21)	0.94 (0.68-1.28)	1.06 (0.84-1.35)	1.06 (0.84-1.35)	0.83 (0.61-1.12)

§ Constrained lags were determined by the patterns shown in the unconstrained model, and those with similar values were treated as equivalent: lag 2 = lag 3.
* p-value = 0.05
** p-value = 0.01

Table A3.7 The estimated cumulative effect of warm season on total, age- and sex-specific respiratory hospital admissions and emergency visits of children aged 0-5 in Edmonton, Alberta, from 2015-2018.

	Warm season effect (IRR (95% CI))		
	Lag 0	Lag 1	Lag 2
Total hospital admissions and emergency visits	1.00 (0.97-1.04)	0.95 ** (0.92-0.98)	1.00 (0.97-1.02)
Age-specific hospital admissions and emergency visits			
Infant (0-1 yrs.)	1.02 (0.97-1.08)	0.97 (0.92-1.02)	0.96 ** (0.92-0.99)
Toddler (2-3 yrs.)	1.05 ** (1.01-1.10)	0.90 ** (0.86-0.95)	1.01 (0.98-1.05)
Preschool (4-5 yrs.)	0.95 ** (0.90-0.99)	0.97 (0.93-1.02)	1.02 (0.98-1.06)
Sex-specific hospital admission and emergency visits			
Male	1.01 (0.97-1.04)	0.94 ** (0.91-0.98)	1.00 (0.97-1.02)
Female	0.99 (0.95-1.04)	0.96 (0.91-1.01)	1.00 (0.96-1.03)

* p-value = 0.05
** p-value = 0.01

Table A3.8 The estimated cumulative effect of cold season on total, age- and sex-specific hospital admissions and emergency visits of children aged 0-5 in Edmonton, Alberta, from 2015-2018.

	Cold season effect (IRR (95% CI))			
	Lag 0	Lag 1 §	Lag 2 §	Lag 3
Total hospital admissions and emergency visits	1.00 (0.99-1.02)	0.99 ** (0.99-1.00)	0.99 ** (0.99-1.00)	0.99 ** (0.98-1.00)
Age-specific hospital admissions and emergency visits				
Infant (0-1 yrs.)	0.99 (0.98-1.01)	0.99 ** (0.98-1.00)	0.99 ** (0.98-1.00)	0.98 ** (0.97-0.99)
Toddler (2-3 yrs.)	1.00 (0.99-1.02)	1.00 (0.99-1.01)	1.00 (1.00-1.01)	0.99 (0.98-1.01)
Preschool (4-5 yrs.)	1.01 (0.99-1.03)	1.00 (0.99-1.01)	1.00 (0.99-1.01)	1.00 (0.98-1.01)
Sex-specific hospital admission and emergency visits				
Male	1.00 (0.99-1.02)	0.99 (0.98-1.00)	1.00 (1.00 -1.01)	1.00 (0.99-1.01)
Female	1.00 (0.99-1.02)	0.99 (0.99-1.00)	0.99 (0.99-1.00)	0.98 ** (0.97-0.99)

§ Constrained lags were determined by the patterns shown in the unconstrained model, and those with similar values were treated as equivalent: lag 1 = lag 2.
* p-value = 0.05
** p-value = 0.01

Appendix 4: Standardized Deviation Residual Plots

Plots of Step I: Estimating the main effects of temperature on hospital admissions and emergency visits for children ages 0 to 5.

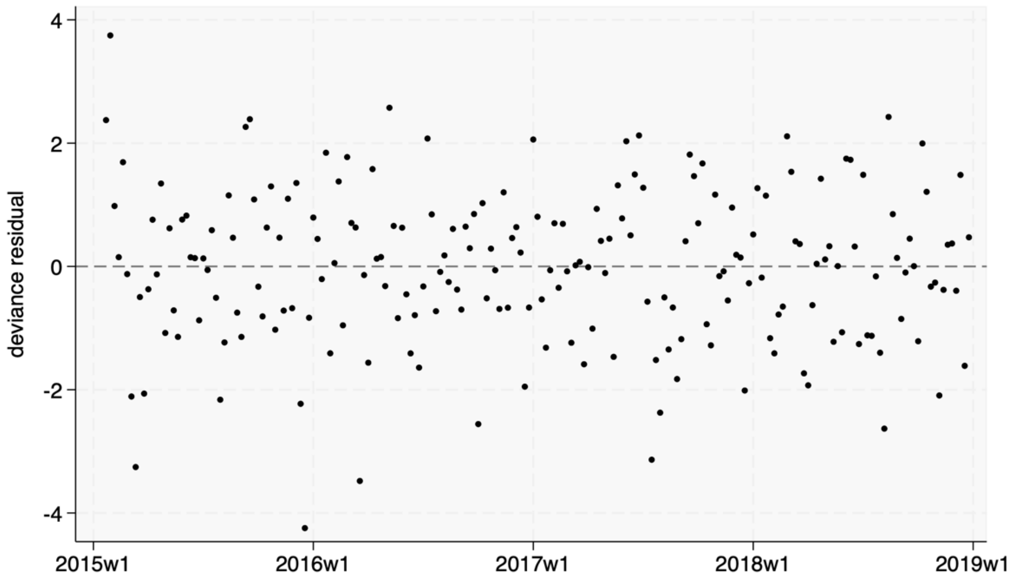

Figure A4.1 Standardized deviance residuals plots for Step I: Main effects of temperature on total hospital admissions and emergency visits for children ages 0 to 5.

Plots Step II: Estimating the impact of extreme heat on total, age- and sex-specific hospital admissions and emergency visits.

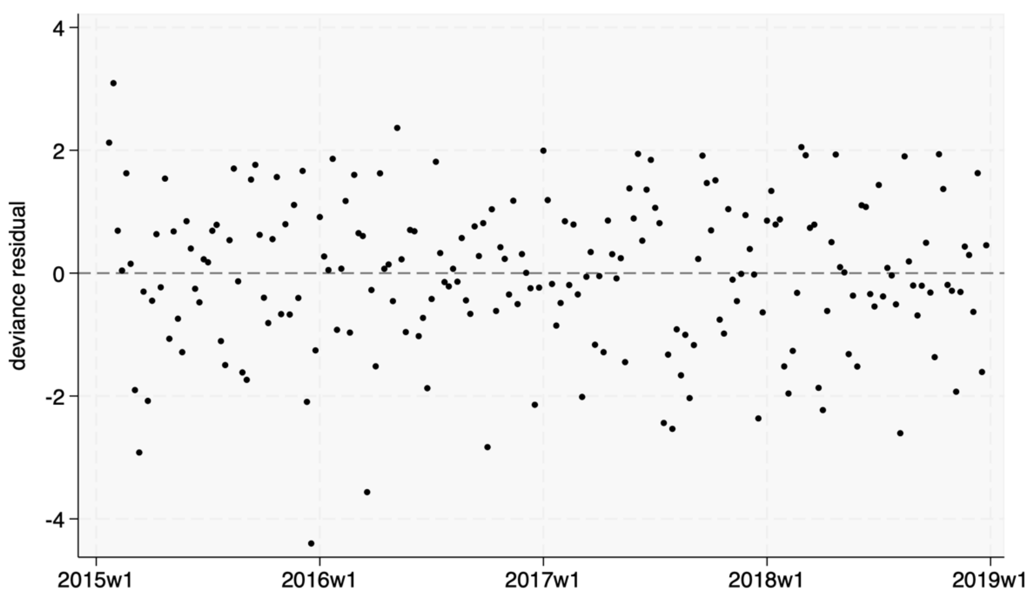

Figure A4.2 Standardized deviance residuals plots for Step II: Impact of extreme heat on total hospital admissions and emergency visits model.

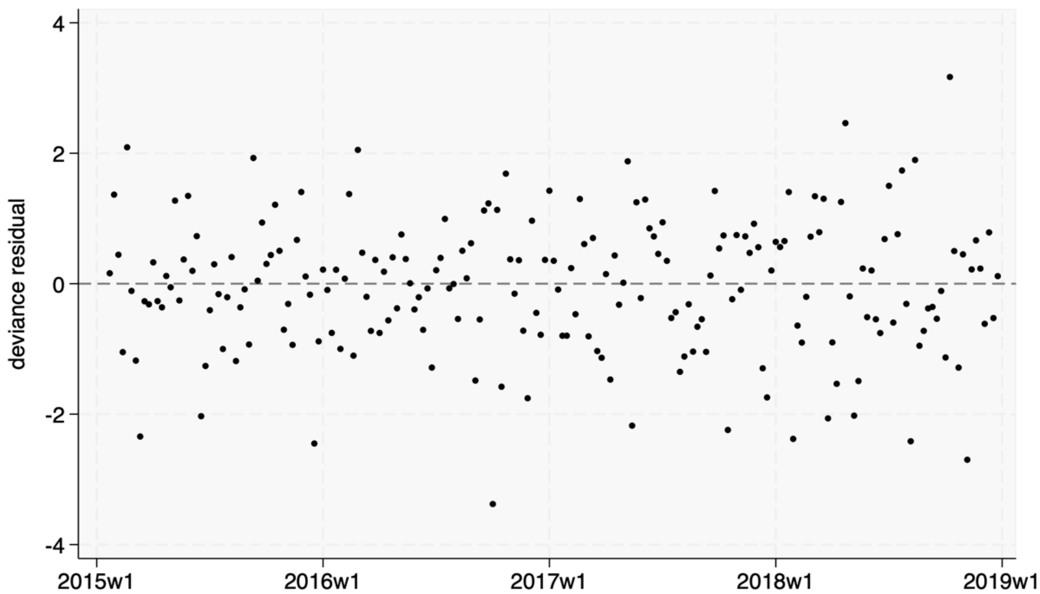

Figure A4.3 Standardized deviance residuals plots for Step II: Impact of extreme heat on age-specific hospital admissions and emergency visits (infant group).

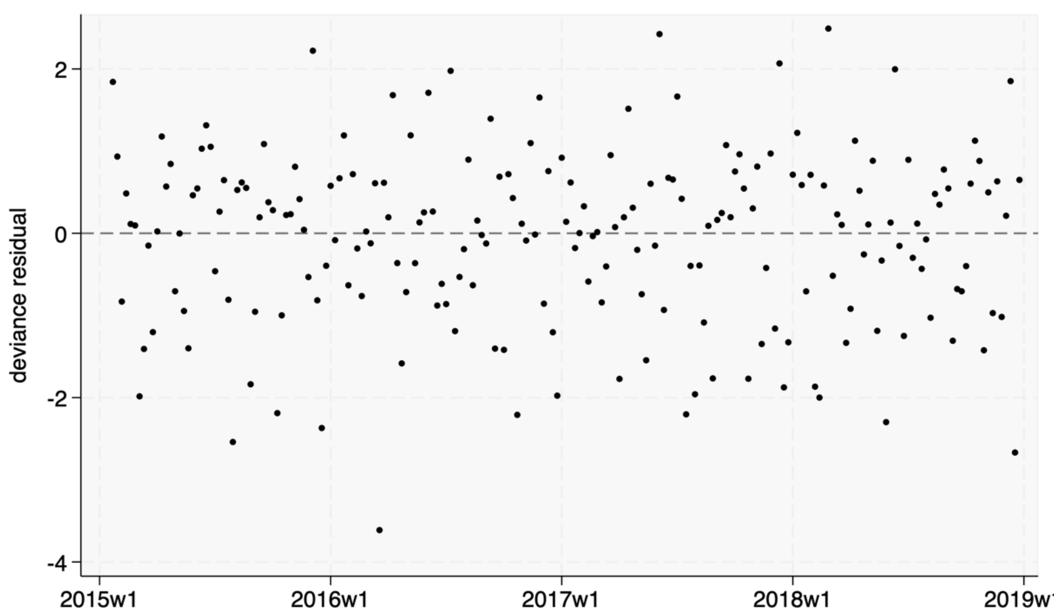

Figure A4.4 Standardized deviance residuals plots for Step II: Impact of extreme heat on age-specific hospital admissions and emergency visits (toddler group).

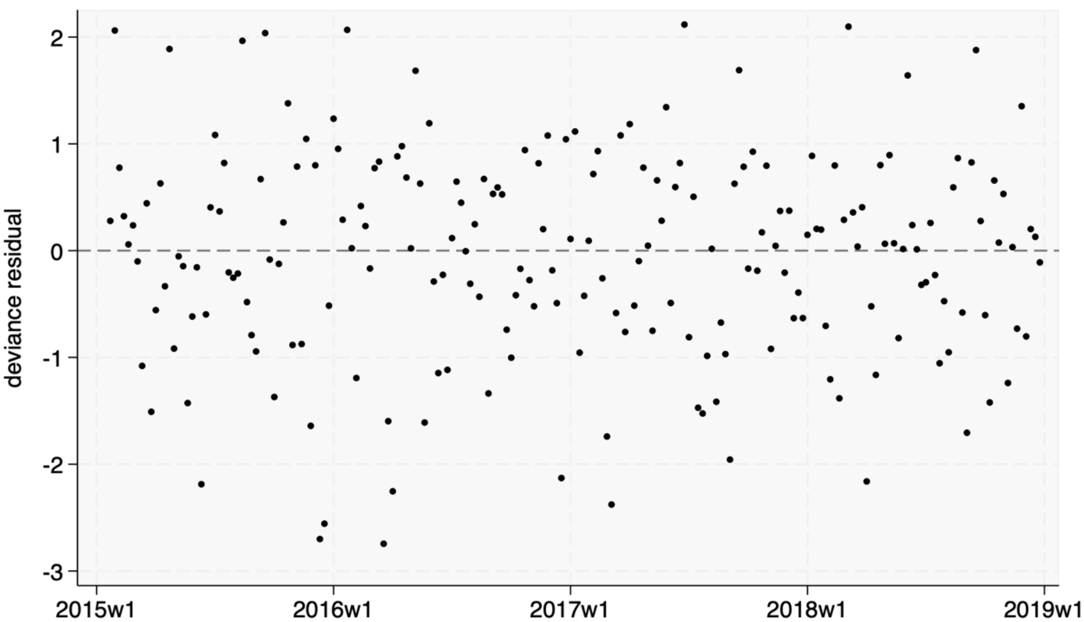

Figure A4.5 Standardized deviance residuals plots for Step II: Impact of extreme heat on age-specific hospital admissions and emergency visits (preschool group).

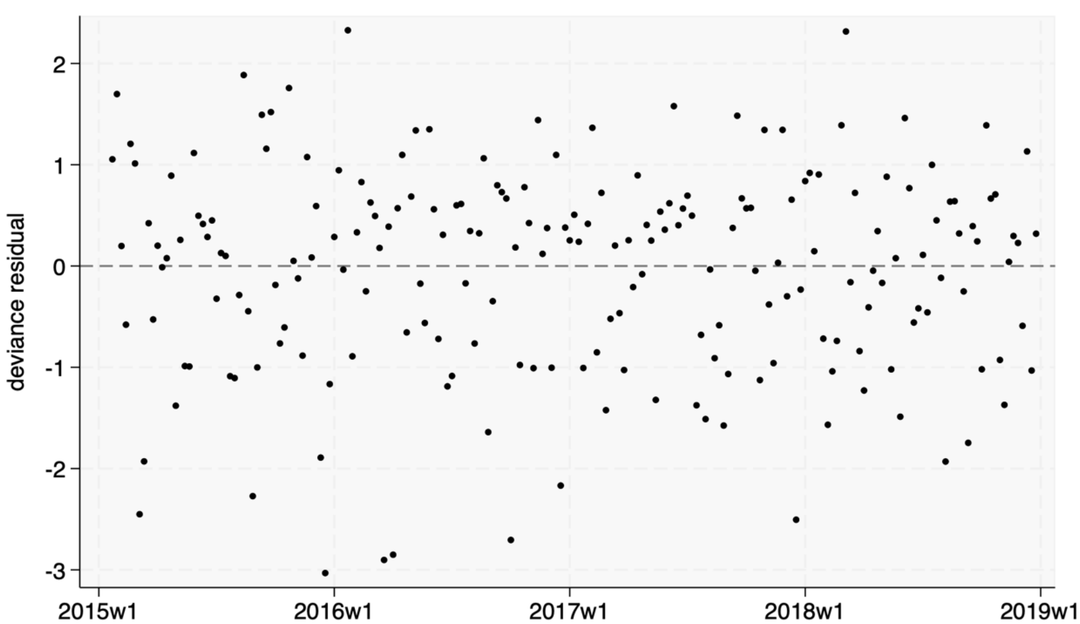

Figure A4.6 Standardized deviance residuals plots for Step II: Impact of extreme heat on sex-specific hospital admissions and emergency visits (male group).

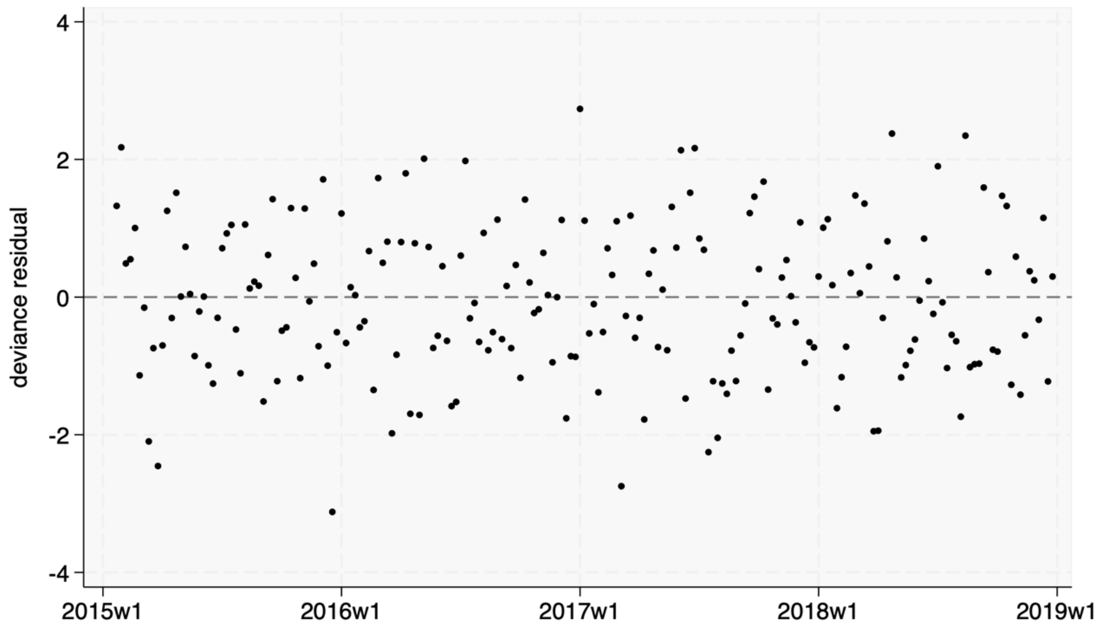

Figure A4.7 Standardized deviance residuals plots for Step II: Impact of extreme heat on sex-specific hospital admissions and emergency visits (female group).

Plots of Step III: Estimating the impact of extreme cold on total, age- and sex-specific hospital admissions and emergency visits.

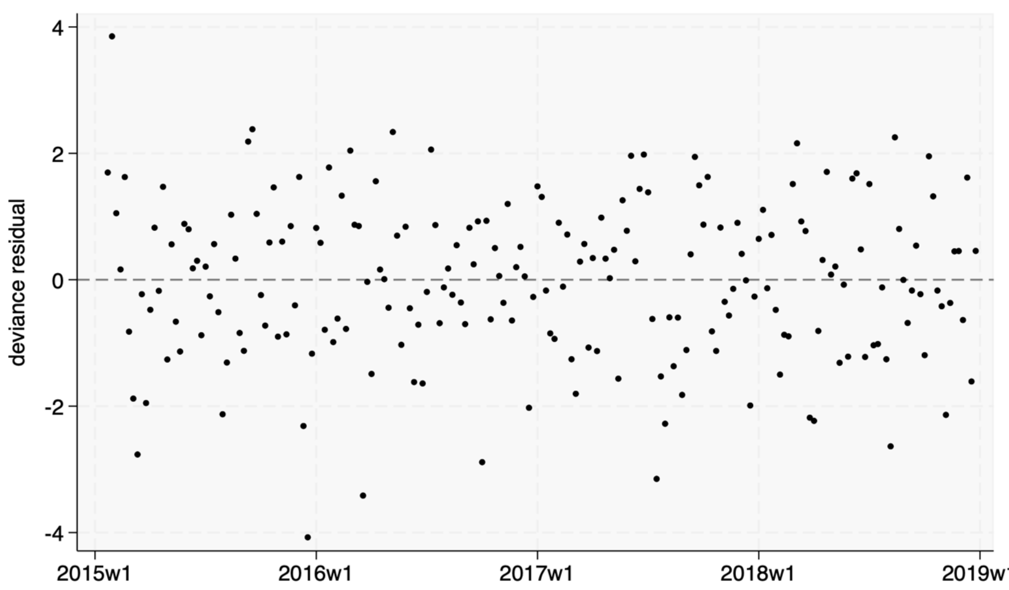

Figure A4.8 Standardized deviance residuals plots for Step III: Impact of extreme cold on total hospital admissions and emergency visits.

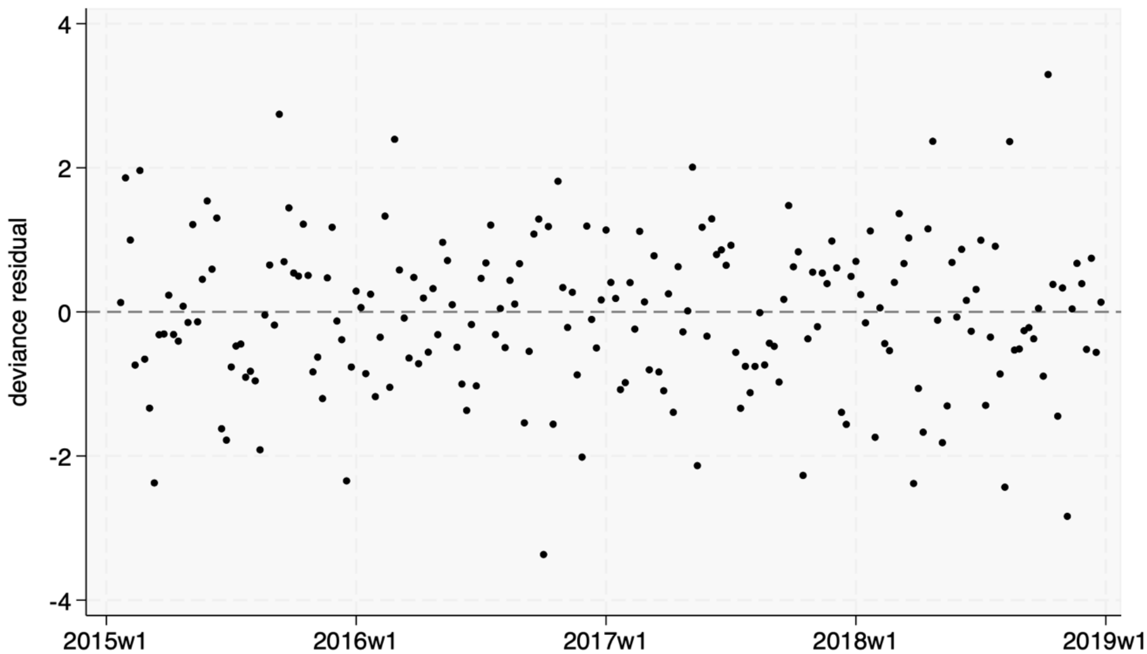

Figure A4.9 Standardized deviance residuals plots for Step III: Impact of extreme cold on age-specific hospital admissions and emergency visits (infant group).

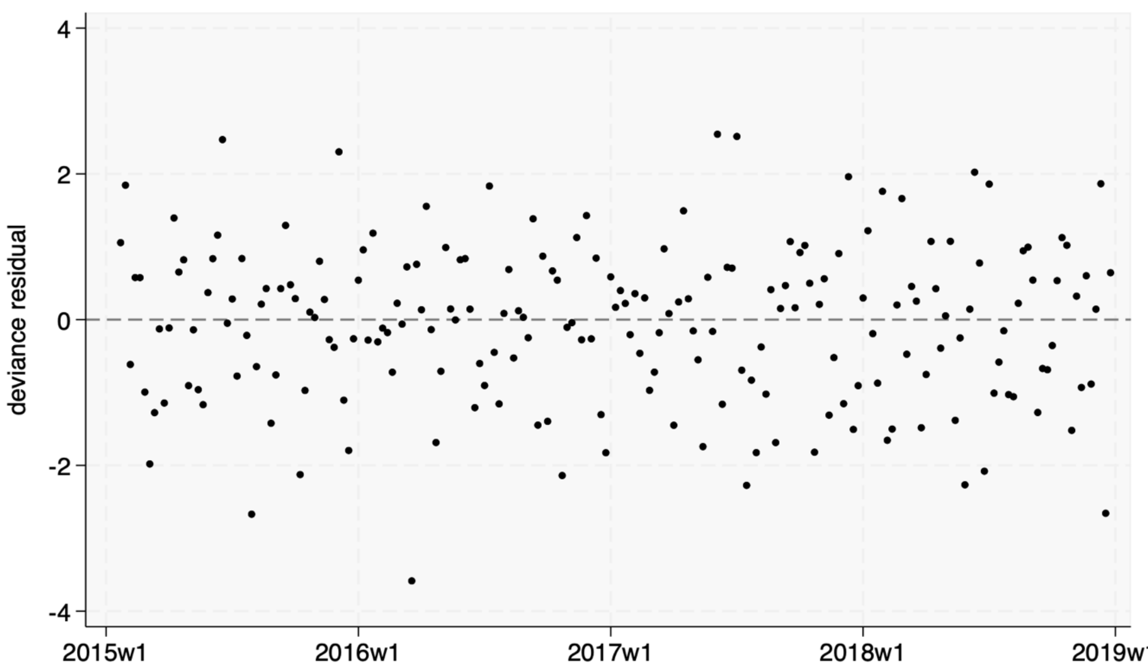

Figure A4.10 Standardized deviance residuals plots for Step III: Impact of extreme cold on age-specific hospital admissions and emergency visits (toddler group).

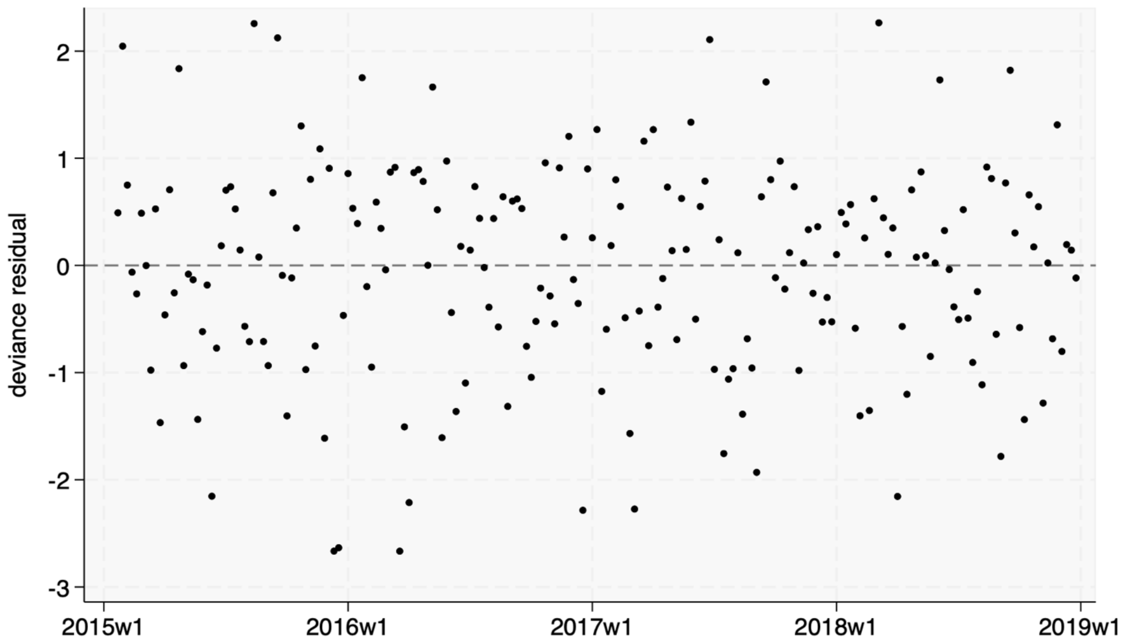

Figure A4.11 Standardized deviance residuals plots for Step III: Impact of extreme cold on age-specific hospital admissions and emergency visits (preschool group).

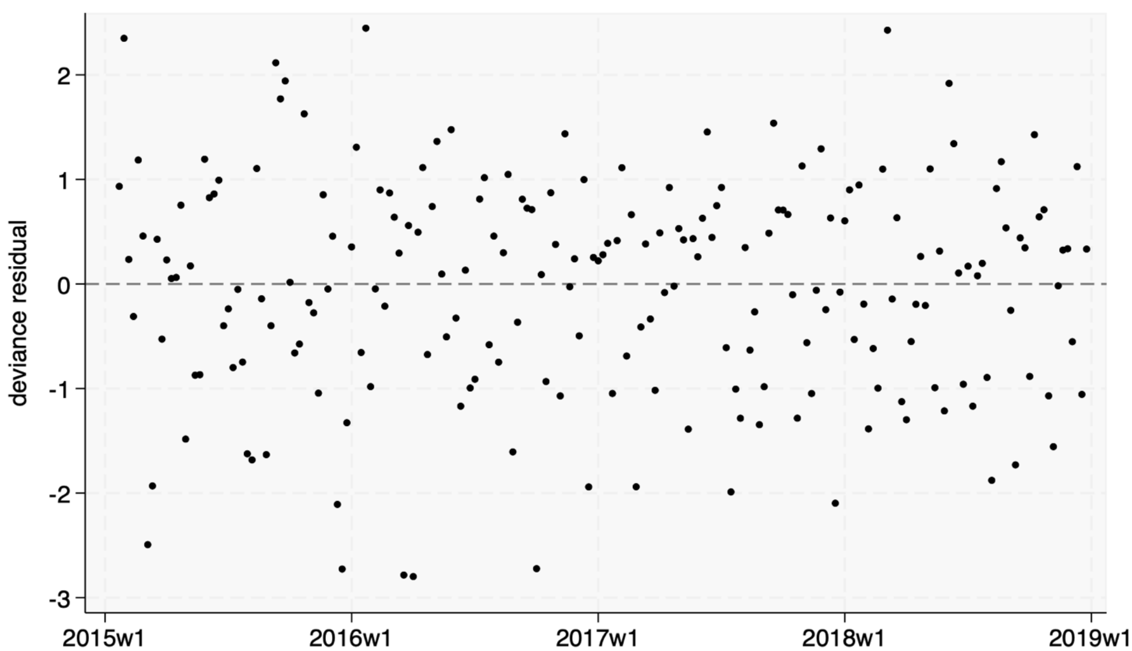

Figure A4.12 Standardized deviance residuals plots for Step III: Impact of extreme cold on sex-specific hospital admissions and emergency visits (male group).

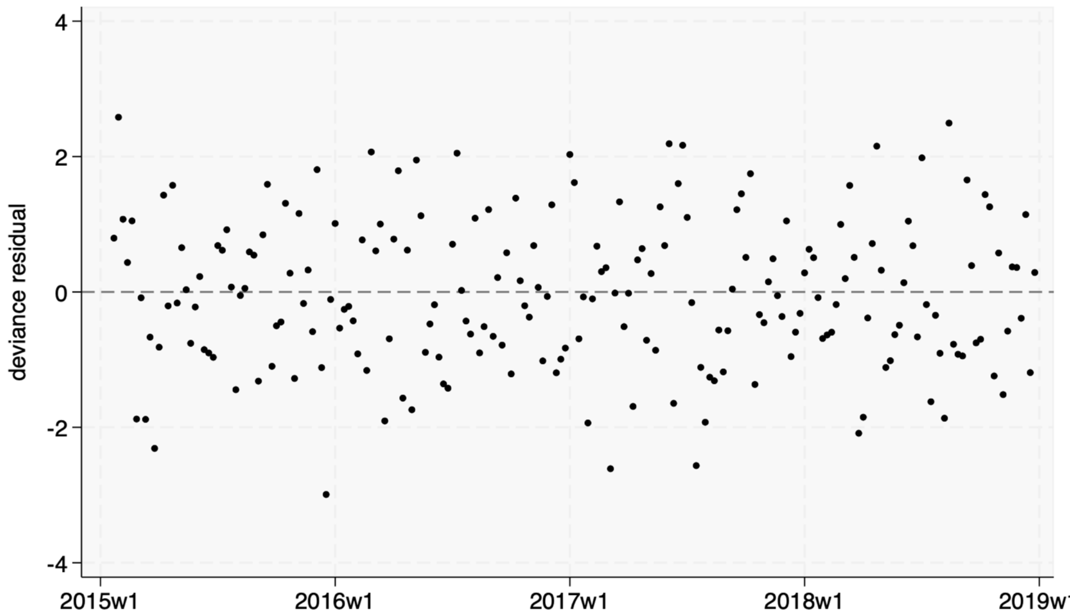

Figure A4.13 Standardized deviance residuals plots for Step III: Impact of extreme cold on sex-specific hospital admissions and emergency visits (female group).

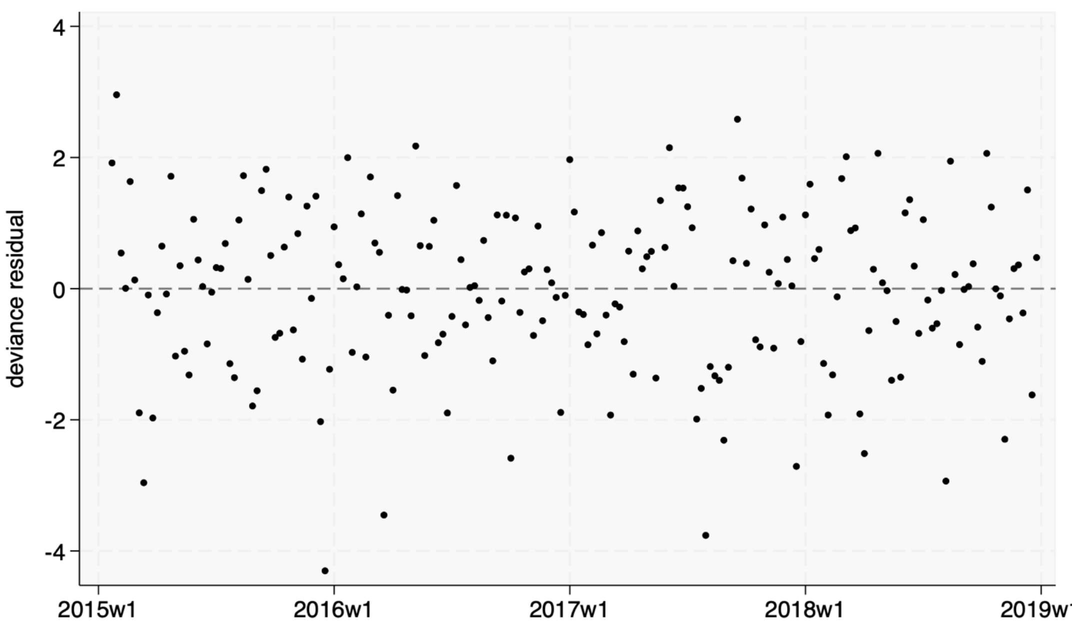

Figure A4.14 Standardized deviance residuals plots for cause-specific (respiratory): Impact of extreme heat on children 0-5 respiratory-related hospital admissions and emergency visits.

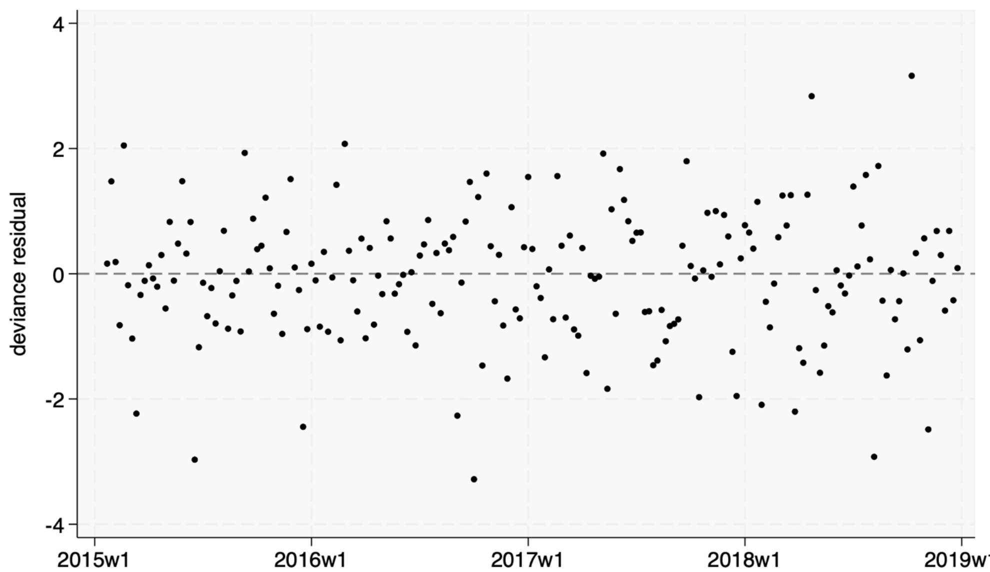

Figure A4.15 Standardized deviance residuals plots for cause-specific (respiratory): Impact of extreme heat on infant's respiratory-related hospital admissions and emergency visits.

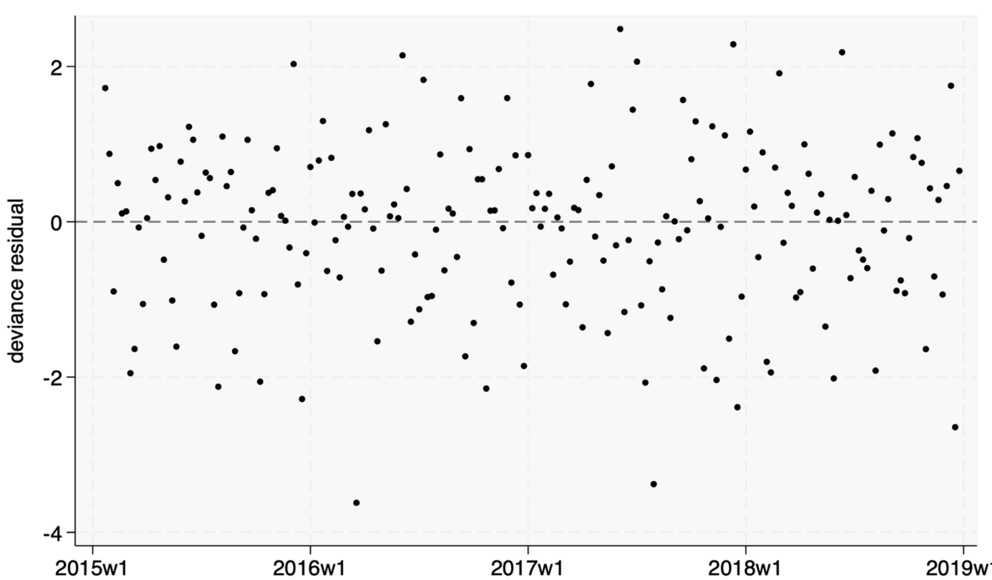

Figure A4.16 Standardized deviance residuals plots for cause-specific (respiratory): Impact of extreme heat on toddler's respiratory-related hospital admissions and emergency visits.

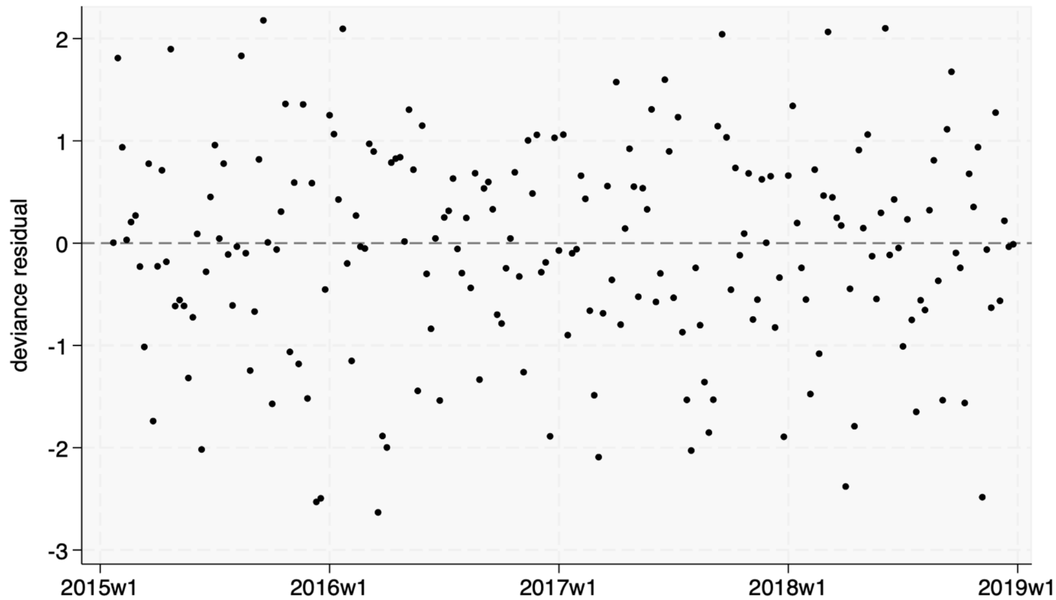

Figure A4.17 Standardized deviance residuals plots for cause-specific (respiratory): Impact of extreme heat on preschooler's respiratory-related hospital admissions and emergency visits.

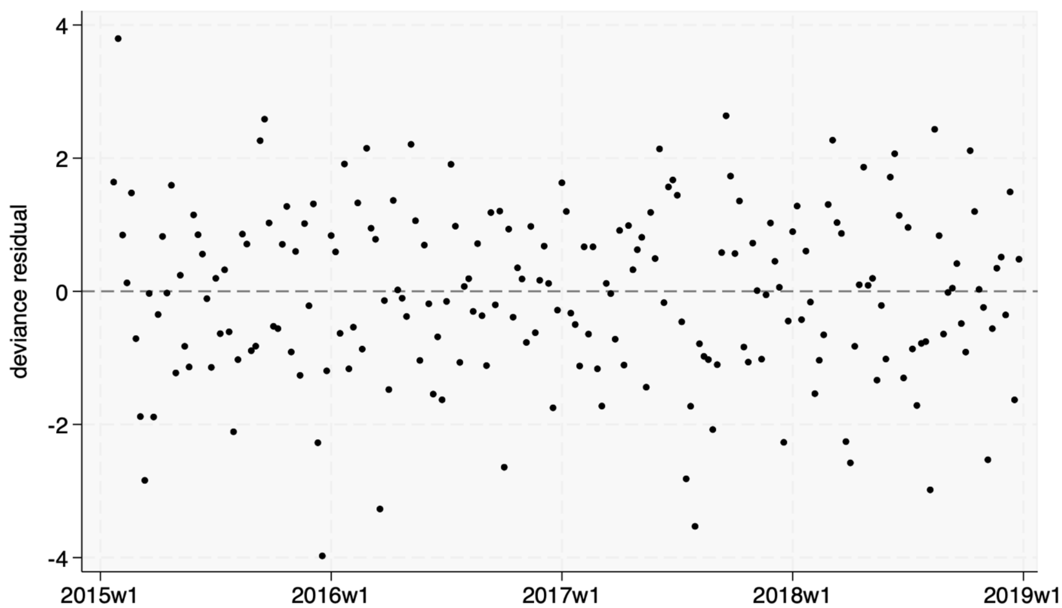

Figure A4.18 Standardized deviance residuals plots for cause-specific (respiratory): Impact of extreme cold on children 0-5 respiratory-related hospital admissions and emergency visits.

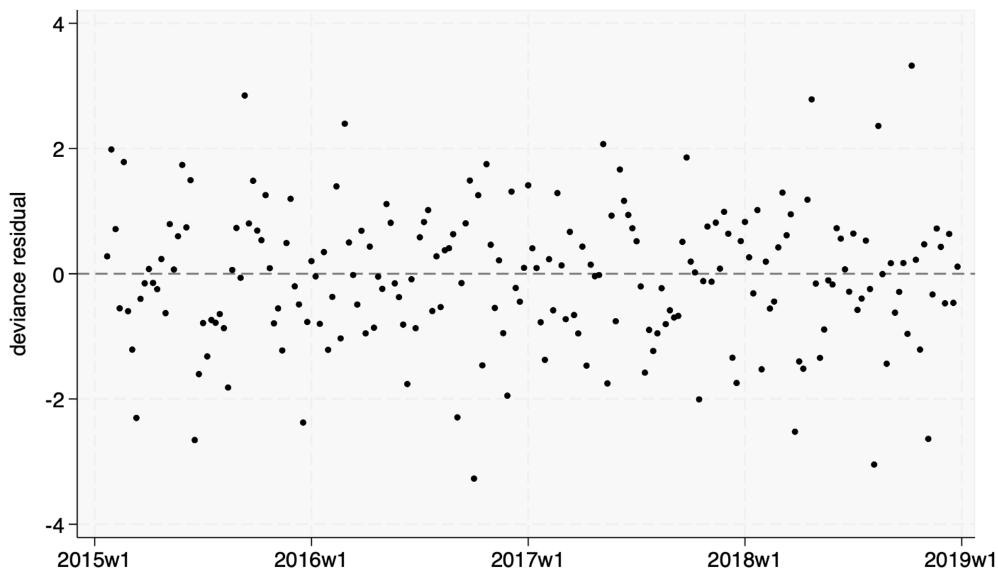

Figure A4.19 Standardized deviance residuals plots for cause-specific (respiratory): Impact of extreme cold on infant's respiratory-related hospital admissions and emergency visits.

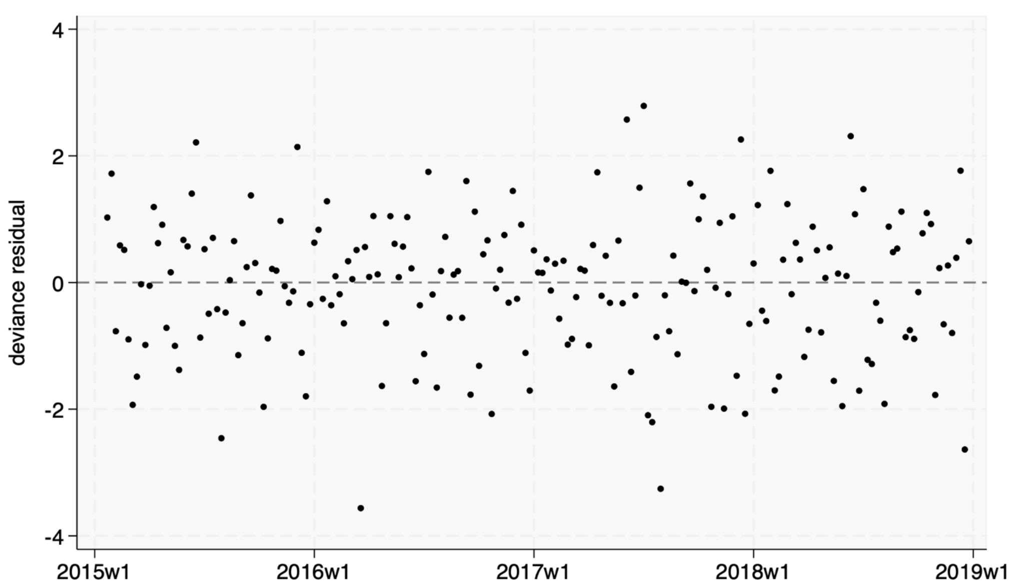

Figure A4.20 Standardized deviance residuals plots for cause-specific (respiratory): Impact of extreme cold on toddler's respiratory-related hospital admissions and emergency visits.

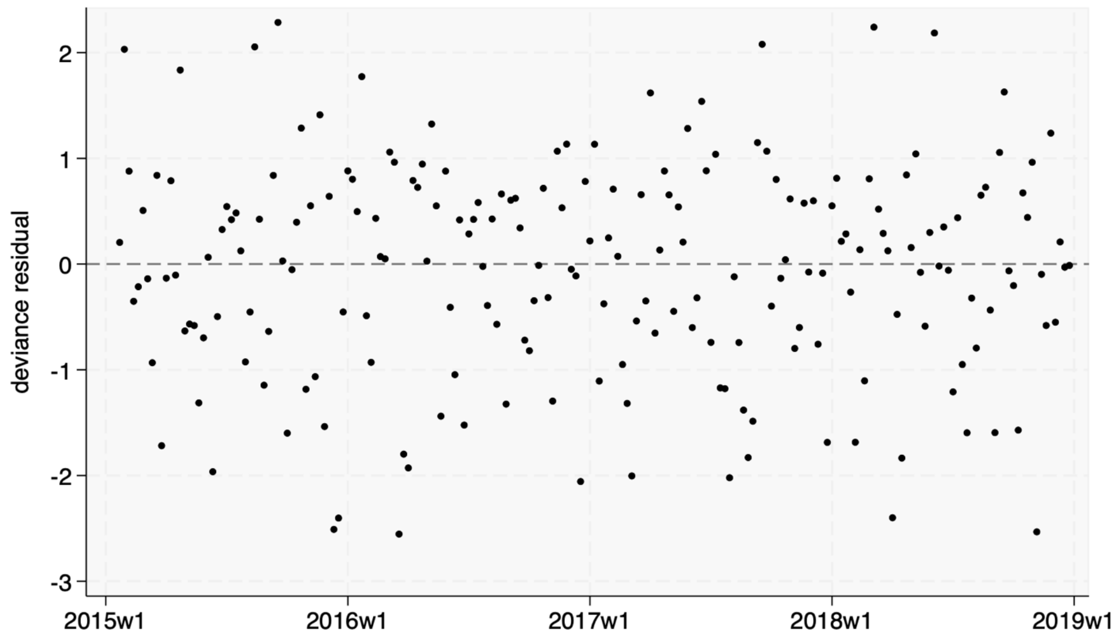

Figure A4.21 Standardized deviance residuals plots for cause-specific (respiratory): Impact of extreme cold on preschooler's respiratory-related hospital admissions and emergency visits.

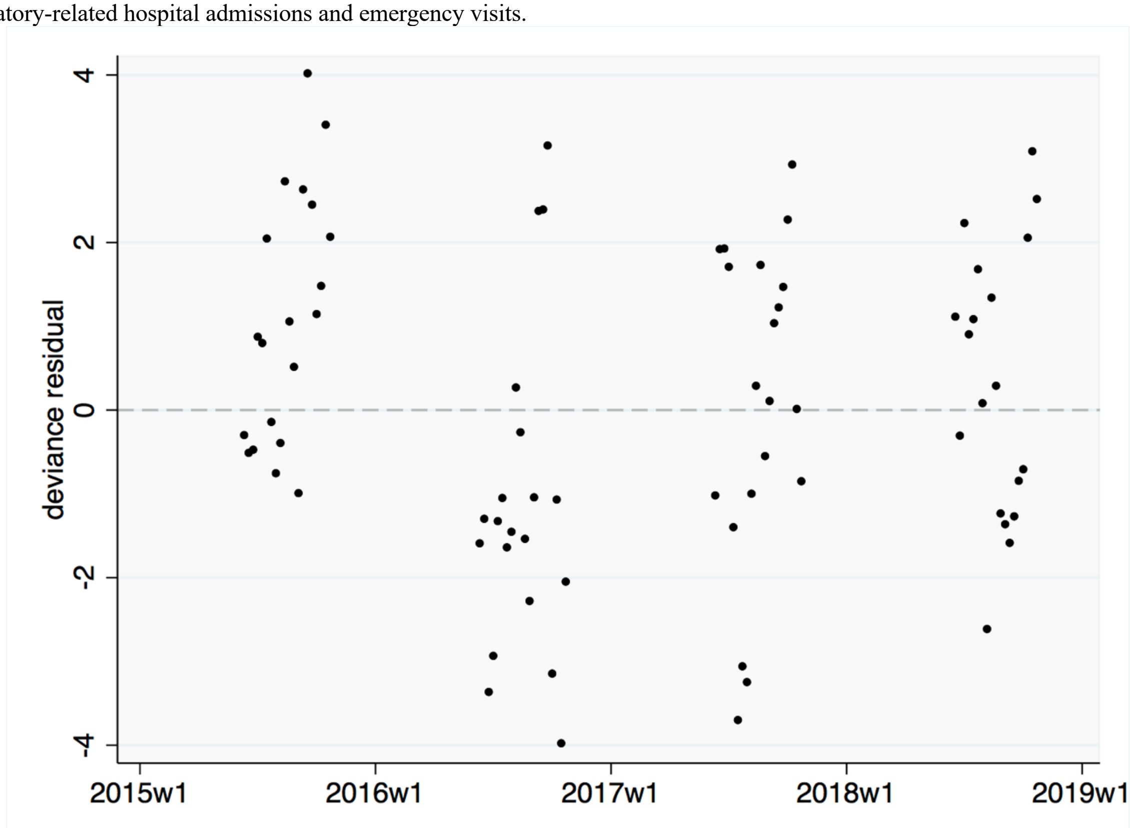

Figure A4.22 Standardized deviance residuals plots for warm season models: Impact of normal ambient temperature during warm season on total children 0-5 hospital admissions and emergency visits.

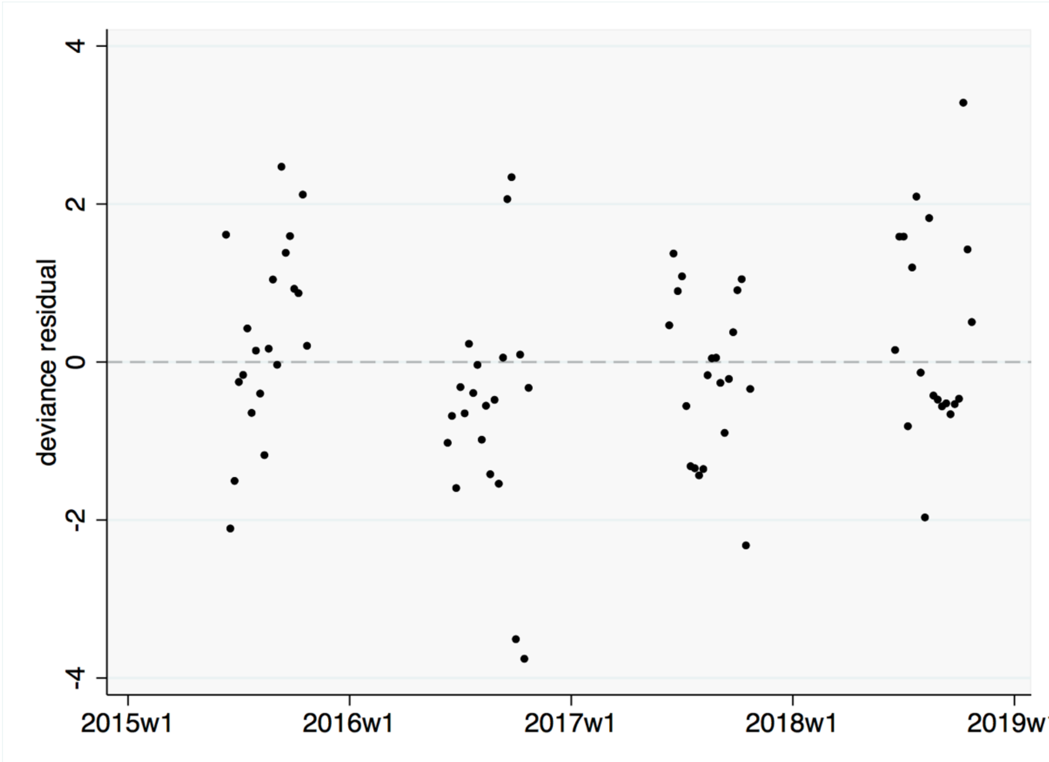

Figure A4.23 Standardized deviance residuals plots for warm season models: Impact of normal ambient temperature during warm season on infant's hospital admissions and emergency visits.

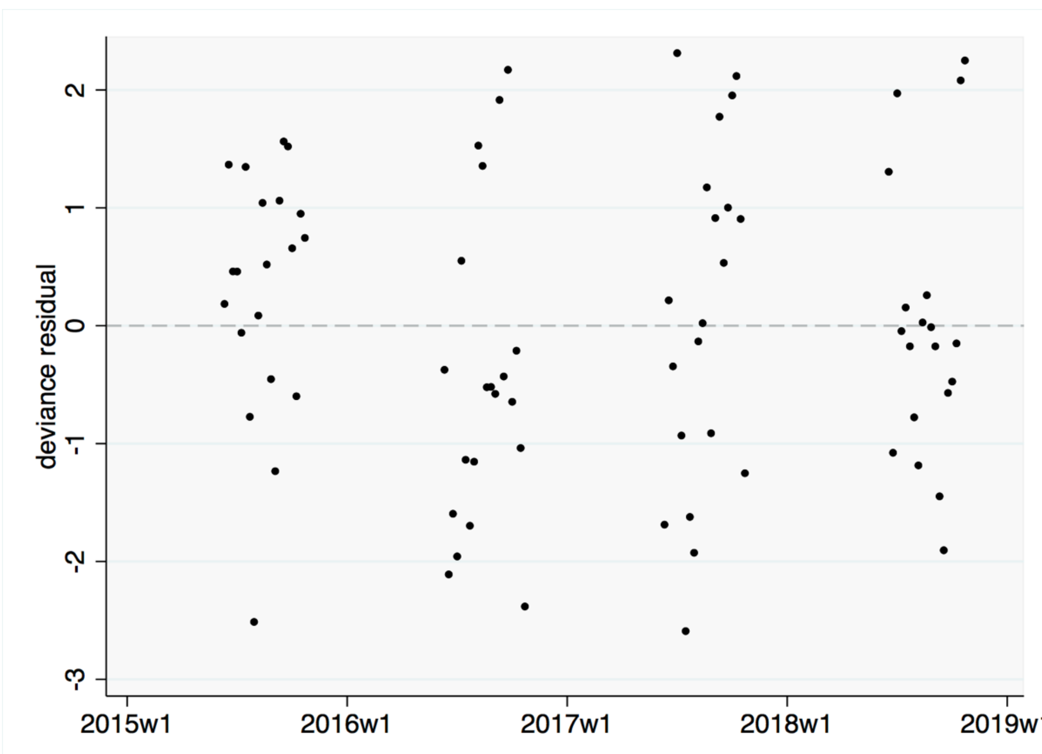

Figure A4.24 Standardized deviance residuals plots for warm season models: Impact of normal ambient temperature during warm season on toddler's hospital admissions and emergency visits.

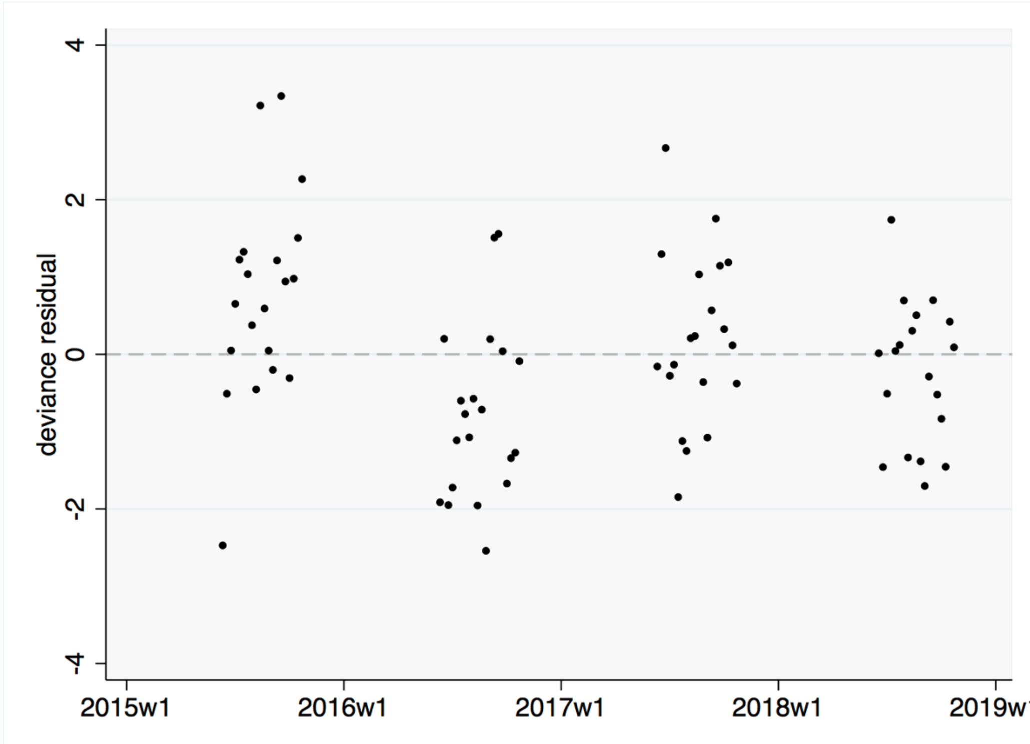

Figure A4.25 Standardized deviance residuals plots for warm season models: Impact of normal ambient temperature during warm season on preschooler's hospital admissions and emergency visits.

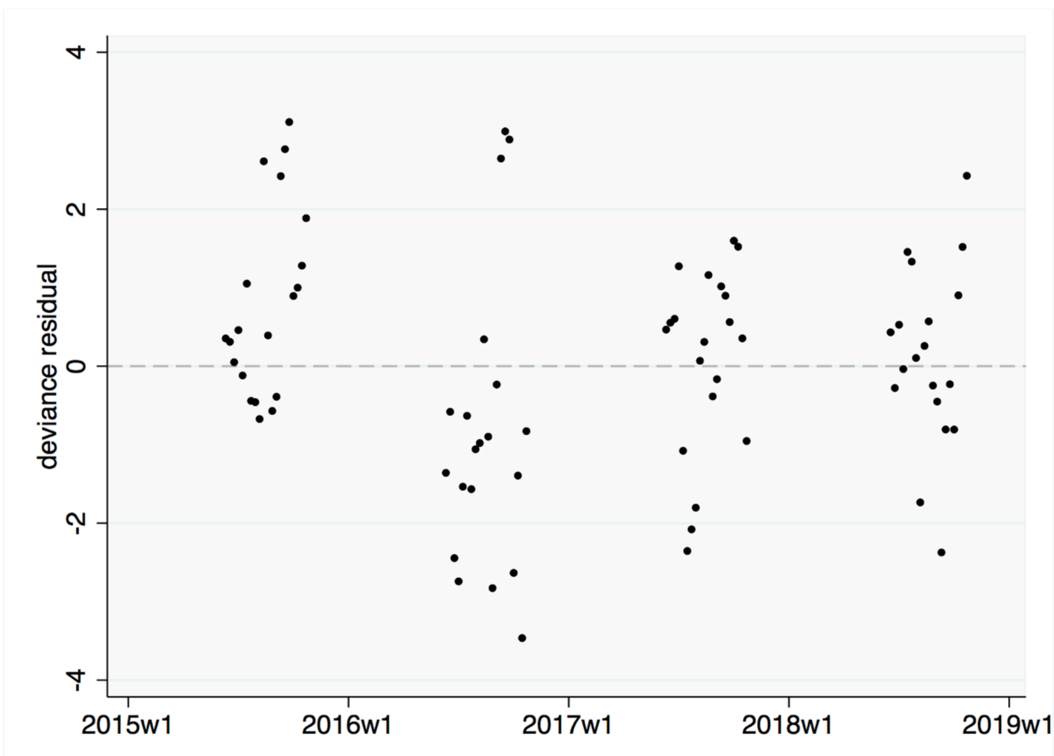

Figure A4.26 Standardized deviance residuals plots for warm season models: Impact of normal ambient temperature during warm season on male children's hospital admissions and emergency visits.

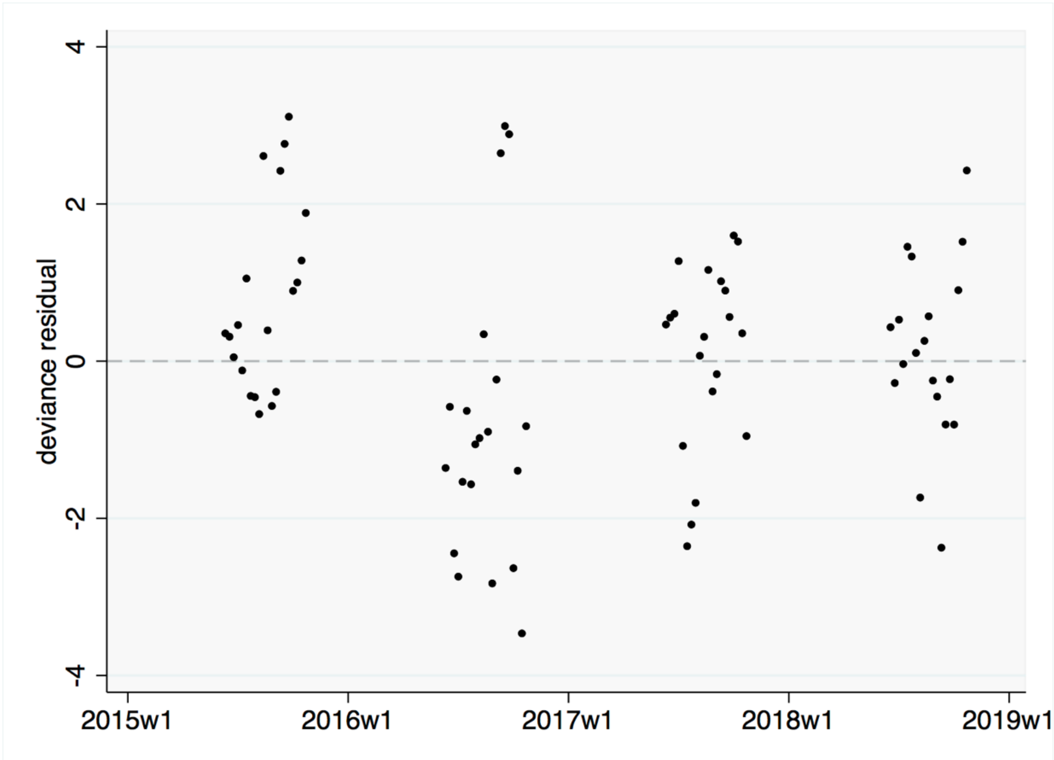

Figure A4.27 Standardized deviance residuals plots for warm season models: Impact of normal ambient temperature during warm season on female children's hospital admissions and emergency visits.

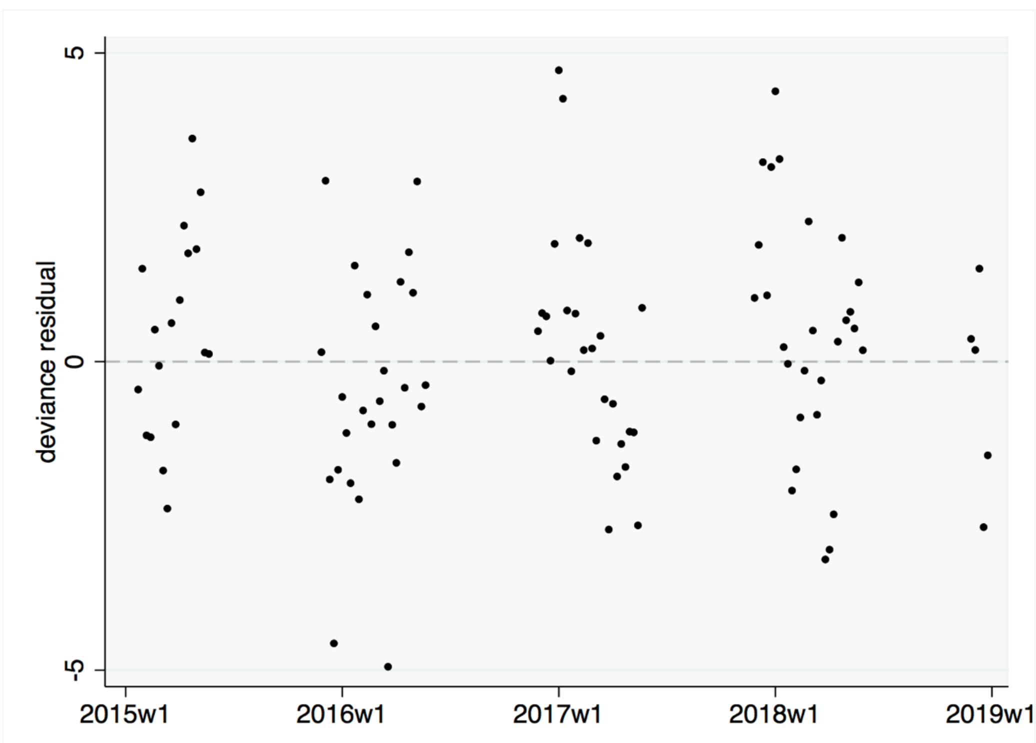

Figure A4.28 Standardized deviance residuals plots for cold season models: Impact of normal ambient temperature during cold season on total children 0-5 hospital admissions and emergency visits.

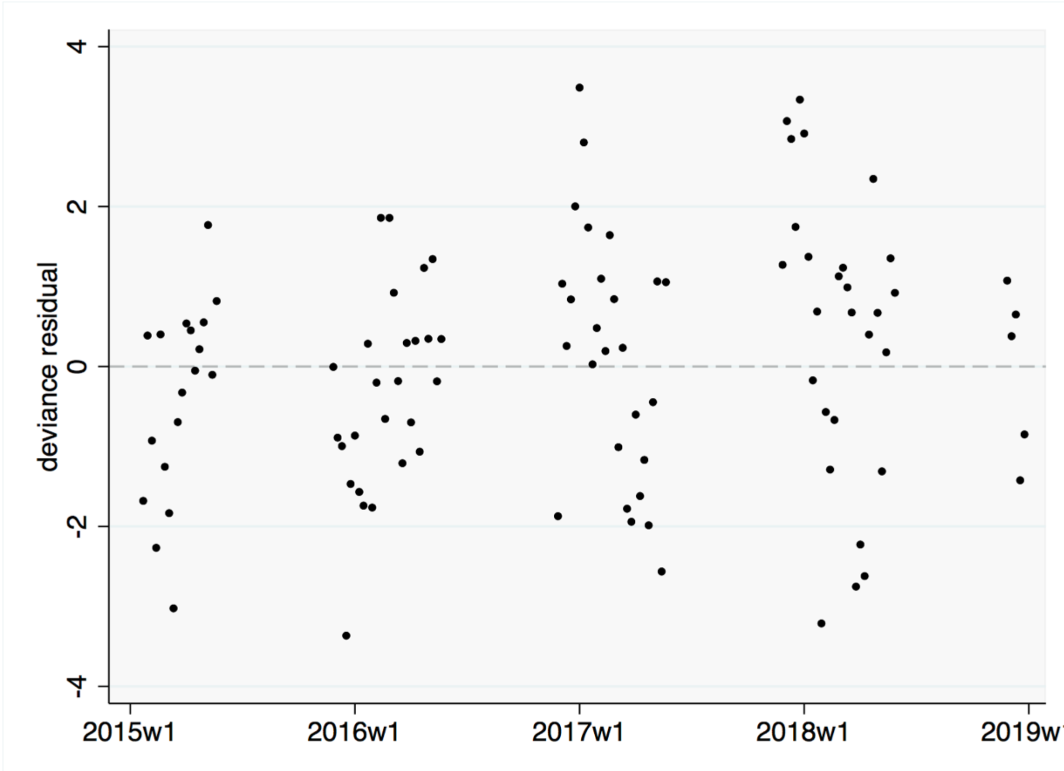

Figure A4.29 Standardized deviance residuals plots for cold season models: Impact of normal ambient temperature during cold season on infant's hospital admissions and emergency visits.

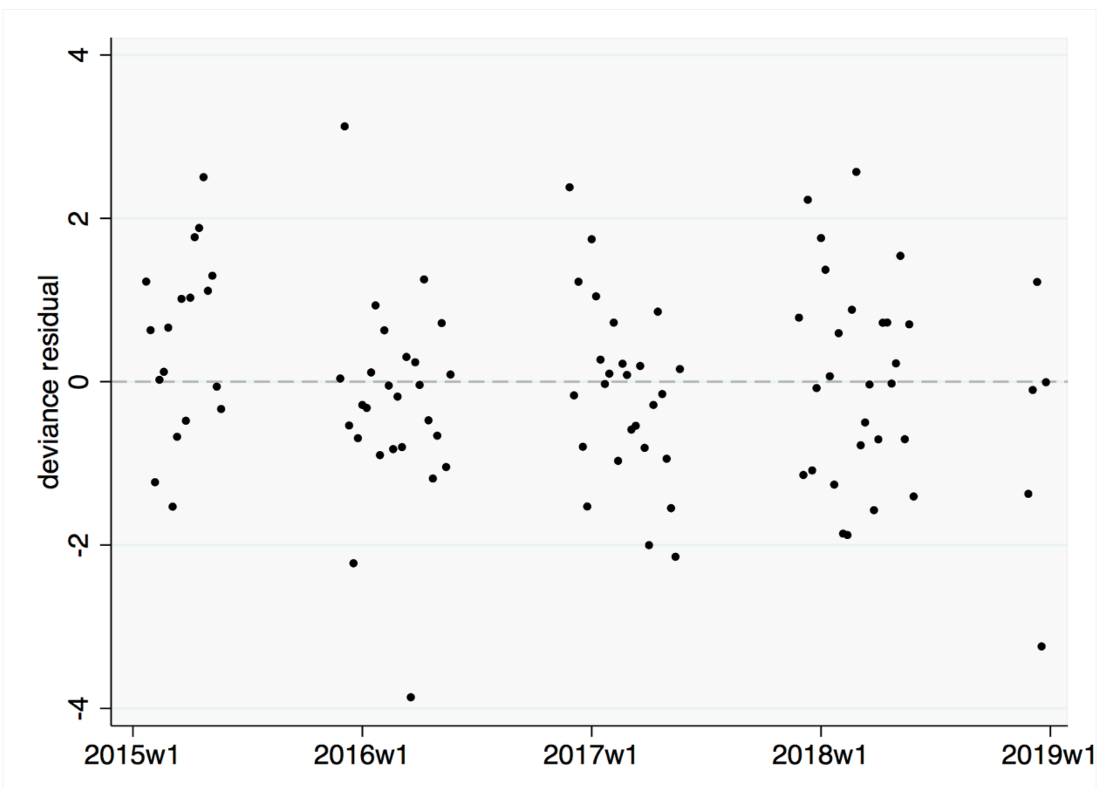

Figure A4.29 Standardized deviance residuals plots for cold season models: Impact of normal ambient temperature during cold season on toddler's hospital admissions and emergency visits.

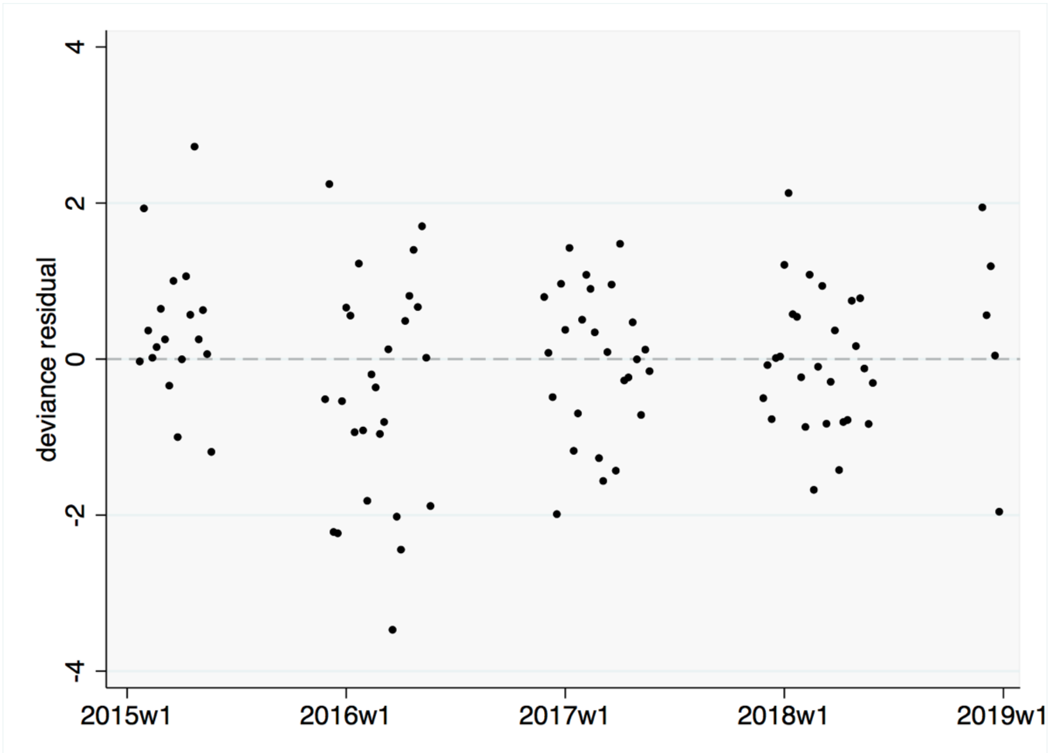

Figure A4.30 Standardized deviance residuals plots for cold season models: Impact of normal ambient temperature during cold season on preschooler's hospital admissions and emergency visits.

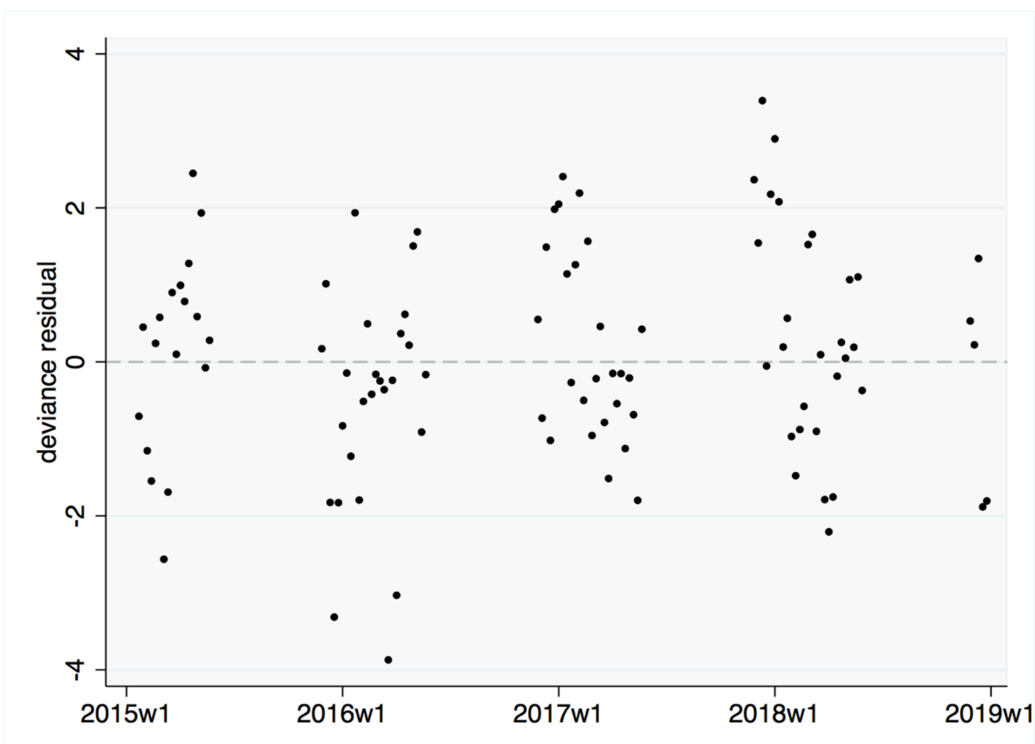

Figure A4.30 Standardized deviance residuals plots for cold season models: Impact of normal ambient temperature during cold season on male children's hospital admissions and emergency visits.

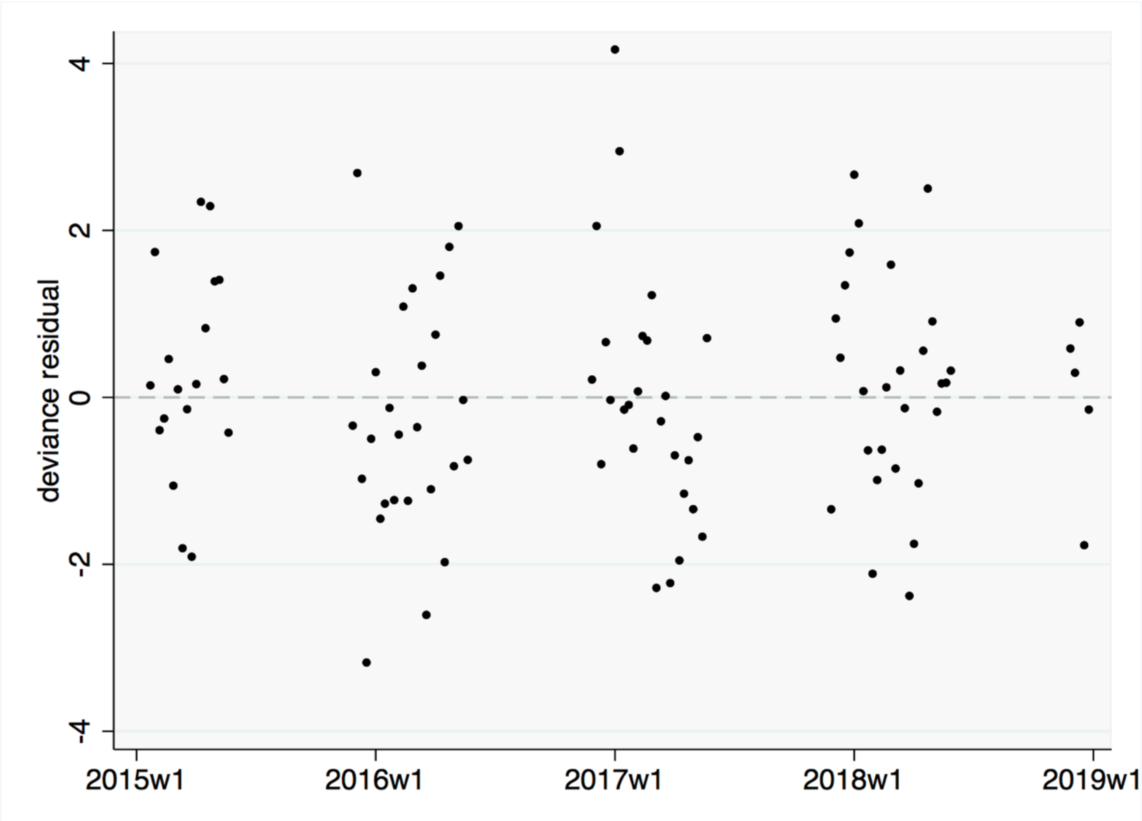

Figure A4.30 Standardized deviance residuals plots for cold season models: Impact of normal ambient temperature during cold season on female children's hospital admissions and emergency visits.

Appendix 5: Variables definitions, statistical methods involved

Table A5.1- Environmental variables data dictionary

Variable	Unit	Years	Description
Mean temperature	ºC	2015-18	Weekly average ambient temperature: averaged over the week using daily data recorded from ACIS [1].
Extreme heat event	ºC	2015-18	An extreme heat event was defined as a period where the weekly average temperature exceeded the 95th percentile of recorded weekly maximum temperatures [1].
Extreme cold event	ºC	2015-18	An extreme cold event was defined as a period where the weekly average temperature fell below the 5th percentile of recorded weekly minimum temperatures [1].
Relative humidity	%	2015-18	The daily average of relative humidity, which is the measure of the moisture the air contains compared to the maximum it could hold at a given temperature, was averaged over the course of the week.
Ozone (O_3)	ppb	2015-18	Weekly average of the maximum rolling 8-hour average ambient concentration per day for O_3 [2].
Particulate matter with diameter ≤2.5µg ($PM_{2.5}$)	µg/m^3	2015-18	The weekly average concentration of particulate matter with a diameter of 2.5 micrometers or less, commonly referred to as $PM_{2.5}$, is measured to assess the amount of these extremely small particles or droplets in the air [2, 3].

References

[1] Data from Alberta Climate Information Service (ACIS). https://acis.alberta.ca (accessed August 30, 2022).

[2] Kampa M, Castanas E. Human health effects of air pollution. Environ Pollut. 2008;151(2):362-367. doi:10.1016/j.envpol.2007.06.012

[3] Xu B, Dong D. Evaluating the Impact of Air Pollution on China’s Inbound Tourism: A Gravity Model Approach. *Sustainability*. 2020; 12(4):1456. https://doi.org/10.3390/su12041456

Table A5.2- Model development steps	
Steps	Description
Data Collection	Data on hospital admissions and emergency visits for children aged 0 to 5 were extracted from the Alberta Health Services database, along with corresponding temperature and environmental data records from Alberta Climate Information Service for the same time period.
Variable selection	Identify temperature variables (average, minimum, maximum temperature). $PM_{2.5}$, O_3, and relative humidity are selected as confounding factors based on evidence from scientific studies that demonstrate their impact on respiratory health, which is often reflected in hospital admissions and emergency visits. The practical experience and contextual knowledge of experts in the field complement this evidence.
Data Pre-processing	The data was cleaned to address missing values, outliers, and anomalies, ensuring it was properly formatted for analysis with weekly timestamps for both hospital visits and environmental readings. Daily hospital visits, temperature, and relative humidity values were aggregated to create weekly averages. For $PM_{2.5}$, raw hourly data were first averaged to daily values, which were then averaged to obtain weekly measurements. Similarly, the maximum 8-hour average concentration of O_3 was calculated from hourly data before being averaged across days and then weeks.
Exploratory Data Analysis	An initial analysis was conducted to understand patterns, trends, and potential seasonal effects in hospital visits and environmental data. Summary statistics were computed, and a correlation matrix for the explanatory variables was generated.
Lag Selection	A maximum lag period of four weeks was maintained. Given that the study utilized weekly datasets, the Akaike Information Criterion (AIC) was chosen as the most suitable metric for selecting the optimal lag period. To adjust for collinearity among these lagged exposure effects, constrained distributed lag nonlinear models were employed. Unconstrained models revealed that individual lag effects were highly correlated and exhibited confounding, necessitating the use of constrained models to address the collinearity issue. The specific constraints applied to the lags were informed by the patterns observed in the unconstrained models, with lags demonstrating similar effects being treated as equivalent.
Seasonality Adjustment	To control for seasonal patterns and trends in the hospital data that were not related to temperature, cubic spline functions of time were incorporated into all models at every step of the analysis. A total of 27 knots were used, strategically placed at reference points determined by the distribution characteristics of the data, such as areas of high variability. The number of knots was calculated using the formula: (number of calendar years x 7) – 1.
Model building	**Step I-** Estimating the main effects of temperature on hospital admissions and emergency visits for children ages 0 to 5: Hospital admissions and emergency visit data for children aged 0 to 5 years were aggregated on a weekly basis. Selected lag periods for weekly average temperature were included in the model as the main exposure variable, along with other potential confounding factors such as, $PM_{2.5}$, O_3, relative humidity, seasonality, and long-time trend were controlled for as covariates. A Poisson regression analysis served as the initial approach for modeling the count data of hospital admissions and emergency visits while acknowledging its underlying assumptions. To address potential over-dispersion, indicated by significant likelihood ratio tests ($p < 0.05$) for the alpha parameter (λ) in the Poisson models, negative binomial regression models were employed.

<table>
<tr><td></td><td>

$$Poisson\ regression = \log(E[Yi]) = \beta 0 + \beta 1X1i + \beta 2X2i + \cdots + \beta pXpi \quad (Eq. A5.1)$$

Where:

- log denotes the natural logarithm.
- $E[Yi]$ is the expected count of hospital admissions and emergency visits for the i^{th} observation.
- Predictor variables (weekly average temperature, $PM_{2.5}$, O_3, relative humidity, spline functions for seasonality).
- β_0 is the intercept term.
- $\beta_1, \beta_2 \ldots, \beta_p$ are the coefficients for each predictor variable.
- $X_{1i}, X_{2i} \ldots, X_{pi}$ are the predictor variables for the i^{th} observation.

$$Negative\ Binomial\ Regression\colon\ log(\mathrm{E[Yi]}) = \beta 0 + \beta 1\mathrm{X1i} + \beta 2\mathrm{X2i} + \ldots + \beta\mathrm{pXpi} + log(\alpha)\ (Eq. A5.2)$$

Where:

- All the terms are as defined above for the Poisson regression.
- α is the over-dispersion parameter

The same model-building process was followed in Steps II and III, with the exception of the definition of the temperature exposure variable and the stratification:
Step II- Estimating the impact of extreme heat on total, age- and sex-specific hospital admissions and emergency visits:
During this step, only extreme heat events were included (i.e., weekly temperatures exceeding the 95^{th} percentile of our average temperature). Hospital visits data were stratified by age into three subgroups: infant, toddler, and preschool age, and sex into male and female subgroups to estimate specific impacts on different subgroups.
Step III- Estimating the impact of extreme cold on total, age- and sex-specific hospital admissions and emergency visits:
During this step, only extreme cold events were included (i.e., weekly temperatures falling below the 5^{th} percentile of our average temperature). Hospital visits data were stratified by age into three subgroups: infant, toddler, and preschool age, and by sex into male and female subgroups to estimate specific impacts on different subgroups.

Other analyses:
Respiratory-cause specific analysis, included children 0-5 hospital encounters due to respiratory diseases only (models were conducted while controlling for air pollution, relative humidity, seasonality and long-term trend).
Normal warm and cold seasons analysis, included models for children encounters during the normal warm season, as well as the cold season (models were conducted while controlling for air pollution, relative humidity).
</td></tr>
<tr><td>Interpretation</td><td>

If the incidence rate ratio (IRR) is:
Equal to 1: This suggests that there is no statistically significant association between the weekly average temperature and the rate of hospital admissions and emergency visits after adjusting for $PM_{2.5}$, O_3, relative humidity, seasonality, and long-term trends.
Greater than 1: This indicates that an increase of one-degree Celsius increase in the weekly average temperature is associated with a proportional increase in the
</td></tr>
</table>

	rate of hospital admissions and emergency visits, with other factors such as $PM_{2.5}$, O_3, relative humidity, seasonality, and long-term trends being accounted for. **Less than 1**: This implies that an increase of one-degree Celsius increase in the weekly average temperature is associated with a proportional decrease in the rate of hospital admissions and emergency visits, once again controlling for $PM_{2.5}$, O_3, relative humidity, seasonality, and long-term trends.
Model Fit	Standardized deviation residuals were used to visually evaluate the fit of the final models included in Steps I, II, and III, the model assumptions, outliers, and influential points.

Figure A5- Health outcome statistics**,** the leading causes for all encounters were respiratory diseases (92.1%), of which asthma (48.3%), bronchiolitis (16.2%), and acute respiratory (13.1%) were the most common respiratory diagnoses. Among the reported cases, injuries constituted over (7.8%), while instances of heat exhaustion (0.03%) and hypothermia (0.02%) were notably rarer.