A Section 508–conformant HTML version of this article is available at https://doi.org/10.1289/EHP13293.

Association of Psychiatric Emergency Visits and Warm Ambient Temperature during Pregnancy: A Time-Stratified Case-Crossover Study

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Background: Acute exposure to high ambient temperature and heat waves during the warm season has been linked with psychiatric disorders. Emerging research has shown that pregnant people, due to physiological and psychological changes, may be more sensitive to extreme heat, and acute exposure has been linked to increased risk of pregnancy complications; however, few studies have examined psychiatric complications.

Objective: Our objective was to examine the association between acute exposure to warm ambient temperatures and emergency department (ED) visits for mental disorders during pregnancy.

Methods: A time-stratified case-crossover design with conditional logistic regression was performed on ∼206,000 psychiatric ED visits for pregnant patients in North Carolina, from May to September 2016 to 2019. Daily average ambient temperature was the main exposure and was linked to daily visits by maternal zip code of residence for prenatal mood and anxiety disorders (PMAD), severe mental illness (SMI), mental disorder of pregnancy (MDP), suicidal thoughts (SUIC), and any psychiatric disorder (Any). Effect modification by trimester, residential segregation, economic segregation, urbanicity, and availability of greenspace was also investigated.

Results: Each 5°C increase in same-day exposure to warm ambient temperature on case days was associated with an increase in incidence rate ratio (IRR) for any psychiatric disorder [IRR = 1.07; 95% confidence interval (CI): 1.01, 1.14] including anxiety (IRR = 1.14; 95% CI: 1.00, 1.30), bipolar disorder (IRR = 1.28; 95% CI: 0.98, 1.67), and suicidal thoughts (IRR = 1.28; 95% CI: 1.00, 1.65) compared to control days. In general, the associations were strongest for warm season temperatures on the same day of exposure or for temperatures averaged over the 3 or 6 d preceding the ED visit. The greatest risk of an incident ED admission for PMAD (RR = 1.20; 95% CI: 1.04, 1.39), particularly for anxiety (RR = 1.30; 95% CI: 1.07, 1.59), and any psychiatric disorder (RR = 1.17; 95% CI: 1.07, 1.28) occurred following cumulative exposure to hot temperatures the week before admission. Higher psychiatric burden from temperature was observed in urban areas and on extreme heat days.

Conclusions: For this pregnant population in the southeastern United States, short-term exposure to high ambient temperatures during the warm season was associated with a greater risk of ED visits for an array of psychiatric disorders. Findings show that climate-related increases in ambient temperature may contribute to psychiatric morbidity in pregnant people. https://doi.org/10.1289/EHP13293

Introduction

Emerging epidemiologic studies have associated environmental factors related to climate change, including temperature extremes and variability, with population changes in mental health-related morbidity and mortality.[1] Acute exposure to high ambient temperature during the warm season has been linked with the exacerbation of psychiatric disorders in persons with an existing mental health condition,[2,3] involuntary admissions to an emergency psychiatric hospital,[4] emergency room visits for total mental disorders,[5] and increased self-reported mental health difficulties.[6] One recent study showed that women were more susceptible to a same-day increase in average temperature for an emergent mental health outcome or intentional injury.[7] For pregnant populations, exposure to extremely hot temperatures has been connected with increased risks for maternal stress[8] and preterm births, particularly among those with an existing depressive disorder.[9] Yet few studies have examined the association between exposure to hot ambient temperature extremes and emergent admissions for mental health complications during pregnancy; fewer studies have identified sensitivities to warm ambient temperature during critical periods of pregnancy.

Elevated heat exposure is a widespread and growing health risk projected to intensify as a direct effect of climate-induced warming and has been shown to disproportionately impact pregnant populations and the developing fetus.[10–14] A number of possible thermoregulatory mechanisms in the blood and brain linking mental health and hot temperature during pregnancy have been proposed, including *a*) physiologic changes in sweat and blood flow that prevent heat loss; *b*) altered brain temperature and function, resulting in diminished brain cooling and declines in blood oxygen saturation; *c*) dehydration and fatigue in persons on certain antidepressants and antipsychotic medicines; and *d*) sleep disturbances and disruptions linked to heatwaves, which are known contributors to the aggravation of mental disorders.[15] Emerging research highlights the role of heat stress proteins (HSP) (e.g., HSP70, HSP90) in establishing neurological homeostasis in the brain and heat tolerance.[16–18] Research on the physiologic mechanisms linking heat exposure during pregnancy and the exacerbation of maternal mental health is limited.

Prior research has shown that changes in ambient temperature demonstrate differential health effects in the warm and cold seasons[19,20] with longer lags in the cold season and shorter lags in the warm season.[21–24] The objective of this study was to examine the association between acute exposure to warm season ambient temperatures and emergency department visits for mental health disorders during pregnancy. We assessed the moderating influence of trimester of exposure, heat wave days, residential and economic segregation, the availability of residential greenspace, and urbanicity.

Methods

Study Population

All emergency department (ED) visits for pregnant persons in North Carolina with a primary or secondary mental disorder diagnosis

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Supplemental Material is available online (https://doi.org/10.1289/EHP13293).
The authors declare they have nothing to disclose.
Conclusions and opinions are those of the individual authors and do not necessarily reflect the policies or views of EHP Publishing or the National Institute of Environmental Health Sciences.
Received 9 May 2023; Revised 10 May 2024; Accepted 16 May 2024; Published 3 June 2024.

between 1 January 2016 and 31 December 2019 were included. Pregnancy-related psychiatric visits were identified using the International Classification of Diseases codes version 10 (ICD-CM-10) for any diagnosis related to pregnancy (Z32, Z34, Z36) or pregnancy complications (O85–O92.79, O09–O16.9, O20–O29.93, O94, O98–O99, O9A–O9A.53). All postpartum encounters (ICD-CM-10: Z39) and pregnancy-related stillbirth (ICD-CM-10: Z37), abortion (ICD-CM-10: O03–O03.9, Z33.2, O04–O04.89, O07–O07.4), or abnormal ectopic pregnancy (O00–O02.9, O08–O08.9) were excluded. Data on patient race (American Indian/Eskimo/Aleut, Asian or Pacific Islander, black, white, other race), sex (female, male), Hispanic (yes, no), payor source (commercial, Medicare/Medicaid, self-pay/uninsured, other), and age in years were included in each ED record. Race and ethnicity were combined and recoded (e.g., non-Hispanic white, non-Hispanic black, Hispanic, other); due to the small sample size, American Indian/Eskimo/Aleut, Asian or Pacific Islander, and other race were combined into an "other" category. Age was categorized into age groups (18–24, 25–34, and 35+ year of age). Data from the NC Emergency Department database were obtained from the University of North Carolina's Cecil G. Sheps Center for Health Services Research. This study was approved by the institutional review board of North Carolina State University.

Psychiatric Outcomes

Psychiatric admissions were identified using either the primary or secondary ICD-CM-10 diagnosis codes to operationalize maternal mental health outcomes: *a*) perinatal mood and anxiety disorders (PMAD) comprised of depressive and anxiety disorders, *b*) severe mental illness (SMI) comprised of bipolar and psychotic disorders, *c*) maternal mental disorders complicating pregnancy (MDP), *d*) suicidality (SUIC) including suicidal ideation and self-harm, and *e*) any mental health disorder (Table S1). While the primary diagnosis is intended to capture the diagnosis most serious and the secondary diagnosis as conditions that coexist at the same time of admission, there is no evidence to suggest that clinicians use these codes uniformly, often patients present with multiple underlying causes, and even less is known about the implementation of these codes among psychiatrists and other mental health professional shortage areas.[25] To address this uncertainty and ensure sufficient sample size for these rare outcomes, we included the primary and secondary diagnosis codes, a common approach to capture acute conditions using hospital administrative data.[21,25,26]

We operationalized PMAD and SMI as conditions that preexisted or recurred during gestation (i.e., a primary mental disorder before pregnancy) and MDP as an incident mental disorder that occurred during pregnancy (i.e., a secondary mental disorder in the prenatal period).[27,28] For this analysis, psychiatric conditions were examined using the overarching diagnostic category (e.g., PMAD) and then by its subcomponents (e.g., depression, anxiety) (Table S2).

Study Design

A time-stratified case-crossover design was used to examine the effects of short-term exposure to ambient temperature. A key feature of this case-only design is that each case serves as its own control[29]; whereby an event or case day (i.e., date of ED visit) was selected and acute exposure was compared to control days within a similar window of exposure in the same month, day of the week, and year (2016–2019) as the event date.[30,31]

Ambient temperature exposure. Our primary exposure metric was the daily average temperature (Tavg). Daily gridded raster temperature data at 4 km resolution were obtained from the PRISM Climate Group (https://prism.oregonstate.edu/). The PRISM data was calculated as an area average based on the average value of all PRISM rasters that spatially intersected the zip code tabulation area (ZCTA) region. This approach was conducted using a ZCTA shapefile from the TIGER/Line Shapefile from the US Census 2018. Daily gridded average temperature (calculated as maximum plus minimum temperature divided by two) and minimum temperature (Tmin) were spatially aggregated using an areal-averaged approach and linked to individual-level ED data using the zip code of maternal residence. For reference, there are over 800 ZCTAs in North Carolina, compared to 100 counties.

Our analysis focused on temperature exposure in the warm (April–September) season only. While the literature is inconclusive on the exact time window for the delayed effects of ambient temperature exposure on mental health, prior research has shown the highest association between hot ambient temperature and psychiatric ED visits on the same day of exposure (i.e., 0-d lag)[21] or up to 3 to 6 d after exposure.[24,32,33] Therefore, we estimated the acute effect of temperature on the same day of the ED admission (lag 0) and for single-day lags (i.e., days 1, 2, 3, 4, 5, and 6). Cumulative effects of average exposure over multiple days were also calculated following prior studies (e.g., Yoo et al.[5] and Peng et al.[22]); whereby the average of the daily temperature across the 2 d before and the day of the ED visit (i.e., 0–2 lag), as well as the 6 d before and the day of ED visit (i.e., 0–6 lag) were calculated. We included two additional binary heat metrics derived from daily Tavg at the zip code level: *a*) extreme heat day (yes/no) defined as a day when the average temperature exceeded the 95th percentile and *b*) heat wave day (yes/no) identified when the day fell within a three consecutive day period in which average temperature was above the 95th percentile based on the 20-year long-term climatology of each zip code and population acclimatization within the last 30 d (i.e., short-term acclimatization) derived from the excess heat factor (EHF).[34] The long-term climatologic reference value for identifying a heatwave event was set to the 95th percentile of the observed daily average temperature on a single-day for all days in a year spanning 2000 to 2019. The excess heat index significance [EHI_{sig} (°C)] identifies an anomalously warm 3-day daily mean temperature that exceeds the climatological 95th percentile (T_{95}) of daily mean temperature of that zip code (i.e., Equation 1), where T_i is the daily temperature. Then, the excess heat index acclimatization [EHI_{accl} (°C)], a measure to capture short-term acclimatization or heat stress within the previous 30 d, identifies 3-d daily mean temperature difference to the average daily mean temperature of the prior 30 d. Lastly, EHF was derived as the product term of EHI_{sig} and EHI_{accl}; a positive EHF indicated heatwave conditions.

$$EHI_{sig} = (T_i + T_{i+1} + T_{i+2})/3 - T_{95}, \quad (1)$$

$$EHI_{accl} = (T_i + T_{i+1} + T_{i+2})/3 - (T_{i-1} + \cdots + T_{i-30})/30. \quad (2)$$

There is currently a national data gap in daily measures for recorded and reliable humidity metrics.[35] Prior research has cautioned against using relative humidity (RH) in temperature–health research because RH is inversely correlated with Tavg and poorly reflects variations in human heat stress.[35,36] Due to the limited availability of high-quality humidity data at health-relevant scales (e.g., zip code), Tmin was included as a proxy for the mean daily dew point, a better estimate than relative humidity for humid regions like the southeastern US.[36–39]

Potential Modifiers

Week of gestation was coded for each admission (ICD-CM-10: Z2A.0–Z3A.49) and operationalized as trimester 1 (estimated

Table 1. Baseline characteristics of the pregnant study population, North Carolina 2016–2019.

Characteristic	PMAD	SMI	MDP	SUIC	Any
No. of event days					
Case days	1,491	291	2,230	633	3,923
Control days	5,095	983	7,628	2,154	13,356
Demographic characteristic of cases					
Race and ethnicity [*n* (%)]					
White	752 (51.02)	127 (44.10)	1,171 (53.08)	324 (51.59)	2,234 (57.31)
Black	553 (37.52)	136 (47.22)	792 (35.90)	230 (36.62)	1,347 (34.56)
Other	61 (4.14)	18 (6.25)	95 (4.31)	30 (4.78)	152 (3.90)
Hispanic	108 (7.33)	7 (2.43)	148 (6.71)	44 (7.01)	165 (4.23)
Missing	42	8	59	19	108
Insurance [*n* (%)]					
Commercial	386 (25.89)	51 (17.53)	513 (23.00)	129 (20.38)	737 (18.74)
Medicare/Medicaid	953 (63.92)	206 (70.79)	1,480 (66.37)	437 (69.04)	2,589 (65.84)
Other	152 (10.19)	34 (11.68)	237 (10.63)	67 (10.58)	606 (15.41)
Uninsured	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)
Age at admission (years) [*n* (%)]					
18–24	587 (39.37)	108 (37.11)	919 (41.21)	268 (47.55)	1,433 (36.44)
25–34	722 (48.42)	156 (53.61)	1,099 (49.28)	301 (47.55)	2,074 (52.75)
35+	182 (12.21)	27 (9.28)	212 (9.51)	64 (10.11)	425 (10.81)
Trimester [*n* (%)]					—
Trimester 1	349 (36.85)	80 (41.45)	763 (38.00)	130 (28.63)	1,030 (43.48)
Trimester 2	372 (39.28)	74 (38.34)	739 (36.80)	213 (46.92)	840 (35.46)
Trimester 3	226 (23.86)	39 (20.21)	506 (25.20)	111 (24.45)	499 (21.06)
Missing	544	98	222	179	1,563
Rurality [*n* (%)]					
Urban	1,162 (77.93)	217 (74.57)	1,790 (80.27)	495 (78.20)	2,991 (76.07)
Suburban	218 (14.62)	62 (21.31)	294 (13.18)	103 (16.27)	649 (16.51)
Rural	111 (7.44)	12 (4.12)	146 (6.55)	35 (5.53)	292 (7.43)
ICE poverty					
T1: Majority low-income (−1.000 to 0.138)	428 (28.71)	90 (30.93)	598 (26.83)	176 (27.80)	1,232 (31.34)
T2: Moderate (−0.139 to 0.004)	635 (42.59)	112 (38.49)	952 (42.71)	266 (42.02)	1,680 (42.74)
T3: Majority high-income (0.005 to 1.000)	428 (28.71)	89 (30.58)	679 (30.46)	191 (30.17)	1,019 (25.92)
ICE race					
T1: Majority black (0.012 to 0.616)	763 (51.17)	158 (54.30)	1,111 (49.82)	328 (51.82)	1,917 (48.75)
T2: Mixed black & white (0.617 to 0.831)	522 (35.01)	97 (33.33)	789 (35.38)	202 (31.91)	1,361 (34.61)
T3: Majority white (0.832 to 1.000)	206 (13.82)	36 (12.37)	330 (14.80)	103 (16.27)	654 (16.63)
ICE race & poverty					
T1: Black, low-income (−1.55 to −0.162)	704 (47.22)	141 (48.45)	1,025 (45.98)	284 (44.87)	1,806 (45.94)
T2: Mixed, moderate (−0.162 to 0.098)	467 (31.32)	96 (32.99)	712 (31.94)	211 (33.33)	1,314 (33.43)
T3: White, high-income (0.99 to 1.000)	320 (21.46)	54 (18.56)	492 (22.07)	138 (21.80)	811 (20.63)
Greenspace per person					
Low TGPP (0 to 2,475.94)	1,320 (93.02)	262 (93.24)	1,974 (92.29)	548 (91.49)	3,407 (91.24)
High TGPP (>2,475.94)	99 (6.98)	19 (6.76)	165 (7.71)	51 (8.51)	327 (8.76)
Missing	72	10	91	34	198
Average ambient exposure levels across case and control days					
Case days [median (SD)]					
Warm season temperature (°C)	24.44 (4.79)	24.23 (4.89)	24.35 (4.73)	24.34 (4.63)	24.17 (4.89)
Above 95th day [temperature (°C)]	27.52 (2.81)	28.40 (2.10)	27.21 (2.70)	27.97 (2.13)	27.16 (2.81)
Heat wave day [temperature (°C)]	27.46 (2.46)	26.80 (2.55)	26.40 (2.54)	27.13 (2.58)	26.83 (2.62)
Control days [median (SD)]					
Warm season temperature (°C)	24.27 (4.85)	24.15 (4.83)	24.35 (4.77)	24.48 (4.57)	24.06 (4.86)
$PM_{2.5}$ ($\mu g/m^3$)	6.14 (3.36)	6.66 (3.55)	6.19 (3.49)	6.68 (3.36)	6.33 (3.42)
Above 95th day	27.31 (2.42)	27.82 (2.63)	27.37 (2.36)	27.51 (2.12)	27.26 (2.54)
Heat wave day	26.82 (2.36)	27.70 (2.90)	26.82 (2.33)	27.64 (3.03)	26.97 (2.81)

Note: Any, any psychiatric disorder; ICE, index of concentration of extremes; MDP, mental disorders of pregnancy; $PM_{2.5}$, particulate matter with aerodynamic diameter ≤2.5 μm; PMAD, perinatal mood and anxiety disorders; SD, standard deviation; SMI, severe mental illness; SUIC, suicidality; TGPP, total greenspace per person.

date of last menstrual period to 13 completed weeks of gestation), trimester 2 (14 to 26 completed weeks of gestation), or trimester 3 (27 weeks to birth). Lastly, the maternal zip code of residence was categorized as urban (codes 1–3), suburban (codes 4–6), or rural (codes 7–10) using the 2010 USDA rural-urban community area (RUCA).[40]

Structural factors like racism and poverty have also been associated with poor mental health during pregnancy.[10,41–43] We adopted the index of the concentration of extremes (ICE) to derive metrics on residential segregation (i.e., a proxy for structural racism), residential economic segregation (i.e., a proxy for poverty), and racialized economic segregation (i.e., multidimensional term demonstrating the overlapping influence of residential racial and economic segregation).[44–46] We relied on five-year estimates from the American Community Survey (ACS) (2015–2019) to obtain ZCTA-level data on total household income, the proportion of non-Hispanic white or non-Hispanic black individuals, and the total population. Each ICE metric was categorized as population-based tertiles: *a*) residential segregation [tertile 1 (T1): majority black, tertile 2 (T2): moderate, and tertile 3 (T3): majority white], *b*) economic segregation (T1: majority low-income, T2: moderate, and T3: majority high-income), and *c*) racialized economic segregation (T1: majority low-income, black communities T2: moderate, and T3: majority high-income, white communities).

Outcome (n)	Exposure	Rate Ratio (95% CI)
PMAD (1,491)	0 days	1.08 (0.98-1.19)
	0-2 days	1.13 (1.01-1.27)
	0-6 days	1.20 (1.04-1.39)
Anxiety (865)	0 days	1.14 (1.00-1.30)
	0-2 days	1.23 (1.06-1.44
	0-6 days	1.30 (1.07-1.59)
Depression (747)	0 days	1.04 (0.91-1.20)
	0-2 days	1.10 (0.94-1.29)
	0-6 days	1.16 (0.94-1.42)
SMI (291)	0 days	1.05 (0.85-1.30)
	0-2 days	1.06 (0.82-1.36
	0-6 days	1.14 (0.82-1.59)
Bipolar (204)	0 days	1.28 (0.98-1.67)
	0-2 days	1.35 (0.98-1.87)
	0-6 days	1.51 (0.99-2.31)
Psychotic disorders (89)	0 days	0.72 (0.50-1.03)
	0-2 days	0.65 (0.43-0.99)
	0-6 days	0.67 (0.39-1.16)
MDP (2,230)	0 days	1.05 (0.97-1.14)
	0-2 days	1.07 (0.97-1.17)
	0-6 days	1.08 (0.96-1.22)
Suicidal (633)	0 days	1.01 (0.87-1.18)
	0-2 days	1.00 (0.84-1.20)
	0-6 days	0.94 (0.75-1.18)
Attempt (380)	0 days	0.86 (0.70-1.05)
	0-2 days	0.96 (0.79-1.17)
	0-6 days	0.88 (0.66-1.17)
Thoughts (253)	0 days	1.28 (1.00-1.65)
	0-2 days	1.22 (0.91-1.62)
	0-6 days	1.04 (0.73-1.49)
Any Psychiatric (3,932)	0 days	1.07 (1.01-1.14)
	0-2 days	1.11 (1.03-1.19)
	0-6 days	1.17 (1.07-1.28)

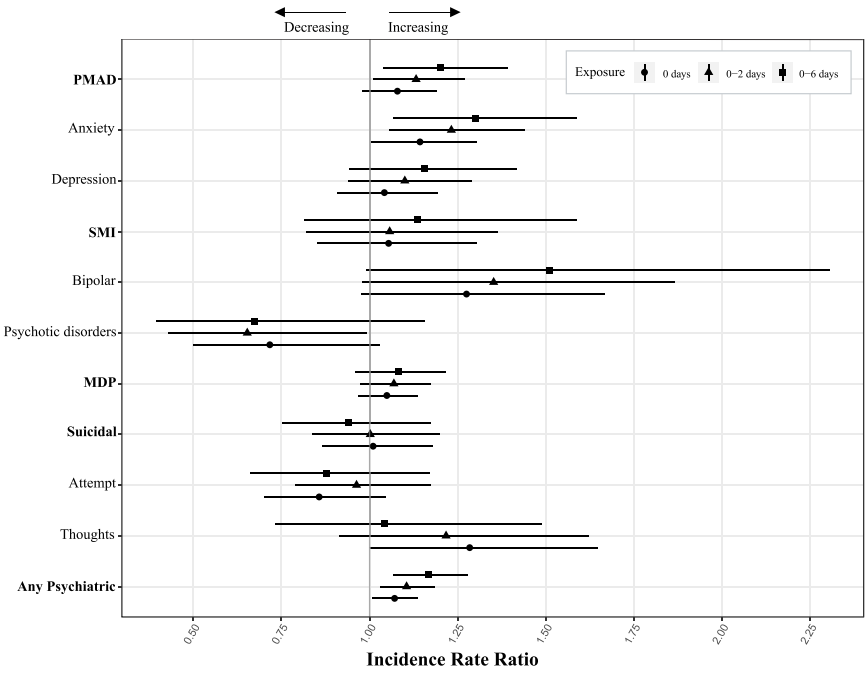

Figure 1. Forest plots of the estimated incidence rate ratios (IRR) and 95% confidence intervals (CI) for the association between a 5°C increase in ambient temperature and psychiatric emergency department (ED) visits from conditional logistic regression models during pregnancy in the warm season (May to September, 2016–2019) for the following conditions: perinatal mood and anxiety disorders (PMAD), severe mental illness (SMI), mental disorders of pregnancy (MDP), suicidality (SUIC), and any psychiatric disorder. n = total number of cases. An IRR >1 suggests ambient temperature increases psychiatric risks during pregnancy.

Built environment factors like proximate and high-availability greenspace have been linked with reduced anxiety and depressive symptoms, as well as stress in pregnant women, guided by the stress reduction theory in environmental psychology.[47–51] Total greenspace per person (TGPP), a proxy for residential availability of greenspace, was derived using a methodology detailed in an earlier publication first derived at the county scale.[50] Publicly available data on green or park space availability were obtained from the Protected Areas Database of the United States (PAD-US) and the Trust for Public Land's Parkserve, and TGPP was calculated by dividing the total greenspace area by the population of that zip code using the ACS 5-year population estimates (2015–2019) and included as a dichotomous variable (at or above 75th percentile, below 75th percentile).

Statistical Analysis

A case-crossover dataset with a case-control indicator (i.e., compare case and control days) as the outcome variable and daily ambient temperature as the exposure was generated separately for each maternal mental disorder. We examined ambient temperature on the same day of the ED admission (e.g., lag 0) and assessed the lag effect of temperature using single (i.e., 3-d, 5-d) and cumulative-day lags (i.e., 0–2 d, 0–6 d). We first tested for nonlinearity between ambient temperature and the risk of an ED admission for each outcome separately by *a*) visual inspection of the shape of the curve by fitting generalized additive models (GAM) in Proc GAMPL (SAS version 9.4; SAS Institute) and *b*) fitting a natural cubic spline for temperature using the effect statement with three equally spaced knots (25th, 50th, and 75th percentiles) using all data.

Conditional logistic regression was used to estimate a 5-unit increase in ambient temperature exposure (°C) on the day of incidence (i.e., lag 0 d of emergent psychiatric admission) and subsequent days before the incidence (e.g., lag 1, lag 2) by matching daily exposure levels on case days with temperature experience on control days on the same day of the week within the same month. A key feature of this case-only design is that each case serves as its own control.[29] All analyses were performed at the zip code level in SAS version 9.4 (SAS Institute) and presented as incidence rate ratio (IRR) and 95% confidence interval (CI) to estimate excess risk in psychiatric-related ED visits per 5-unit increase in ambient temperature. Forest plots were generated using R (R core team 2022). Observations with missing data were omitted from the analyses.

Secondary analyses were performed to examine the following potential effect modifiers: *a*) trimester of exposure (trimester 1, trimester 2, trimester 3); *b*) urbanicity of residence (e.g., urban, suburban, or rural); *c*) available greenspace per person (at or above 75th percentile, below 75th percentile); *d*) residential segregation (T1: majority black, T2: moderate, and T3: majority white), economic segregation (T1: majority low-income, T2: moderate, and T3: majority high-income), and racialized and economic segregation (T1: majority low-income, black; T2: moderate; and T3: majority high-income, white); and *e*) extreme heat day (yes, no) or heat-wave days (yes, no) using an interaction term in the model and considered statistically significant at $p < 0.05$ (alpha = 0.05). An interaction term in the conditional logistic regression was included to assess effect modification (i.e., product terms show deviations from multiplicative joint effects) to test the association between ambient temperature and maternal mental disorders by each effect modifier.

In a sensitivity analysis, we included Tmin (a proxy for dew point) in our model as prior studies have shown that the association between ambient temperature and health effects have changed minimally in the presence of meteorologic factors like humidity.[52]

Results

Table 1 shows the descriptive statistics of the sample and exposure profiles. There were 1,491 case days for PMAD, 2,230 for

Table 2. Incidence rate ratios and 95% confidence intervals for the association between a 5°C increase in ambient temperature and psychiatric emergency department visits from conditional logistic regression models in the warm season in North Carolina (May to September, 2016–2019) across urban, suburban, and rural communities.

	Urban				Suburban				Rural				
Exposure duration and diagnosis	*n*	IRR	95% CI		*n*	IRR	95% CI		*n*	IRR	95% CI		*p*-EM
0 days													
PMAD	1,162	1.08	[0.97	1.21]	218	1.03	[0.80	1.33]	111	1.02	[0.67	1.54]	0.87
Depression	611	1.03	[0.88	1.19]	87	1.25	[0.82	1.89]	49	0.92	[0.49	1.73]	0.64
Anxiety	647	1.20	[1.03	1.40]	147	0.94	[0.69	1.28]	71	1.09	[0.66	1.79]	0.36
SMI	217	1.13	[0.87	1.42]	62	0.89	[0.56	1.42]	12	0.57	[0.18	1.87]	0.40
Bipolar	146	1.49	[1.06	2.06]	49	1.01	[0.60	1.70]	9	0.39	[0.09	1.66]	0.13
Psychiatric disorder	71	0.72	[0.48	1.07]	15	0.49	[0.18	1.36]	3	2.42	[0.07	79.69]	0.60
MDP	1,790	1.05	[0.96	1.15]	294	1.06	[0.85	1.33]	146	0.95	[0.68	1.32]	0.79
Suicidal	495	1.04	[0.88	1.24]	103	0.98	[0.64	1.50]	35	0.63	[0.33	1.21]	0.32
Thoughts	197	1.34	[1.01	1.77]	44	1.56	[0.78	3.14]	12	0.35	[0.09	1.35]	0.14
Attempts	298	0.87	[0.70	1.09]	59	0.71	[0.41	1.24]	23	0.8	[0.36	1.76]	0.75
Any outcome	2,991	1.09	[1.02	1.17]	649	1.04	[0.90	1.20]	292	0.86	[0.68	1.08]	0.11
0–2 days													
PMAD	1,162	1.19	[1.04	1.35]	218	0.94	[0.70	1.27]	111	0.90	[0.59	1.49]	0.23
Depression	611	1.1	[0.92	1.30]	87	1.21	[0.75	1.95]	49	0.95	[0.46	1.95]	0.75
Anxiety	647	1.4	[1.16	1.67]	147	0.87	[0.60	1.24]	71	0.86	[0.49	1.49]	0.03
SMI	217	1.09	[0.81	1.46]	62	0.9	[0.52	1.58]	12	0.98	[0.26	3.73]	0.82
Bipolar	146	1.47	[0.99	2.17]	49	1.14	[0.60	2.16]	9	0.85	[0.19	3.81]	0.65
Psychiatric disorder	71	0.69	[0.43	1.09]	15	0.33	[0.10	1.08]	3	1.8	[0.07	44.76]	0.41
MDP	1,790	1.09	[0.98	1.20]	294	0.98	[0.75	1.29]	146	0.99	[0.67	1.47]	0.76
Suicidal	495	1.03	[0.85	1.26]	103	0.95	[0.60	1.50]	35	0.56	[0.24	1.32]	0.36
Thoughts	197	1.29	[0.93	1.78]	44	1.24	[0.60	2.56]	12	0.36	[0.08	1.70]	0.29
Attempts	298	0.89	[0.69	1.15]	59	0.79	[0.44	1.42]	23	0.69	[0.24	1.99]	0.82
Any outcome	2,991	1.16	[1.07	1.26]	649	1.01	[0.85	1.20]	292	0.74	[0.56	0.98]	0.003
0–6 days													
PMAD	1,162	1.23	[1.04	1.45]	218	1.07	[0.73	1.58]	111	1.01	[0.56	1.83]	0.66
Depression	611	1.13	[0.91	1.41]	87	1.24	[0.67	2.29]	49	1.46	[0.55	3.85]	0.96
Anxiety	647	1.43	[1.14	1.80]	147	1.05	[0.66	1.69]	71	0.82	[0.40	1.69]	0.23
SMI	217	1.24	[0.84	1.83]	62	0.96	[0.47	1.96]	12	0.48	[0.08	2.77]	0.51
Bipolar	146	1.81	[1.08	3.03]	49	1.05	[0.46	2.36]	9	0.85	[0.09	8.17]	0.49
Psychiatric disorder	71	0.7	[0.38	1.28]	15	0.61	[0.14	2.55]	3	0.15	[0.00	6.51]	0.71
MDP	1,790	1.12	[0.99	1.28]	294	0.91	[0.64	1.29]	146	0.92	[0.57	1.51]	0.37
Suicidal	495	0.96	[0.75	1.24]	103	0.83	[0.46	1.49]	35	0.78	[0.30	2.01]	0.81
Thoughts	197	1.09	[0.74	1.63]	44	1.05	[0.43	2.57]	12	0.39	[0.07	2.31]	0.54
Attempts	298	0.89	[0.65	1.22]	59	0.67	[0.30	1.50]	23	1.02	[0.33	3.16]	0.77
Any outcome	2,991	1.22	[1.10	1.35]	649	1.11	[0.90	1.39]	292	0.73	[0.51	1.06]	0.02

Note: Any outcome, any psychiatric disorder; CI, confidence interval; ED, emergency department; IRR, incidence rate ratios; MDP, mental disorders of pregnancy; *n*, total number of cases; *p*-EM, *p*-value for the interaction term; PMAD, perinatal mood and anxiety disorders; SMI, severe mental illness; SUIC, suicidality.

MDP, 291 for SMI, and 633 for SUIC during the warm season. A larger proportion of the sample were Medicaid beneficiaries, between the ages of 25 and 35 years old, resided in urban zip codes, and were white with the exception of a higher proportion of black pregnant people presenting to the ED with SMI. Roughly 50% of cases for each outcome lived in majority black low-income communities, and more than 90% of cases resided in communities with low greenspace availability. The median temperature on a warm season day was 24°C and 27°C for an extreme heat or heat wave day.

We did not detect nonlinearity in GAM models (Figure S1) and relied on conditional logistic regression to model the linear association between ambient temperature and each maternal mental disorder. Results from conditional logistic regression models showed an increased risk of ED visits during pregnancy for PMAD, SMI, SUIC, and any psychiatric condition in the warm season (Figure 1). In general, compared to same-day exposure or single-day lags, the highest risk of admission across all conditions occurred for cumulative 0–2 d and cumulative 0–6 d exposure periods (Figure 1; Table S3). One exception included a higher risk for suicidal thoughts for same day exposure (IRR = 1.28; 95% CI: 1.00, 1.65) compared to control days. The strongest association occurred in response to the accumulation of hot ambient temperatures (i.e., 0–6 d) resulting in a 20% increased risk for PMAD ($IRR_{0–6\,days}$ = 1.20; 95% CI: 1.04, 1.39), a 30% increase in risk for anxiety ($IRR_{0–6\,days}$ = 1.30; 95% CI: 1.07, 1.59), and a 52% increased risk for bipolar disorder ($IRR_{0–6\,days}$ = 1.51; 95% CI: 0.99, 2.31) per 5°C increase in temperature.

We observed significant heterogeneity in the association between ambient temperature and maternal mental disorders across urban, suburban, and rural communities (Table 2). The association between warm temperatures and increased risk for any maternal health outcome was highest in urban areas on case days, particularly for pregnant persons presenting to the ED following cumulative exposure over 0–2 d for anxiety ($p_{interaction} = 0.03$) and any outcome ($p_{interaction} < 0.003$) compared to control days. The association persisted for any outcome during pregnancy in urban areas following cumulative exposure over 0–6 lags ($p_{interaction} = 0.02$).

Results did not show effect modification by trimester, greenspace per person, residential segregation, residential poverty, or racialized economic segregation (Table 3–7). There was weak evidence of effect modification by extreme heat day for same-day and 0–2 d exposure periods ($p_{interaction} = 0.10$). Compared to nonextreme heat days, the association between warm ambient temperature and any mental health outcome remained more pronounced on an extreme heat day for 0 d (IRR = 1.37; 95% CI: 1.05, 1.80) and 0–2 d (IRR = 1.27; 95% CI: 1.03, 1.58) exposure periods (Table 8).

Effect estimates adjusted for Tmin were nearly equal to models that included only ambient temperature (<10% difference);

Table 3. Incidence rate ratios and 95% confidence intervals for the association between a 5°C increase in ambient temperature and psychiatric emergency department visits from conditional logistic regression models in the warm season in North Carolina (May to September, 2016–2019) across trimester.

	Trimester 1				Trimester 2				Trimester 3				
Exposure duration and diagnosis	*n*	IRR	95% CI		*n*	IRR	95% CI		*n*	IRR	95% CI		*p*-EM
0 days													
PMAD	349	1.06	[0.87	1.29]	372	1.17	[0.95	1.43]	226	1.13	[0.87	1.46]	0.82
Depression	155	1.08	[0.85	1.37]	189	1.19	[0.89	1.58]	119	1.09	[0.77	1.55]	0.85
Anxiety	221	1.22	[0.89	1.65]	216	1.19	[0.89	1.58]	126	1.09	[0.77	1.55]	0.71
SMI	80	1.24	[0.90	1.71]	74	1.1	[0.72	1.69]	39	0.92	[0.53	1.59]	0.85
Bipolar	61	1.15	[0.73	1.81]	50	1.55	[0.89	2.69]	22	0.75	[0.34	1.63]	0.32
Psychiatric disorder	19	0.85	[0.35	2.11]	26	0.58	[0.29	1.15]	17	1.12	[0.51	2.45]	0.44
MDP	763	0.97	[0.85	1.12]	739	1.1	[0.95	1.26]	506	1.1	[0.93	1.29]	0.39
Suicidal	130	1.01	[0.72	1.41]	213	1.05	[0.80	1.37]	111	0.99	[0.69	1.42]	0.97
Thoughts	58	1.03	[0.65	1.64]	83	1.31	[0.84	2.05]	40	1.17	[0.67	2.04]	0.70
Attempts	72	0.99	[0.61	1.60]	130	0.91	[0.65	1.28]	71	0.86	[0.53	1.40]	0.89
Any outcome	1,030	1.03	[0.92	1.15]	840	1.08	[0.95	1.23]	499	1.12	[0.94	1.34]	0.75
0–2 days													
PMAD	349	1.25	[0.99	1.57]	372	1.23	[0.97	1.58]	226	1.08	[0.81	1.44]	0.73
Depression	155	1.33	[0.98	1.80]	189	1.3	[0.93	1.80]	119	1.13	[0.77	1.66]	0.58
Anxiety	221	1.43	[1.01	2.03]	216	1.25	[0.88	1.77]	126	1.08	[0.73	1.60]	0.80
SMI	80	1	[0.62	1.61]	74	1.06	[0.63	1.76]	39	0.84	[0.42	1.69]	0.88
Bipolar	61	1.13	[0.65	1.95]	50	1.56	[0.79	3.07]	22	0.77	[0.31	1.95]	0.48
Psychiatric disorder	19	0.6	[0.21	1.69]	26	0.55	[0.25	1.18]	17	0.94	[0.33	2.67]	0.71
MDP	763	1	[0.86	1.18]	739	1.19	[1.01	1.41]	506	1.09	[0.90	1.31]	0.35
Suicidal	130	1.15	[0.79	1.68]	213	1.1	[0.80	1.52]	111	0.96	[0.62	1.49]	0.82
Thoughts	58	0.98	[0.59	1.65]	83	1.36	[0.79	2.33]	40	1.19	[0.58	2.45]	0.45
Attempts	72	1.37	[0.79	2.36]	130	0.97	[0.65	1.46]	71	0.82	[0.47	1.41]	0.70
Any outcome	1,030	1.09	[0.96	1.25]	840	1.11	[0.95	1.29]	499	1.04	[0.85	1.27]	0.86
0–6 days													
PMAD	349	1.37	[1.02	1.85]	372	1.2	[0.89	1.62]	226	0.89	[0.61	1.30]	0.21
Depression	155	1.39	[0.95	2.02]	189	1.2	[0.80	1.80]	119	1.02	[0.62	1.68]	0.14
Anxiety	221	1.62	[1.03	2.55]	216	1.23	[0.82	1.87]	126	0.81	[0.48	1.36]	0.62
SMI	80	1.17	[0.64	2.13]	74	1.11	[0.53	2.31]	39	0.76	[0.33	1.79]	0.71
Bipolar	61	1.33	[0.66	2.67]	50	1.66	[0.65	4.24]	22	1.11	[0.31	4.06]	0.88
Psychiatric disorder	19	0.76	[0.23	2.47]	26	0.53	[0.17	1.64]	17	0.55	[0.17	1.80]	0.85
MDP	763	1.05	[0.86	1.28]	739	1.24	[1.00	1.53]	506	0.98	[0.77	1.24]	0.37
Suicidal	130	1.26	[0.77	2.06]	213	0.98	[0.67	1.43]	111	0.84	[0.48	1.49]	0.58
Thoughts	58	0.76	[0.38	1.55]	83	1.25	[0.67	2.32]	40	0.88	[0.36	2.14]	0.57
Attempts	72	1.99	[0.98	4.03]	130	0.85	[0.53	1.36]	71	0.82	[0.40	1.71]	0.12
Any outcome	1,030	1.21	[1.02	1.43]	840	1.14	[0.93	1.39]	499	0.97	[0.75	1.26]	0.38

Note: Any outcome, any psychiatric disorder; CI, confidence interval; ED, emergency department; IRR, incidence rate ratios; MDP, mental disorders of pregnancy; *n*, total number of cases; *p*-EM, *p*-value for the interaction term; PMAD, perinatal mood and anxiety disorders; SMI, severe mental illness; SUIC, suicidality.

therefore, Tmin was not included as a time-varying confounder in our models (Table S3).

Discussion

Our study is one of the first in the US to demonstrate a strong link between acute exposure to hot ambient temperature in the warm season and the increased risk of psychiatric emergency department visits during pregnancy. Results showing excess heat-induced risks were especially pronounced for women diagnosed with perinatal mood and anxiety disorder, a severe mental illness (i.e., bipolar disorder), or those experiencing suicidal thoughts. Findings revealed no differences in psychiatric risks in the warm season across trimesters of pregnancy. Important disparities were observed in urban areas for any psychiatric morbidity and anxiety. This study contributes that the accumulation of hot temperatures over acute periods during pregnancy may be an important environmental risk factor for psychiatric morbidity, particularly for PMAD, including anxiety, and bipolar disorder, while same-day exposure may be an important risk for maternal suicidal ideation.

To our knowledge, no prior studies have examined the short-term effects of ambient temperature on psychiatric ED visits for pregnant persons. Prior epidemiologic research has shown sex-based differences in hospital admissions for preexisting mental and behavioral disorders following exposure to ambient temperature; whereby, women of reproductive age were more sensitive to high ambient temperature exposure in Brazil[53]; Lisbon, Portugal[54]; and Shanghai, China.[22] Only one other US-based case-crossover study has noted higher rates of ED visits on extreme heat days at the county scale for a range of mental health disorders, including mood and anxiety disorders, schizophrenia, and self-harm.[21] While this study did include women of reproductive age (18 to 44 years), pregnant women were not included, and unlike our sample composed of primarily Medicaid beneficiaries in a Southern state—a group likely more vulnerable to heat—this sample included commercially insured adults in the US. Our results highlighting higher risk for same-day and cumulative exposure averaged over 3- and 7-day windows at the subcounty scale stand in contrast with this large US population-based study examining men and women that demonstrated no lagged effect of temperature for specific psychiatric ED admissions.[21]

Emerging research elucidating the direct effects of extreme heat on pregnancy health has prioritized the identification of critical windows of exposure in which pregnant women may be more sensitive.[12] Elevated risk of ED visits for PMAD, particularly for depression and suicidal attempt, were generally more common following cumulative exposure to warm temperatures in the first trimester, though our results are limited to a small sample size because not all cases received a diagnosis code to denote week of gestation during the ED visit. Results demonstrated a higher risk of ED visits for any psychiatric disorder in response to same-day or 0–2 day lag in exposure on an extreme heat day. The relationship between exposure to high ambient temperature and increased suicide risks are well documented in recent systematic reviews

Table 4. Incidence rate ratios and 95% confidence intervals for the association between a 5°C increase in ambient temperature and psychiatric emergency department visits from conditional logistic regression models in the warm season in North Carolina (May to September, 2016–2019) for high versus low total greenspace per person.

	Low TGPP (0–2,475.94)				High TGPP (>2,475.94)				
Exposure duration and diagnosis	*n*	IRR	95% CI		*n*	IRR	95% CI		*p*-EM
0 days									
PMAD	99	1.08	[0.97	1.19]	1,320	1.1	[0.97	1.64]	0.93
Depression	50	1.02	[0.58	1.79]	665	1.06	[0.92	1.22]	0.90
Anxiety	53	1.22	[0.72	2.06]	764	1.14	[0.99	1.30]	0.80
SMI	19	0.55	[0.20	1.53]	262	1.06	[0.85	1.32]	0.22
Bipolar	14	0.4	[0.13	1.28]	182	1.31	[0.99	1.73]	0.05
Psychiatric disorder	5	2.7	[0.12	62.63]	82	0.7	[0.49	1.01]	0.40
MDP	165	1.03	[0.76	1.41]	1,974	1.06	[0.97	1.15]	0.90
Suicidal	51	1.1	[0.64	1.90]	1,862	1.01	[0.86	1.20]	0.78
Thoughts	19	0.86	[0.37	2.02]	218	1.33	[1.01	1.75]	0.34
Attempts	32	1.31	[0.63	2.75]	330	0.85	[0.68	1.05]	0.26
Any outcome	327	1.01	[0.81	1.25]	3,407	1.08	[1.01	1.15]	0.54
0–2 days									
PMAD	99	1.15	[1.02	1.30]	1,320	0.96	[0.60	1.53]	0.46
Depression	50	0.83	[0.44	1.57]	665	1.13	[0.96	1.34]	0.36
Anxiety	53	1.14	[0.60	2.16]	764	1.24	[1.05	1.46]	0.81
SMI	19	0.42	[0.11	1.56]	262	1.08	[0.83	1.40]	0.17
Bipolar	14	0.46	[0.11	1.97]	182	1.38	[0.99	1.93]	0.15
Psychiatric disorder	5	0.26	[0.01	6.41]	82	0.68	[0.44	1.04]	0.56
MDP	165	1.02	[0.72	1.44]	1,974	1.08	[0.98	1.19]	0.75
Suicidal	51	0.79	[0.42	1.49]	1,862	1.05	[0.86	1.28]	0.40
Thoughts	19	0.62	[0.25	1.55]	218	1.28	[0.93	1.76]	0.14
Attempts	32	0.99	[0.40	2.43]	330	0.92	[0.72	1.19]	0.88
Any outcome	327	0.96	[0.75	1.24]	3,407	1.12	[1.04	1.21]	0.25
0–6 days									
PMAD	99	1.06	[0.57	1.95]	1,320	1.21	[1.04	1.42]	0.67
Depression	50	1.02	[0.44	2.33]	665	1.16	[0.94	1.44]	0.75
Anxiety	53	1.17	[0.50	2.74]	764	1.32	[1.07	1.63]	0.79
SMI	19	0.41	[0.09	1.89]	262	1.19	[0.84	1.67]	0.18
Bipolar	14	0.65	[0.10	4.33]	182	1.55	[1.00	2.40]	0.38
Psychiatric disorder	5	0.15	[0.01	3.84]	82	0.73	[0.42	1.27]	0.34
MDP	165	0.97	[0.62	1.51]	1,974	1.1	[0.97	1.24]	0.59
Suicidal	51	0.78	[0.36	1.69]	1,862	0.95	[0.74	1.21]	0.64
Thoughts	19	0.6	[0.18	2.02]	218	1.01	[0.68	1.48]	0.42
Attempts	32	0.93	[0.34	2.50]	330	0.91	[0.67	1.24]	0.97
Any outcome	327	0.98	[0.71	1.36]	3,407	1.18	[1.07	1.30]	0.28

Note: Low TGPP is below 75th percentile and high TGPP is at or above the 75th percentile. Any outcome, any psychiatric disorder; CI, confidence interval; ED, emergency department; IRR, incidence rate ratios; MDP, mental disorders of pregnancy; *n*, total number of cases; *p*-EM, *p*-value for the interaction term; PMAD, perinatal mood and anxiety disorders; SMI, severe mental illness; SUIC, suicidality; TGPP, total greenspace per person.

and meta-analysis[20,55,56]; however, significant gaps remain on the etiologic mechanisms underpinning the timing of prenatal exposure and associated elevated risk in pregnancy.

While pregnant populations residing in urban areas were more vulnerable to severe mental illness following exposure to hot temperatures, estimates from rural areas were based on a small number of cases. Previous data from UK- and US-based studies revealed that perinatal mood and anxiety disorders are much more common in rural areas,[57,58] while suicidal ideation is more common in urban compared to rural or suburban locations.[59] Reasons behind rural–

Table 5. Incidence rate ratio and 95% confidence intervals for the association between a 5°C increase in ambient temperature and psychiatric emergency department visits from conditional logistic regression models in the warm season in North Carolina (May to September, 2016–2019) across tertiles of the index of concentration of extremes economic segregation metric.

	T1: Majority low-income (−1.000 to 0.138)				T2: Moderate (−0.139 to 0.004)				T3: Majority high-income (0.005 to 1.000)				
ICE economic segregation	*n*	IRR	95% CI		*n*	IRR	95% CI		*n*	IRR	95% CI		*p*-EM
PMAD	428	0.99	[0.82	1.18]	635	1.19	[1.02	1.39]	428	1.02	[0.86	1.22]	0.23
Depression	223	0.97	[0.75	1.24]	294	1.2	[0.96	1.50]	230	0.97	[0.76	1.23]	0.33
Anxiety	247	1.01	[0.79	1.29]	388	1.21	[1.00	1.47]	230	1.19	[0.93	1.53]	0.48
SMI	90	1.09	[0.75	1.59]	112	1.11	[0.79	1.56]	89	0.95	[0.64	1.41]	0.83
Bipolar	55	1.46	[0.86	2.49]	85	1.19	[0.80	1.77]	64	1.26	[0.77	2.06]	0.83
Psychiatric disorder	37	0.77	[0.45	1.29]	27	0.9	[0.46	1.76]	25	0.47	[0.22	1.00]	0.42
MDP	598	1.03	[0.88	1.20]	952	1.11	[0.98	1.25]	679	0.99	[0.86	1.14]	0.46
Suicidal	176	0.93	[0.68	1.25]	266	1.05	[0.83	1.32]	191	1.03	[0.78	1.37]	0.81
Thoughts	81	1.26	[0.80	1.98]	109	1.28	[0.86	1.90]	63	1.32	[0.84	2.09]	0.99
Attempts	95	0.7	[0.46	1.07]	157	0.94	[0.70	1.26]	128	0.86	[0.59	1.25]	0.54
Any outcome	1,232	1.06	[0.96	1.18]	1,680	1.14	[1.04	1.25]	1,019	0.98	[0.87	1.10]	0.12

Note: Any outcome, any psychiatric disorder; CI, confidence interval; ED, emergency department; ICE, index of concentration of extremes; IRR, incidence rate ratios; MDP, mental disorders of pregnancy; *n*, total number of cases; *p*-EM, *p*-value for the interaction term; PMAD, perinatal mood and anxiety disorders; SMI, severe mental illness; SUIC, suicidality.

Table 6. Incidence rate ratio and 95% confidence intervals for the association between a 5°C increase in ambient temperature and psychiatric emergency department visits from conditional logistic regression models in the warm season in North Carolina (May to September, 2016–2019) across tertiles of the index of concentration of extremes racialized segregation metric.

	T1: Majority black (0.012–0.616)				T2: Mixed black & white (0.617–0.831)				T3: Majority white (0.832–1.000)				
ICE residential segregation	*n*	IRR	95% CI		*n*	IRR	95% CI		*n*	IRR	95% CI		*p*-EM
PMAD	763	1.14	[0.99	1.30]	522	0.98	[0.84	1.15]	206	1.15	[0.87	1.53]	0.36
Depression	373	1.2	[0.99	1.46]	280	0.97	[0.78	1.21]	94	0.77	[0.51	1.16]	0.10
Anxiety	460	1.14	[0.95	1.36]	285	1.04	[0.84	1.30]	120	1.56	[1.05	2.32]	0.22
SMI	158	0.88	[0.67	1.17]	97	1.41	[0.92	2.16]	36	1.24	[0.71	2.17]	0.16
Bipolar	101	1.13	[0.78	1.64]	70	1.68	[0.97	2.92]	33	1.23	[0.70	2.16]	0.50
Psychiatric disorder	59	0.6	[0.39	0.93]	27	1.05	[0.53	2.08]	3	2.46	[0.02	357.04]	0.35
MDP	1,111	1.04	[0.93	1.17]	789	1.01	[0.89	1.16]	330	1.18	[0.95	1.48]	0.49
Suicidal	328	0.93	[0.75	1.15]	202	1.04	[0.80	1.37]	103	1.28	[0.84	1.96]	0.39
Thoughts	148	1.24	[0.89	1.72]	68	1.33	[0.85	2.08]	37	1.41	[0.68	2.91]	0.93
Attempts	180	0.74	[0.55	0.98]	134	0.9	[0.64	1.27]	66	1.22	[0.72	2.05]	0.24
Any outcome	1,917	1.05	[0.97	1.14]	1,361	1.1	[1.00	1.22]	654	1.06	[0.91	1.24]	0.75

Note: Any outcome, any psychiatric disorder; CI, confidence interval; ED, emergency department; ICE, index of concentration of extremes; IRR, incidence rate ratios; MDP, mental disorders of pregnancy; *n*, total number of cases; *p*-EM, *p*-value for the interaction term; PMAD, perinatal mood and anxiety disorders; SMI, severe mental illness; SUIC, suicidality.

urban differences in pregnancy-related mental health morbidity have been attributed to lower access and availability of mental health services and interpersonal (e.g., intimate partner crisis, financial difficulty, substance misuse) and sociodemographic factors (e.g., inadequate and late access to prenatal care, lack of transportation, and traveling distance to services).[60]

While our study revealed no association between ambient temperature and maternal psychiatric risks during pregnancy for communities with a greater availability of greenspace, a recent longitudinal study in the Southeast showed that pregnant persons residing in communities with high green or park space availability were at a lower risk of presenting with a maternal mental disorder.[27] More research on the adaptive measures to a changing climate, such as the efficacy of nature-based interventions is needed, as greenspace may have significant potential to reduce the health burden of extreme heat and heat waves during pregnancy.[61]

Implications for Clinical Practice/Clinicians

Although high temperatures have been connected to adverse birth outcomes,[62] additional awareness among obstetric providers is needed on the full range of maternal health impacts from heat. Clinician awareness should translate into anticipatory guidance on high-temperature pregnancy risk and increased access to mental health care and support interventions (e.g., 988 National Suicide and Crisis Lifeline). Important resources already exist to assist providers in determining the number of extreme heat days in the upcoming month to implement extra support/check-ins for their most vulnerable prenatal populations (Heat & Health Tracker, US Centers for Disease Control and Prevention; https://ephtracking.cdc.gov/Applications/heatTracker/). Most importantly, programs supporting screening and treating perinatal depression and mental illness, like NC Maternal Mental Health MATTERS,[63] should be integrated as standard for prenatal care practice. Finally, clinicians can advocate in their communities for policies that increase access to mental health support resources and that mitigate heat-related health harms.

Strengths and Limitations

To the best of our knowledge, no other studies have examined the implications of high ambient temperatures on pregnancy mental health. By self-matching each individual, we were able to control for the influence of prenatal risk factors (e.g., maternal age, race) that do not change throughout a pregnancy and potential bias introduced by seasonal or longer-term trends.[64–66] Lastly, unlike prior studies, we examined temperature exposure during pregnancy at the subcounty scale, the finest spatial scale available for this dataset. The aggregation of larger geographic units (e.g., county scale) can result in imprecise statistical inference by masking variation across diverse geographic populations.[67–69] Compared to counties, the use of zip code reduces the potential for spatial misclassification and the

Table 7. Incidence rate ratio and 95% confidence intervals for the association between a 5°C increase in ambient temperature and psychiatric emergency department visits from conditional logistic regression models in the warm season in North Carolina (May to September, 2016–2019) across tertiles of the index of concentration of extremes racialized economic segregation metric.

	T1: Majority black, low-income (−1.55 to −0.162)				T2: Mixed, moderate (−0.162 to 0.098)				T3: Majority white, high-income (0.99 to 1.000)				
ICE racialize economic segregation	*n*	IRR	95% CI		*n*	IRR	95% CI		*n*	IRR	95% CI		*p*-EM
PMAD	704	1.13	[0.98	1.31]	467	0.99	[0.84	1.17]	320	1.11	[0.89	1.39]	0.46
Depression	339	1.13	[0.92	1.39]	255	0.95	[0.76	1.19]	153	1.07	[0.78	1.48]	0.52
Anxiety	431	1.18	[0.98	1.42]	248	1.04	[0.82	1.32]	186	1.23	[0.92	1.65]	0.61
SMI	141	1.04	[0.78	1.40]	96	0.89	[0.62	1.30]	54	1.55	[0.88	2.75]	0.29
Bipolar	89	1.45	[0.97	2.16]	73	0.87	[0.56	1.33]	42	2.08	[1.04	4.16]	0.07
Psychiatric disorder	53	0.66	[0.42	1.03]	24	0.94	[0.46	1.93]	12	0.62	[0.19	2.00]	0.70
MDP	1,025	1.1	[0.97	1.23]	712	0.95	[0.83	1.10]	492	1.1	[0.92	1.31]	0.27
Suicidal	284	0.95	[0.75	1.19]	211	1.04	[0.79	1.36]	138	1.11	[0.79	1.56]	0.73
Thoughts	125	1.2	[0.84	1.72]	83	1.42	[0.91	2.24]	45	1.28	[0.74	2.21]	0.85
Attempts	159	0.79	[0.59	1.07]	128	0.86	[0.61	1.20]	93	1.01	[0.65	1.56]	0.68
Any outcome	1,806	1.12	[1.02	1.22]	1,314	1.04	[0.94	1.15]	811	1.02	[0.89	1.18]	0.47

Note: Any outcome, any psychiatric disorder; CI, confidence interval; ED, emergency department; ICE, index of concentration of extremes; IRR, incidence rate ratios; MDP, mental disorders of pregnancy; *n*, total number of cases; *p*-EM, *p*-value for the interaction term; PMAD, perinatal mood and anxiety disorders; SMI, severe mental illness; SUIC, suicidality.

Table 8. Incidence rate ratio and 95% confidence intervals for the association between a 5°C increase in ambient temperature and psychiatric emergency department visits from conditional logistic regression models in the warm season in North Carolina (May to September, 2016–2019) by extreme heat or heat wave days.

		Above 95th			Below 95th				Heatwave			Non-heatwave			
Exposure duratison and diagnosis	*n*	IRR	95% CI		IRR	95% CI		*p*-EM	IRR	95% CI		IRR	95% CI		*p*-EM
0 days															
PMAD	1,491	1.24	0.79	1.96	0.80	0.51	1.25	0.61	0.89	0.55	1.43	1.13	0.70	1.82	0.47
Anxiety	865	1.02	0.58	1.82	0.98	0.55	1.74	0.98	0.78	0.41	1.49	1.28	0.67	2.43	0.28
Depression	747	1.62	0.84	3.15	0.62	0.32	1.20	0.67	1.00	0.51	1.95	1.00	0.51	1.95	0.43
SMI	291	0.35	0.07	1.64	2.89	0.61	13.67	0.28	0.78	0.27	2.22	1.29	0.45	3.70	0.91
Bipolar	204	0.43	0.09	2.05	2.31	0.49	10.93	0.58	0.80	0.27	2.43	1.25	0.41	3.78	0.93
Psychiatric disorders	89	—	—	—	—	—	—	—	—	—	—	—	—	—	—
MDP	2,230	1.32	0.91	1.92	0.76	0.52	1.10	0.36	1.42	1.00	2.02	0.70	0.50	1.00	0.06
Suicidal	633	0.74	0.32	1.72	1.35	0.58	3.13	0.36	0.91	0.47	1.78	1.10	0.56	2.14	0.47
Thoughts	253	1.16	0.41	3.28	0.87	0.31	2.45	0.70	0.99	0.35	2.78	1.01	0.36	2.85	0.36
Attempts	380	0.38	0.09	1.58	2.66	0.63	11.13	0.28	0.85	0.36	2.02	1.18	0.50	2.79	0.88
Any	3,932	1.37	1.05	1.80	0.73	0.56	0.95	0.10	1.20	0.93	1.55	0.83	0.64	1.08	0.56
0–2 days															
PMAD	1,491	1.19	0.85	1.69	0.84	0.59	1.18	0.53	0.87	0.58	1.30	1.15	0.77	1.71	0.38
Anxiety	865	1.02	0.65	1.60	0.98	0.63	1.54	0.84	0.80	0.47	1.37	1.25	0.73	2.13	0.25
Depression	747	1.45	0.87	2.40	0.69	0.42	1.14	0.79	0.97	0.54	1.71	1.04	0.58	1.84	0.31
SMI	291	0.44	0.13	1.50	2.28	0.67	7.82	0.30	0.76	0.32	1.85	1.31	0.54	3.18	0.93
Bipolar	204	0.48	0.13	1.68	2.10	0.59	7.45	0.54	0.83	0.33	2.10	1.21	0.48	3.05	0.99
Psychiatric disorders	89	—	—	—	—	—	—	—	—	—	—	—	—	—	—
MDP	2,230	1.22	0.91	1.62	0.82	0.62	1.10	0.50	1.23	0.91	1.65	0.82	0.61	1.10	0.23
Suicidal	633	0.79	0.42	1.51	1.26	0.66	2.41	0.26	1.00	0.58	1.74	1.00	0.57	1.73	0.59
Thoughts	253	1.26	0.57	2.87	0.79	0.35	1.80	0.57	1.30	0.59	2.88	0.77	0.35	1.70	0.48
Attempts	380	0.41	0.14	1.24	2.44	0.81	7.39	0.20	0.83	0.38	1.80	1.21	0.57	2.64	0.86
Any	3,932	1.27	1.03	1.58	0.79	0.64	0.97	0.10	1.16	0.94	1.44	0.86	0.69	1.07	0.55
0–6 days															
PMAD	1,491	1.18	0.90	1.55	0.85	0.65	1.11	0.25	0.98	0.72	1.33	1.02	0.75	1.38	0.85
Anxiety	865	1.07	0.74	1.53	0.94	0.65	1.35	0.51	0.99	0.66	1.47	1.01	0.68	1.52	0.67
Depression	747	1.44	0.99	2.11	0.69	0.47	1.02	0.51	1.11	0.72	1.70	0.90	0.59	1.38	0.53
SMI	291	0.48	0.18	1.27	2.08	0.79	5.53	0.21	0.70	0.32	1.50	1.44	0.67	3.10	0.79
Bipolar	204	0.53	0.19	1.48	1.90	0.68	5.32	0.46	0.82	0.36	1.88	1.22	0.53	2.78	0.89
Psychiatric disorders	89	0.21	—	—	4.86	—	—	0.21	0.22	0.01	3.45	4.58	0.29	72.38	0.50
MDP	2,230	1.16	0.92	1.45	0.87	0.69	1.09	0.90	1.15	0.91	1.46	0.87	0.69	1.10	0.34
Suicidal	633	1.03	0.66	1.60	0.97	0.63	1.51	0.66	1.07	0.68	1.69	0.94	0.59	1.47	0.54
Thoughts	253	1.70	0.95	3.05	0.59	0.33	1.06	0.86	1.62	0.83	3.14	0.62	0.32	1.20	0.64
Attempts	380	0.57	0.27	1.19	1.76	0.84	3.65	0.30	0.77	0.40	1.47	1.30	0.68	2.49	0.58
Any	3,932	1.18	1.00	1.40	0.85	0.71	1.00	0.16	1.12	0.94	1.34	0.89	0.75	1.06	0.77

Note: —, no data; Above 95th, at or above 27°C; Any outcome, any psychiatric disorder; Below 95th, below 27°C; CI, confidence interval; ED, emergency department; ICE, index of concentration of extremes; IRR, incidence rate ratios; MDP, mental disorders of pregnancy; *n*, total number of cases; *p*-EM, *p*-value for the interaction term; PMAD, perinatal mood and anxiety disorders; SMI, severe mental illness; SUIC, suicidality.

urban, suburban, and rural classifications are based on this spatial unit. The characterization of temperature exposure at the zip code is a significant improvement to prior research that has largely been focused on the county scale.

One limitation involved the identification of maternal mental disorders by relying on administrative billing data, as these routinely collected data are subject to administrative coding error and clinical diagnostic error, particularly for psychiatric diagnosis.[70] Another limitation to consider is that the ED presentation of a case may potentially be capturing the most severe and higher risk cases based on underlying socioeconomic factors (e.g., access to health services), which may mean our results are generalizable to a more high-risk population. Although the majority of our sample included Medicaid beneficiaries, we did observe a large number of commercially insured pregnant persons arriving at the ER during extreme heat and heat wave days. Lastly, exposure misclassification is likely given that temperature experience for each birthing person was approximated by averaging tempering across a 24-h period and zip code, a large spatial boundary that expands beyond a maternal residence. Individual-level temperature experience collected from station-based weather monitors with limited geographic resolution is an imperfect proxy for the actual personal temperature experience. Furthermore, we were unable to collect data on time spent indoors in the air conditioning or total time spent each day in high-heat thermal environments; thus, our results are based on ecologic inference from daily change in maternal mental health and daily changes in warm season average temperature. While we examined Tmin as a proxy for dew point, special care should be taken when including daily averages of humidity variables given that some metrics, like RH, display some diurnal variation that is highly inversely correlated with temperature while others demonstrate residual correlation with air temperature (e.g., RH) and should be avoided.[35,36] Prior epidemiologic research has shown that temperature, independent of humidity, is associated with the exacerbation of mental disorders.

Conclusion

Our findings show that exposure to warm ambient temperatures during pregnancy is an environmental risk factor for a wide array of emergency psychiatric visits. Both same-day and cumulative exposure to warm temperatures yielded higher psychiatric risks. Results can be used to inform clinical and public health guidance on susceptible windows of pregnancy and identify birthing populations in need of enhanced protection to reduce the adverse impacts of a changing climate on mental health during pregnancy. Climate change has significant potential to impact not only the health of a pregnant person but also their child. Future research is needed to understand the long-term consequences of climate-related warm temperature increases on the health of pregnant persons and their children.

Acknowledgments

J.D.R.: conceptualization, data curation, formal analysis, methodology, writing, review, and editing; M.M.S.: writing, review, and editing; A.B.: writing, review, and editing; C.R.: formal analysis, review, and editing; K.C.: data curation, formal analysis, review, and editing; L.W.: data curation, writing, review, and editing; and S.R.: data curation, writing, review, and editing.

This study was supported in part by grants from the National Institutes of Health's National Institute of Environmental Health Sciences (NIEHS) [1R03ES031228-01A1 (J.D.R. and M.M.S.)], [1R15ES033817-01 (S.R. and L.W.)] and a grant from the National Oceanic and Atmospheric Administration (NOAA) Climate Program Office Climate Adaptation Partnerships program [NA21OAR4310312 (J.D.R., C.R., and K.C.)] and through the Cooperative Institute for Satellite Earth Systems under Cooperative Agreement [NA19NES4320002 (J.D.R.)].

The NIH and NOAA had no role in the design or conduct of the study; data analysis or interpretation; preparation, review, or approval of the manuscript; or decision to submit the manuscript for publication.

Due to the restricted nature of the individual health data, the authors are unable to share data used in this publication.

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