Supplementary Information

Extreme weather and asthma: A systematic review and meta-analysis

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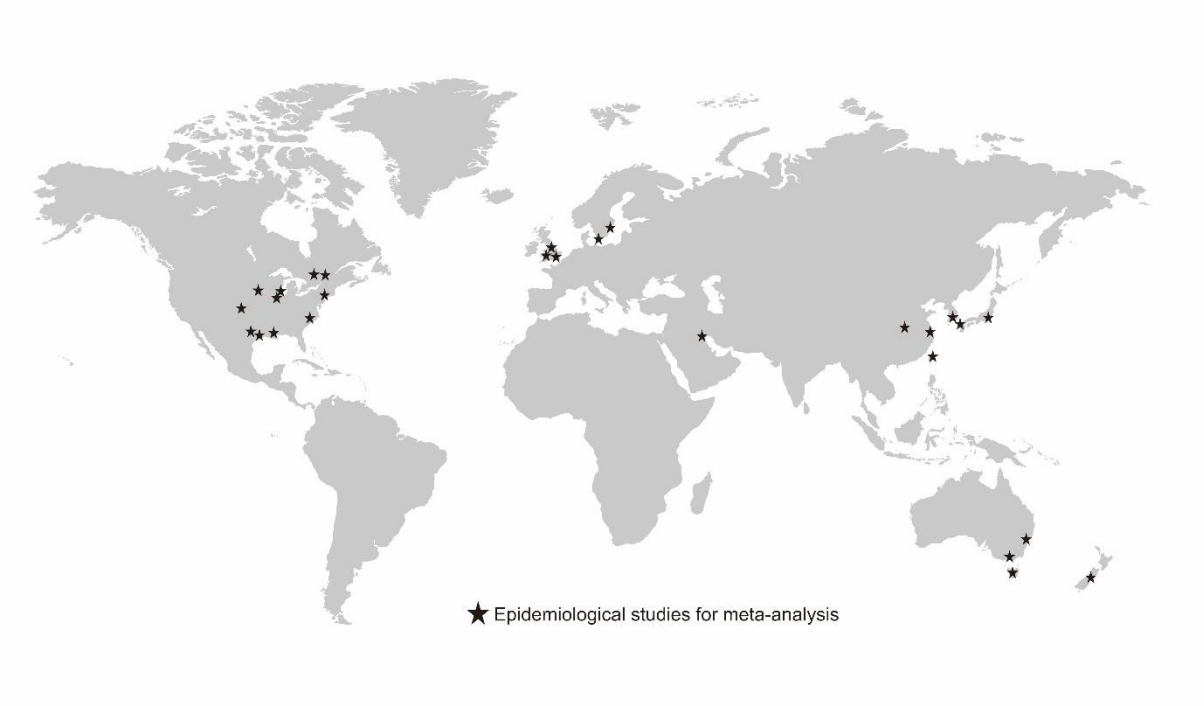

Figure S1. Regions covered by the studies included.

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Table S1 Search strategies used for online databases

Database	Search strategies	Records
PubMed	(asthma* OR wheeze* OR wheezing* OR respiratory allergy* OR "asthma"[MeSH Terms]) AND (“meteorology”[Title/Abstract] OR “climate change”[Title/Abstract] OR “climate”[Title/Abstract] OR “climat*”[Title/Abstract] OR “extreme weather”[Title/Abstract] OR “extreme weather event”[Title/Abstract] OR “extreme climate event”[Title/Abstract] OR “ice storm”[Title/Abstract] OR “blizzard”[Title/Abstract] OR “dust storm”[Title/Abstract] OR “hail”[Title/Abstract] OR “lightning”[Title/Abstract] OR “tornado”[Title/Abstract] OR “flood”[Title/Abstract] OR “hurricanes”[Title/Abstract] OR “cold spell”[Title/Abstract] OR “heatwave”[Title/Abstract])	1202
Web of Science	(TS=(asthma OR wheeze OR wheezing OR respiratory allergy)) AND (TS=(meteorology OR climate change OR climate OR climat OR extreme weather event OR extreme climate event OR ice storm OR blizzard OR dust storm OR hail OR lightning OR tornado OR flood OR hurricanes OR cold spell OR heatwave))	1672
Medline and EMBASE	1) (asthma or wheeze or wheezing or repiratory allergy).mp. [mp=title, abstract, original title, name of substance word, subject heading word, floating sub-heading word, keyword heading word, protocol supplementary concept word, rare disease supplementary concept word, unique identifier, synonyms] 2) (meteorology or climate change or climate or climat or extreme weather event or extreme climate event or ice storm or blizzard or dust storm or hail or lightning or tornado or flood or hurricanes or cold spell or heatwave).mp. [mp=title, abstract, original title, name of substance word, subject heading word, floating sub-heading word, keyword heading word, protocol supplementary concept word, rare disease supplementary concept word, unique identifier, synonyms] 3) 1 and 2	3548
ProQuest	ABSTRACT,TITLE(asthma OR wheeze OR wheezing OR respiratory allergy) AND ABSTRACT,TITLE(meteorology OR climate change OR climate OR climat OR extreme weather OR extreme weather event OR extreme climate event OR ice storm OR blizzard OR dust storm OR hail OR lightning OR tornado OR flood OR hurricanes OR cold spell OR heatwave)	510

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Table S2. Characteristics of studies that included in systematic review and meta-analysis

ID	Reference (year)	Location (continent)	Study period	Study design	Age (years)	Sample size	Outcome	Type	Effect estimates (95%CI)	Extreme weather events
Included study for meta-analysis (n = 31)										
1	Anderson, et al. (2001)	Cardiff/ Newport, United Kingdom	1990-1996	Cross-sectional study	All	Not given	Asthma (ICD codes 493.0, 493.1 and 493.9)	HAs	The effects of thunderstorm on asthma: OR = 1.300 (95% CI: 1.008-1.676)	**Thunderstorm**
2	Blindauer, et al. (1999)	New York, USA	1996	Case control study	All	4457	Asthma (ICD-9, 493)	EDs	The effects of blizzard on asthma: **Gender** Male OR = 1.42 (95% CI: 0.73-2.76) Female OR = 0.70 (95% CI: 0.36-1.37) Overall patients OR = 1.00 (95% CI: 0.50-1.99)	**Blizzard**
3	Campbell, et al. (2019)	Tasmania, Australia	2008-2016	A case-crossover	All	8546	Asthma (ICD-10, J45/J46)	EDs	The effects of cold spells on asthma: OR = 1.401 (95% CI 0.939-2.090)	**Heatwave**
4	Celenza, et al. (1996)	West Central London, United Kingdom	June-July 1994	Cross-sectional study	All	148	Asthma	EDs	The effects of thunderstorm on asthma: RR = 3.21 (95% CI: 1.65-6.23)	**Thunderstorm**
5	Chang, et al. (2021)	Taiwan	2008-2011	Case-cohort study	All	1264	Asthma (ICD-9-CM: 493)	Asthma mortality	The effects of typhoon on asthma: RR = 1.99 (95% CI: 1.24–3.17)	**Typhoon**
6	Chen, et al. (2021)	Beijing, China	2012-2015	Time-stratified case-	All	Average number of daily asthma hospital admissions	Asthma (ICD-10: J45–J46)	HAs	The effects of cold spells on asthma (Model 4 controlled for relative humidity and O_3) RR Lag0 = 1.05 (95% CI: 0.92-1.20); RR Lag1-2 = 1.09 (95% CI: 0.96-1.23); RR Lag3-6 = 1.07 (95% CI: 0.95-1.20); RR Lag7-14 =	**Cold spells**

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				crossover study					1.12 (95% CI: 1.02-1.25); RR Lag15-30 =1.03 (95% CI: 0.93-1.14); RR Lag1-30 = 1.06 (95% CI: 0.97-1.17) **Gender** Male: RR Lag0-30 = 1.64 (95% CI: 0.94-2.84) Female: RR Lag0-30 = 2.90 (95% CI: 1.85-4.54) **Age** 19-64 years old: RR Lag0-30 = 2.46 (95% CI: 1.56-3.89) ≥65 years old: RR Lag0-30 = 2.11 (95% CI: 1.22-3.64)	
7	Cowan et al (2021)	North Carolina, USA	2010-2011	Time series	All	39688	Asthma (ICD-9 493.XX)	EDs	The effects of hurricane on asthma RR = 1.02 (95% CI: 0.97-1.08).	**Hurricane**
8	Fagan, et al. (2001)	Illinois, USA	Spring 1994	Cross-sectional study	Grades 7-12D	2693	Asthma	Asthma symptoms	The effects of flood on asthma: OR = 1.86 (95% CI: 1.42-2.44).	**Flood**
9	Fanny, et al. (2021)	Houston, USA	2016-2017	Retrosepctive cross-sectional study	0-18 years old	39514	Asthma (ICD-9-CM: 493; ICD-10-AM: J45-J46)	EDs	The effects of hurricane on asthma: OR = 1.81 (95% CI: 1.52-2.14)	**Hurricane**
10	Figgs, et al. (2019)	Douglas County, Colorado, USA	2011-2012	Case control study	All	38476	Asthma (ICD-9, 493)	EDs	The effects of heatwave on asthma: Heatwave (Model A): crude: OR, Lag0 = 1.25 (95% CI: 1.02-1.53); adjust: OR, Lag0 = 1.23 (95% CI: 0.96-1.57) Heatwave (Model B): crude: OR, Lag0 = 1.21 (95% CI: 0.99-1.48); adjust: OR, Lag0 = 1.19 (95% CI: 0.96-1.47)	**Heatwave**
11	Fitzgerald, et al. (2014)	New York, USA	1991–2006	Time series	All	396043	Asthma (ICD-9, 493)	HAs	The effects cold spell on asthma: During a cold spell (December-March): RR = 0.951 (95% CI: 0.921-0.981); After a cold spell (December-March): RR = 0.983 (95% CI: 0.965-1.002) **During a cold spell:** **Gender:**	**Cold spells**

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								Females: RR = 0.940 (95% CI: 0.915-0.975); Males: RR = 0.952 (95% CI: 0.928-0.977) **Age:** Young: RR = 0.912 (95% CI: 0.880-0.945); School age: RR = 0.938 (95% CI: 0.903-0.975); Adults: RR = 0.990 (95% CI:0.956-1.026); Seniors: RR = 0.931 (95% CI:0.881-0.985)	
12	Guo, et al. (2012)	Shanghai, China	2007-2009	Time series	0-14	20104	Asthma (ICD-9, 493)	OVs	The effects of cold spells on asthma: Cold spells (Model 4 controlled for relative humidity and O3) RR Lag 0 = 1.05 (95% CI: 0.92,1.20); RR Lag 1-2 = 1.09 (95% CI: 0.96,1.23); RR Lag 3-6 = 1.07 (95% CI: 0.95,1.20); RR Lag 7-14 = 1.12 (95% CI: 1.02,1.25); RR Lag 15-30 = 1.03 (95% CI: 0.93,1.14); RR Lag 1-30 = 1.06 (95% CI: 0.97,1.17)	**Cold spells**
13	Hasunuma, et al. (2021)	Fukuoka, Japan	April 1 to June 30, 2013	A case-crossover	6-12 years old	160	Asthma (ICD-9, 493)	Asthma sympotms	The effects of dust storm on asthma: RR = 5.17 (95% CI: 1.02-26.12)	**Dust storm**
14	Hoppe, et al. (2012)	Iowa, USA	2008-2009	A case-crossover	All	71	Asthma (ICD-9-CM: 493; ICD- 10-AM: J45-J46)	Asthma diagnosis, Asthma symptoms	The effects of flood on asthma: **Asthma diagnosis:** Unadjusted OR = 2.07 (95% CI: 0.61-7.06) and adjusted OR: 2.16 (95% CI: 0.59-7.92) **Asthma symptoms:** Unadjusted OR = 1.77 (95% CI: 0.55-5.68) and adjusted OR: 1.75 (95% CI: 0.50-6.15)	**Flood**
15	Kontowicz, et al. (2022)	Iowa, USA	2007-2017	Cross-sectional study	All	62286	Asthma (ICD-9-CM: 493; ICD- 10-AM: J45-J46)	Asthma symptoms	The effects of flood on asthma: RR = 1.04 (95% CI: 0.989–1.09)	**Flood**
16	Liu, et al. (2021)	Heifei, China	2013-2016	Time series	0-18	32220	Asthma (ICD-10, J45)	HAs	The effects of cold spells on asthma: Cold spells (daily minimum AT 5^{th} 3 days): RR, Lag0= 0.997 (95% CI: 0.911,1.092); RR, Lag1= 1.058 (95% CI: 1.009,1.110); RR, Lag2= 1.100 (95% CI: 1.050,1.152); RR, Lag3= 1.109 (95% CI: 1.051, 1.169) **Gender:**	**Cold spells**

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								Male: RR, Lag 0-7= 1.434 (95% CI: 1.094,1.881); Female: RR, Lag 0-7= 1.370 (95% CI: 0.928,2.025) **Age:** Infant: RR, Lag0-7 = 0.973 (95% CI: 0.508,1.864); Pre-school children: RR, Lag0-7 = 1.242 (95% CI: 0.902,1.711); School age children: RR, Lag0-7 = 2.066 (95% CI: 1.443,2.957)	
17	Lõhmus et al (2022)	Stockholm, Sweden	2001-2017	Time series	All	737377	Asthma (ICD-10-AM: J45-J46)	OVs	The effects of thunderstorm on asthma: RR = 1.26 (95% CI: 1.16–1.37)	**Thunderstorm**
18	Ma, et al. (2021)	in 47 Japanese Prefectures	1972-2015	Time series	All	107664	Asthma (ICD-8: 493; ICD-9: 493; and ICD-10: J45–J46)	Asthma mortality	The effects of cold spell on asthma: Lag 0 d (RR = 0.41, 95% CI: –1.23, 2.08), Lag 0–14 d (RR =3.06, 95% CI: –3.84,10.44) and Lag 0–21 d (RR = 2.07, 95% CI: –6.32, 11.23).	**Cold Spell**
19	Merrifield, et al. (2013)	Sydney, New South Wales, Australia	2004-2009	Cross-sectional study	All	4339772	Asthma (ICD-9-CM: 493; ICD-10-AM: J45-J46)	EDs, HAs	The effects of dust storm on asthma: Emergency department visit related to asthma during dust storm: RR = 1.230 (95% CI: 1.099-1.377) Hospital admission related to asthma during dust storm: RR = 1.141 (95% CI 0.991-1.313) **Gender:** Emergency department visit: Males: RR = 1.282 (95% CI: 1.205-1.365); Females: RR = 1.318 (95% CI: 1.233-1.409). Asthma hospital admissions: Males: RR = 1.254 (95% CI: 1.066-1.475) Females: RR = 1.418 (95% CI: 1.227- 1.638)	**Dust storm**
20	Newson, et al. (1997)	England	1990-1994	Time series	All	873	Asthma	HAs	The effects of thunderstorm on asthma: **Age:** 0-14 years old: OR = 1.25 (95% CI 1.11-1.39) ≥15 years old: OR = 1.26 (95% CI 1.12-1.41) All ages: OR = 1.25 (95% CI 1.15-1.36)	**Thunderstorm**

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21	Park, et al. (2022)	Louisiana, USA	2010-2012	Cross-sectional study	All	63789	Asthma (ICD-9-CM: 493)	EDs	The effects of thunderstorm on asthma: RR = 1.270 (95% CI: 1.056-1.527) **Age:** Children: 0-18 years old: RR = 1.270 (95% CI: 1.056-1.527) Adults 19-<65 years old: RR = 1.061 (95% CI: 0.880-1.279) Older adults ≥65 years old: RR = 0.887 (95% CI: 0.572-1.375)	**Thunderstorm**
22	Ramesh, at al. (2022)	Texas, USA	September 18-21, 2019	Case control study	All	3251700	Asthma	EDs	The effects of flood on asthma: RR = 1.22 (95% CI: 1.05–1.41)	**Flood**
23	Rappold, et al. (2011)	North Carolina, USA	2018	Cross-sectional study	All	4280	Asthma (ICD-9-CM: 493)	EDs	The effects of thunderstorm on asthma: OR = 1.65 (95% CI: 1.25–2.17)	**Thunderstorm**
24	Smith, et al. (2022)	Midwestern, USA	2007-2018	Retrosepctive cohort study	All	142333	Asthma (ICD-9-CM: 493; ICD-10-AM: J45-J46)	EDs	The effects of thunderstorm on asthma: RR Lag0 = 1.047 (95% CI: 1.012, 1.083); RR Lag1 = 1.006 (95% CI: 0.975, 1.038); RR Lag2 = 0.998 (95% CI: 0.967, 1.030); RR Lag3 = 0.967 (95% CI: 0.936, 0.998); RR Lag4 = 0.969 (95% CI: 0.939, 1.001); RR Lag 5 = 0.968 (95% CI: 0.937, 0.999); RR Lag 6 = 0.978 (95% CI: 0.948, 1.010); RR Lag 7 = 0.986 (95% CI: 0.955, 1.018); RR Lag 8 = 1.016 (95% CI: 0.984, 1.048); RR Lag 9 = 0.979 (95% CI: 0.948, 1.011)	**Thunderstorm**
25	Sohail, et al. (2020)	Finland	2001-2017	Time series	≥18 years old	Not given	Asthma (ICD-10, J45/J46)	HAs	The effects of heatwave on asthma: Heatwaves in summer months P90, All heatwave (4 or more days): RR = 0.956 (95% CI: 0.725-1.260); P90, Short heatwave (4-7 days): RR = 1.215 (95% CI: 0.892-1.656); P90, Long heatwave (10 days): RR = 0.475 (95% CI: 0.282-1.197); P99 heatwave (3 or more days): RR = 1.113 (95% CI: 0.734-1.642) **Age:** P90 heatwave days in summer months (June–August) **P90, All heatwave (4 or more days)** 18-64 years, RR = 1.178 (95% CI: 0.714-1.944); 65-74 years, RR = 0.667 (95% CI: 0.312-1.424); 75- years, RR = 1.385 (95% CI: 0.948-2.262) **P90, Short heatwave (4-7 days)**	**Heatwave**

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								18-64 years, RR = 1.471 (95% CI: 0.817-2.646); 65-74 years, RR = 1.002 (95% CI: 0.615-1.315); 75 years, RR = 1.724 (95% CI: 0.923-3.003) P90, Long heatwave (10 or more days): 18-64 years, RR = 0.773 (95% CI: 0.320-1.864); 65-74 years, RR = 0.238 (95% CI: 0.061-0.941); 75 years, RR = 0.742 (95% CI: 0.321-1.715) P99 heatwave days in summer months: All heatwave (3 or more days) 18-64 years, RR = 1.271 (95% CI: 0.614-2.628); 65-74 years, RR = 0.713 (95% CI: 0.270,1.882); 75- years, RR = 1.689 (95% CI: 0.914,3.121)	
26	Son, et al. (2014)	Korea	2003-2008	Time series	All	233890	Asthma (ICD-10, J45/J46)	HAs	The effects of heatwave on asthma: Heatwaves (P98, 2- days)**:** RR = 1.091 (95% CI: 0.813,1.463)	**Heatwave**
27	Thalib and Al-Taiar (2012)	Kuwait	1996-2000	Time series	All	88267	Asthma (ICD-9, 493)	HAs	The effects of dust storm on asthma: RR Lag0 = 1.071 (95% CI: 1.024,1.117); RR Lag1 = 1.030 (95% CI: 0.983,0.077); RR Lag2 = 1.014 (95% CI: 0.967-1.061); RR Lag3 = 1.001 (95% CI: 0.954-1.048); RR Lag5 = 0.966 (95% CI: 0.918-1.013) **Age:** <15 years old: RR Lag0 = 1.093 (95% CI: 1.032-1.155); RR Lag1 = 1.029 (95% CI: 0.967-1.090); RR Lag2 = 1.022 (95% CI: 0.960-1.084); RR Lag3 = 0.996 (95% CI: 0.934-1.058); RR Lag5 = 0.983 (95% CI: 0.921-1.045) 15-64 years old: RR Lag0 = 1.062 (95% CI: 0.984-1.141); RR Lag1 = 1.044 (95% CI: 0.966-1.123); RR Lag2 = 1.032 (95% CI: 0.954-1.110); RR Lag3 = 1.034 (95% CI: 0.956-1.112); RR Lag5 = 0.934 (95% CI: 0.855-1.013) ≥65 years old: RR Lag0 = 0.925 (95% CI: 0.756-1.094); RR Lag1 = 0.970 (95% CI: 0.803-1.137); RR Lag2 = 0.891 (95% CI: 0.722-1.059); RR Lag3 = 0.901 (95% CI: 0.73-,1.070); RR Lag5 = 0.992 (95% CI: 0.826-1.0159)	**Dust storm**
28	Turcotte-Tremblay, et al. (2014)	Montreal, Canada	2011	Cross-sectional study	12 years old children	68	Asthma	Asthma symptoms,	The effects of ice storm on asthma: Asthma symptoms OR = 1.11 (95% CI: 1.01–1.23) Asthma diagnosis OR = 1.09 (95% CI: 1.00–1.19)	**Ice Storm**

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								Asthma diagnosis		
29	Villeneuve, et al. (2005)	Ottawa, Canada	1992-2000	Case-crossover study	2-15 years old	18970	Asthma	EDs	The effects of thunderstorm on asthma: OR = 1.35 (95% CI: 1.02–1.77)	**Thunderstorm**
30	Yang, et al. (2005)	Taipei, Taiwan	1996-2001	Case control study	All	1673	Asthma (ICD-9 code 493)	HAs	The effects of dust storm on asthma: RR = 1.08 (95% CI: 0.97–1.20)	**Dust storm**
31	Yitshak-Sade, et al. (2014)	Australia and New Zealand	2005-2011	Time series	0-18 years old	42920	Asthma (ICD-9 code 493)	HAs	The effects of dust storm on asthma: RR = 1.10 (95% CI: 0.97-1.25) **Age** 0-2 years old: RR = 1.07 (95% CI: 0.90-1.26), age ≥3 years old: RR = 1.16 (95% CI: 1.05-1.56)	**Dust storm**

CM, clinical modification; EDs, emergency department visits; HAs, hospital admissions; ICD, International Classification of Diseases; OR, odds ratio; OVs, outpatient visits; RR, relative risk or risk ratio

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Table S3. Quality assessment and risk of bias of included studies for meta-analysis

ID	Study (Publication year)	Were the criteria for inclusion in the sample clearly defined?	Were the study subjects and the setting described in detail?	Was the exposure measured in a valid and reliable way?	Were objective, standard criteria used for measurement of the condition?	Were confounding factors identified?	Were strategies to deal with confounding factors stated?	Were the outcomes measured in a valid and reliable way?	Was appropriate statistical analysis used?	Total
1	Anderson, et al. (2011)	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	7
2	Blindauer, et al. (1999)	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	7
3	Campbell, et al. (2019)	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	7
4	Celenza, et al. (1996)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	8
5	Chang, et al. (2014)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	8
6	Chen, et al. (2021	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	7
7	Cowan, et al. (2021)	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	7
8	Fagan, et al. (2001)	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	7
9	Fanny, et al. (2021)	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	7
10	Figgs, et al. (2019)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	8
11	Fitzgerald, et al. (2014)	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	7
12	Guo, et al. (2012)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	8
13	Hasunuma, et al (2021)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	8
14	Hoppe, et al. (2012)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	8
15	Kontowicz, et al. (2022)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	8
16	Liu, et al. (2012)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	8

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17	Lohmus, et al. (2022)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	8
18	Ma, et al. (2021)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	8
19	Merrifield, et al. (2013)	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	7
20	Newson, et al. (2019)	Yes	Yes	Yes	Yes	No	No	Yes	Yes	6
21	Park, et al. (2022)	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	7
22	Ramesh, et al. (2021)	Yes	Yes	Yes	Yes	No	No	Yes	Yes	6
23	Rappold, et al. (2011)	Yes	Yes	Yes	Yes	No	No	Yes	Yes	8
24	Smith, et al. (2022)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	8
25	Sohail, et al. (2020)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	8
26	Son, et al. (2014)	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	7
27	Thalib and Al-Taiar (2012)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	8
28	Turcotte-Tremblay, et al. (2021)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	8
29	Vileneuve et al. (2005)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	8
30	Yang, et al. (2005)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	8
31	Yitshak Sade, et al. (2014)	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	7

Note: * Risk of bias assessment was accessed by the Joanna Briggs Institute (JBI);

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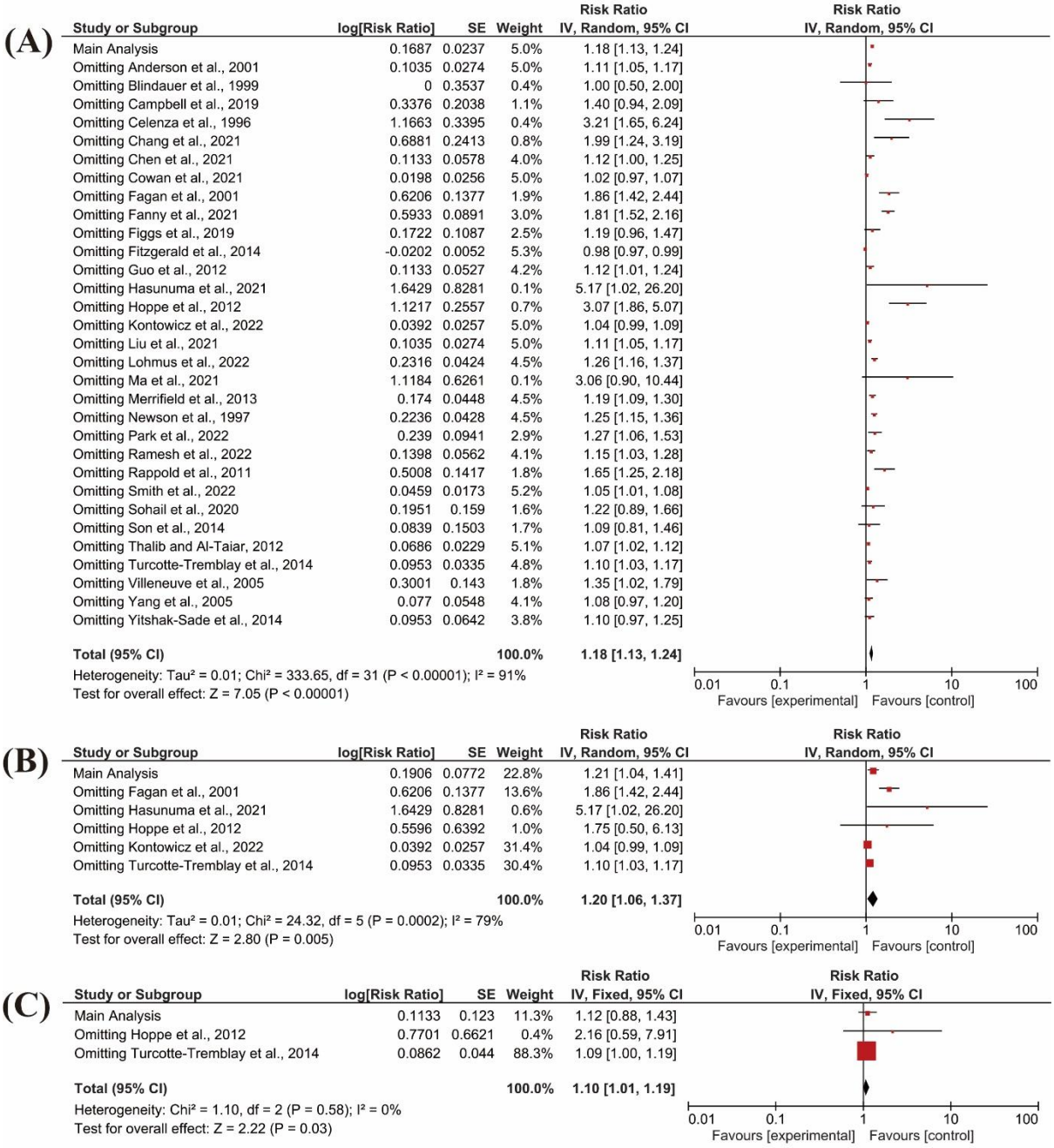

Figure S2. Forest plot with sensitivity analysis for extreme weather events with general asthma outcomes A) asthma events B) asthma symptoms C) asthma diagnosis.

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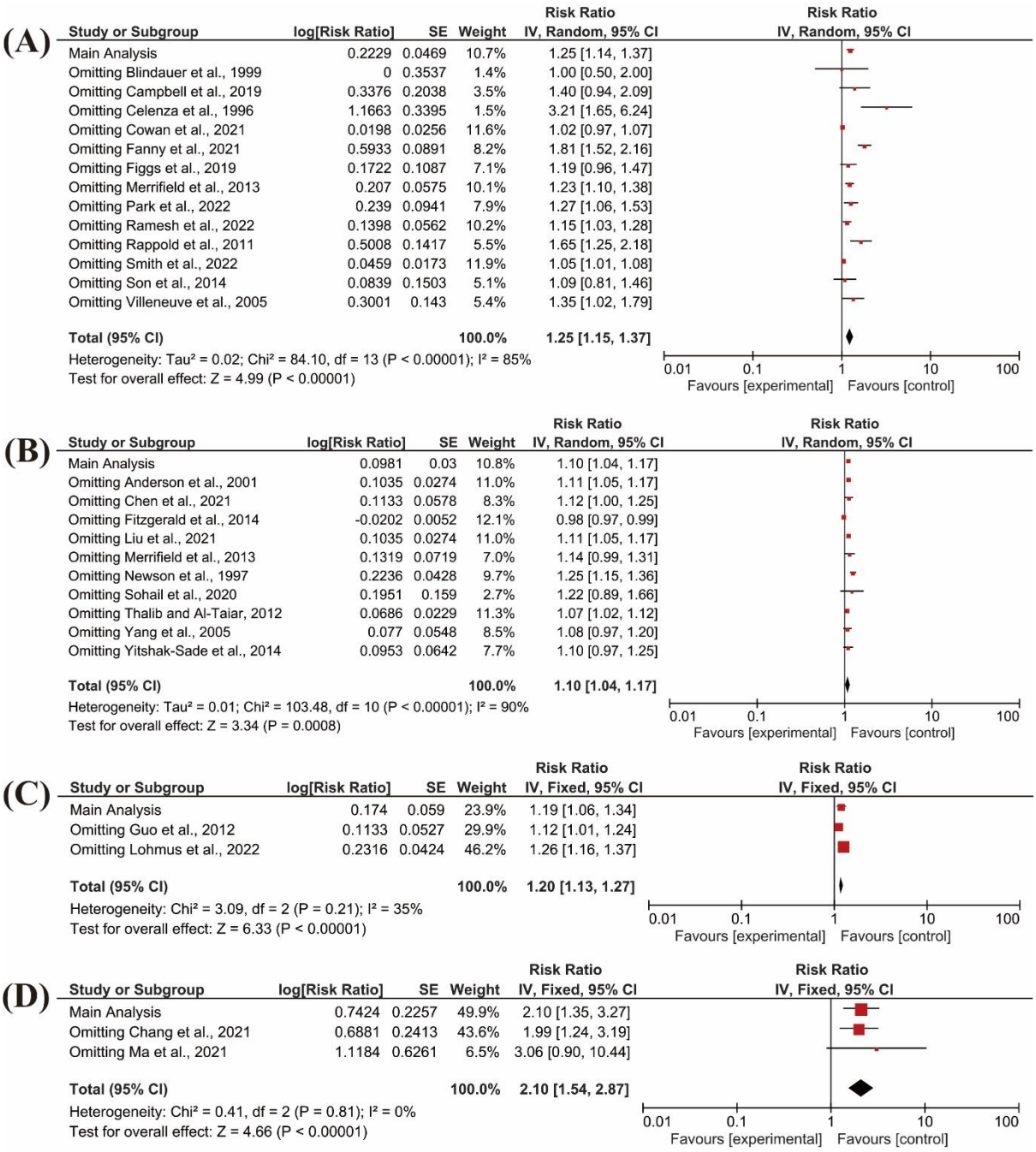

Figure S3. Forest plot with sensitivity analysis for extreme weather events with acute exacerbations of asthma A) asthma emergency department visits B) asthma hospital admission C) asthma outpatient visits D) asthma mortality.