

Thunderstorm asthma: a review, risks for Aotearoa New Zealand, and health emergency management considerations

Carol Stewart, Nicole L Young, Nicholas D Kim, David M Johnston, Richard Turner

ABSTRACT

AIM: To provide an up-to-date review of thunderstorm asthma (TA), identifying causative factors, and to discuss implications for management of TA in New Zealand.

METHODS: A literature search was carried out to identify articles that investigate the characteristics and causative factors of TA. Nine electronic databases were searched, yielding 372 articles, reduced to 30 articles after screening for duplication and relevance.

RESULTS: TA is globally rare, with 29 reported events since 1983, but is expected to increase in frequency as Earth warms. Triggers include both pollen (particularly ryegrass pollen) and fungal spores. Individual risk factors include outdoor exposure, sensitivity to triggering allergens and history of seasonal allergic rhinitis. History of asthma is not a strong risk factor but is associated with severity of outcome. Limited data on demographic characteristics suggests that individuals aged between 20 and 60 and (in Australasia) of Asian/Indian ethnicity are at higher risk. A single TA event has been reported in New Zealand to date, but much of New Zealand may be at risk of future events given that ryegrass pastures are widely distributed, and summer thunderstorms can occur anywhere.

CONCLUSIONS: We recommend developing rapidly deployable public messaging to support the health emergency management response to future TA events, together with the instigation of routine aeroallergen monitoring.

Until recently, thunderstorm asthma (TA) was thought to be a relatively rare phenomenon, but recent events have resulted in it being labelled as a growing threat to public health.¹ TA refers to an observed increase in asthma (acute bronchospasm) cases within hours of thunderstorms, brought about by a combination of specific meteorological conditions, the presence of high concentrations of aeroallergens, the formation of respirable allergen particles <10 µm diameter and the exposure (usually outdoors) of populations who are sensitised to the allergens.^{2,3}

Aeroallergens are airborne allergen particles, primarily pollen and fungal spores. While whole pollen grains are strongly correlated with symptoms of allergic rhinitis, they are too large to penetrate deep into the airways, with a typical size range of 12–60 µm.^{4,5} Ryegrass pollen, for example, which has very strong allergenic properties and is known to be a primary cause of allergic rhinitis in humans, has a diameter of 30–40 µm.⁶

The aetiological role of thunderstorms in reported TA epidemics is thought to be the fragmentation of whole pollen, and other aeroallergen, grains, into large numbers of fine, respirable particles (SPPs, or sub-pollen particles) of size ≤2.5 µm that can pass into

the lower respiratory tract where they can induce bronchoconstriction.^{6,7,8,9} The proposed mechanism involves pollen, and other aeroallergen grains, being lifted into thunderstorm systems by warm updrafts, followed by rupturing into fragments, transport downwards in cold downdrafts and then dispersion by strong lateral outflows at ground level, exposing populations (Figure 1). Proposed rupturing mechanisms include mechanical friction from wind gusts, water-induced swelling in high humidity conditions, and lightning-induced hydrostatic shock. Although rupturing mechanisms are still poorly understood, Emmerson et al.⁶ note that humidity remained very low throughout a severe, and comprehensively documented, TA event in Melbourne, Australia in November 2016,¹⁰ and that of the range of mechanisms they investigated using atmospheric modelling, only lightning counts generated a pattern consistent with observations of SPP concentrations.

The purpose of this article is to provide a concise, up-to-date review of reported TA episodes worldwide, including New Zealand's first reported cases of TA in Hamilton in December 2017.⁵ Contributing factors, where reported, are discussed and analysed, together with implications for New Zealand for emergency preparedness for health services and a discussion of

expected future trends in frequency of TA events in a warming world.

Methods

We carried out a literature search to identify primary research articles that document specific TA events *and* report on environmental conditions, suspected triggers and/or individual risk factors. Here we refer to an epidemic as a greater-than-twofold increase in asthma-related hospital or other healthcare presentations following a thunderstorm.^{10,11} Key search terms were drafted and then refined after a trial search to ensure relevant synonyms were included. The final search strategy was as follows:

- Asthma OR hayfever OR hay fever OR pollen OR allergen OR allergic OR allergy OR acute rhinitis OR allergic rhinitis;
AND
- Outbreak OR event OR epidemic OR crisis;
AND
- Thunderstorm OR storm OR meteorological OR weather OR airborne;
AND
- Public health OR health.

Nine electronic databases were searched (Academic Search Premier, Medline, Ovid, Google Scholar, Australia/New Zealand Reference Centre, Science Direct, Health Source Nursing/Aca-

demio Edition, Scopus and CINAHL Complete). A total of 372 articles were retrieved and were further screened for duplication and relevance, after which 30 articles remained. Articles not published in English were excluded as no translation services were available.

Results

From the available literature, 29 TA events were identified, with the first recorded event reported in Birmingham, England, in July 1983,¹⁶ and the most recent in Yulin, China, in September 2018.¹⁷ These events are presented in chronological order in Table 1.

Suspected triggers

The most commonly reported aeroallergen was pollen, in 19 of the 23 events (83%) where suspected triggers were reported (Table 1). Grass pollen was the most common (in 12 events, or 52%). Fungal spores were described in 9 of the 23 events (39%). The most common fungal spore types reported were *Didymella exitialis* for four events and *Alternaria alternata* for three events. Triggers varied geographically: for Australia, which has experienced the highest number (11) of TA episodes of any country, grass pollen is the primary triggering allergen, but in the UK, where seven TA episodes have been reported, allergens are more varied and more commonly include fungal spores. In Yulin, China, mugwort pollen is an important seasonal aeroallergen.¹⁷

Figure 1: Indicative processes associated with uptake and discharge of aeroallergens in a mature cumulonimbus cloud.

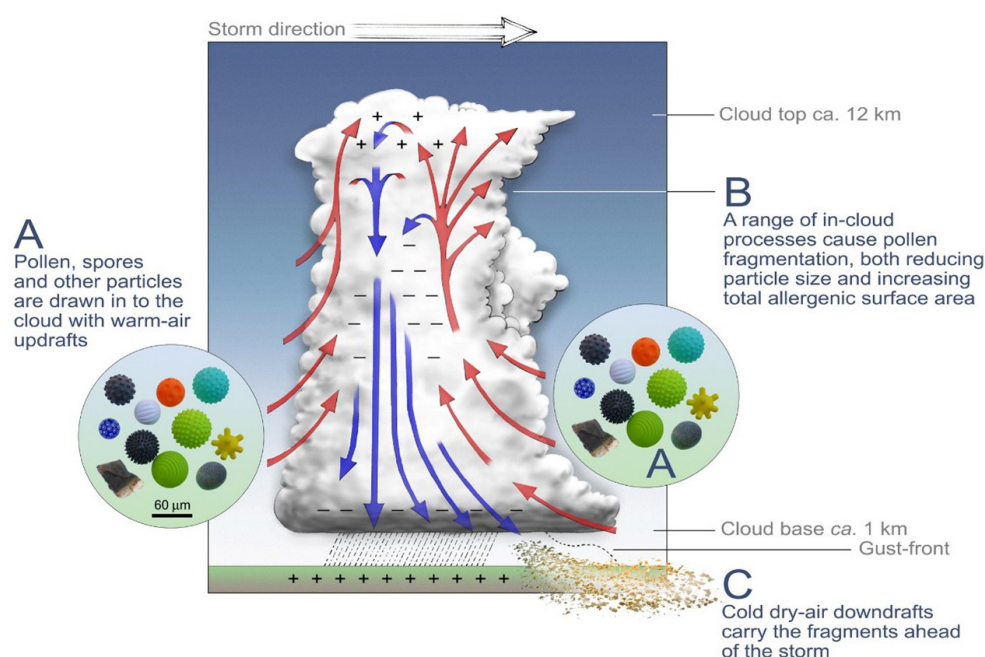


Table 1: Reported epidemic thunderstorm asthma events.

Month and year	Location of event and reference	Hospital presentations	Hospital admissions	Deaths	Fold-increase in hospital presentations	Age, gender and ethnicity where reported	Suspected triggers	Climate & environment conditions	History of related conditions
July 1983	Birmingham, England ¹⁶	106	32	0	5	Age range 14 months–63 years; mean age 24.7 years. 58% male.	FS (<i>Didymella exitialis</i> , <i>Sporobolomyces</i>)	Temp: 30 °C	-
June 1984	Nottingham, England ³⁵	19	2	0	5	-	FS (<i>Didymella exitialis</i>)	Temp: 25 °C Wind: 40 kph	53% hx asthma 47% hx allergic rhinitis
November 1984	Melbourne, Australia ^{36,37}	85	16	0	-	-	NS	Temp: 22 °C Rain: 12.4 mm / 24 hours	95% hx of asthma 95% hx of allergic rhinitis
November 1987	Melbourne, Australia ^{37,38}	154	26 (one to ICU)	1	10	-	GP (ryegrass) & tree pollen	Temp: 27 °C Rain: 45.6 mm / 24 hours	-
July 1989	Leicester, England ¹¹	-	32	0	7	Median age: 24	FS (<i>Didymella</i>)	Rain & recent harvests	Majority had hx asthma
November 1989	Melbourne, Australia ^{37,38}	277	47 (three to ICU)	0	12	-	GP (ryegrass) & tree pollen	Temp: 25 °C Rain: 7.8 mm / 24 hours	-
November 1990	Tamworth, Australia ^{37,39}	233	110	0	7	-	GP	-	80% hx asthma
June 1994	London, England ^{40,41}	640	104 (five to ICU)	1	10	57% of presentations aged 21–40	GP	Lightning strikes & rainfall, sudden fall in temperature and increase in windspeed as thunderstorm passed	63% hx allergic rhinitis
October 1997	Wagga Wagga, Australia ²²	215	41; two required intubation and ventilation	0	7	Of 148 TA cases surveyed, 46% male, average age 28	GP (ryegrass) FS: <i>Cladosporium</i> (mould); 61% of TA patients allergic.	-	Of 148 TA cases surveyed, 90% recent hx allergic rhinitis, 64% hx asthma. 96% of TA patients surveyed allergic to ryegrass pollen.

Table 1 (continued): Reported epidemic thunderstorm asthma events.

Month and year	Location of event and reference	Hospital presentations	Hospital admissions	Deaths	Fold-increase in hospital presentations	Age, gender and ethnicity where reported	Suspected triggers	Climate & environment conditions	History of related conditions
October 1998	Newcastle, Australia ⁴²	6	0	0	4	Age range: 16–67	GP	Wind: 80 kph Rainfall Pollen concentration: 120-fold increase	100% hx allergic rhinitis
July 2000	Calgary, Canada ¹⁸	157	0	0	9	Of 46 patients surveyed: median age: 31. Gender: male 65%	FS: <i>Alternaria</i> , <i>Myxomycetes</i> (7x), <i>Ustilaginales</i> , <i>Helicomyces</i> (3x), <i>Stemphillium</i> . Pollen: families <i>Amaranthaceae</i> (12x), <i>Chenopodiaceae</i> (12x). Algae (25x). Fold-increases in brackets.	Stagnant air mass preceding thunderstorm may have allowed spores and pollens to accumulate. Atmospheric pressure drop was also recorded. Sudden onset of high winds (up to 70 km/h).	Of 46 patients surveyed: 39% hx asthma; 35% hx allergic rhinitis; 17% hx allergies; 78% hx \geq 1 of the above
May 2001	Madrid, Spain ²¹	154	-	0	-	Age range: 4–79	GP, olive pollen	-	95% hx asthma
July 2002	Cambridge, England ²³	57	3	1	10	Of 26 cases surveyed, mean age was 38.6 (range 18–67); 58% male	FS (<i>Alternaria</i> , <i>Cladosporium</i> and <i>Didymella</i> species)	During week before, little rain and relative humidity decreased from 93% to 60%. Very high ozone concentrations of 180 $\mu\text{g} / \text{m}^3$. <i>Didymella</i> ~43,000 grains / m^3 , <i>Alternaria</i> 655 / m^3	Of 26 cases surveyed, 23 (88%) had IgE sensitisation to <i>Alternaria</i> , 25 (96%) had seasonal asthma symptoms
November 2002	Al-Khobar, Saudi Arabia ⁴³	NS	0	NS	-	-	NS	Rain	-

Table 1 (continued): Reported epidemic thunderstorm asthma events.

Month and year	Location of event and reference	Hospital presentations	Hospital admissions	Deaths	Fold-increase in hospital presentations	Age, gender and ethnicity where reported	Suspected triggers	Climate & environment conditions	History of related conditions
November 2003	Melbourne, Australia ^{37,44}	70	0	-	3	-	GP	Daily GP concentration: 128 grains / m ³ Rain: 1.2 mm / 24 hours Wind: >90 kph	Majority had hx asthma
June 2004	Naples, Italy ⁴⁵	7	7 (one to ICU)	0		Gender: male 43%. Age range: 38–60 for 6 adults and one girl of 11.	Nettle pollen (<i>Parietaria</i>)	<i>Parietaria</i> species pollen concentration: 144 grains / m ³	57% hx asthma 29% hx allergic rhinitis 100% sensitised to <i>Parietaria</i> pollen but not grass pollens
June 2005	South-East England ^{1,11,46}	NS	-	NS	6	-	NS	Lightning strikes & rainfall	40% hx asthma 38% hx allergic rhinitis
May 2010	Barletta, Italy ²⁵	20	20	0	10	Mean age: 44. Age range: 9–81. Gender: male 55%	Olive pollen	Olive pollen concentration: 278 grains / m ³ Temp: 29 °C	60% hx asthma 30% hx allergic rhinitis
November 2010	Melbourne, Australia ^{11,37}	36	0	0	10	-	GP	Temp: 35 °C Daily grass pollen concentration: 56–117 grains / m ³ Rain: 23 mm / 24 hours	-
November 2011	Melbourne, Australia ¹¹	30	-	0	2	-	GP	Pollen grain concentration: 727 grains/m ³	84% hx allergic rhinitis
July 2013	London, England ⁴⁷	40	0	0	4	Majority aged between 20–40.	NS	-	Most no hx asthma

Table 1 (continued): Reported epidemic thunderstorm asthma events.

Month and year	Location of event and reference	Hospital presentations	Hospital admissions	Deaths	Fold-increase in hospital presentations	Age, gender and ethnicity where reported	Suspected triggers	Climate & environment conditions	History of related conditions
November 2013	Ahvas, Iran ²⁴	2000	37 (three to ICU)	0	-	Gender: male 46%; 61% aged 20–40; 24% aged 40–60	NS	-	40% hx asthma 83% hx allergic rhinitis
October 2014	Canberra, Australia ¹⁴	15	-	0	4	-	GP	Pollen concentration: > 100 grains / m ³	
October 2015	Central Israel ¹⁹	-	-	NS	2.5	-	FS, pollen	Wind gusts of > 130 kph; 17,000 cloud-to-ground lightning strikes; ~10-fold increase in PM _{2.5} and PM ₁₀ concentration.	
November 2016	Melbourne, Australia ^{10,15}	3,365	476, with 35 admitted to ICU.	10	6.7	Of 1,435 ED presentations surveyed, mean age 32.0 years, 56% male, 39% of Asian or Indian ethnicity.	GP (ryegrass)	Grass pollen concentrations extremely high (> 100 grains / m ³). As gust front crossed Melbourne, temperatures dropped 10 °C and humidity increased to > 70%, wind gusts of up to 90 kph.	43% of 1,435 ED presentations surveyed had hx asthma, with 28% having current asthma. Of 85 patients assessed by Lee et al. (2017), 100% were sensitised to ryegrass pollen, 99% had hx of allergic rhinitis, 60% had no prior diagnosis of asthma.
December 2016	Kuwait City, Kuwait ²⁶	844	45, with 26 admitted to ICU.	11	-	At Mubarak Al-Kabir hospital (n = 17 admissions): 58.8% male, average age 39 years.	Salsola pollen (<i>Chenopodiaceae</i> and <i>Amaranthaceae</i> families), FS (<i>Alternaria</i>).	Temp: 28 °C	At Mubarak Al-Kabir hospital (n = 16): 94% hx asthma 44% hx allergic rhinitis

Table 1 (continued): Reported epidemic thunderstorm asthma events.

Month and year	Location of event and reference	Hospital presentations	Hospital admissions	Deaths	Fold-increase in hospital presentations	Age, gender and ethnicity where reported	Suspected triggers	Climate & environment conditions	History of related conditions
December 2017	Hamilton, New Zealand ⁵	38	4	0	2.4	Median age: 26. Gender: 37% male. Ethnicity: 39% Asian or Indian.	NS	Wind gusts up to 37 kph, 770 lightning strikes.	53% hx asthma, 48% hx allergic rhinitis.
May 2018	Milan, Italy ⁴⁸	2	2	-	-	Gender: female 100%; ages 41, 45.	Pollen	-	Both patients had hx allergic rhinitis, mild asthma, sensitivity to grass pollen.
September 2018	Yulin, China ¹⁷	392	51	-	16	Pediatric patients, range 3–14 years old, median age 7. Gender: male 74% in ED, 72% of inpatients.	Pollen (mugwort) & FS	Temp: 27 °C	45% hx asthma 77% hx allergic rhinitis

Notes: FS=fungal spores; hx=history; kph=kilometres per hour; NS=not specified; GP=grass pollen.

The level of detail in reporting suspected triggers varied widely across the studies. Some had access to data from aerobiological monitoring stations, which enabled positive identification of pollen and fungal spore species and quantification of their airborne concentrations.^{10,18} Others provide only a flowering calendar for various allergenic plants at the study locality,¹⁹ and some do not report suspected triggers at all.⁵

Seasonality of TA episodes

The timing of reported TA episodes is summarised in Figure 2. Strong seasonality is apparent for TA events in Australasia, with all events occurring between October and December (mid-spring to early summer) with a peak in November (late spring). The event in Hamilton, New Zealand, occurred in early December;⁵ all other events in Australia occurred in October or November. In the Northern Hemisphere, similar seasonality is observed for TA events in the UK, Canada, Spain and Italy, with events occurring between May and July (late spring to midsummer), building to a peak in July. However, TA events in Saudi Arabia, Iran, Kuwait, China and Israel were more distributed over the months of September through December, with too few events at any of these locations to ascribe seasonality.

Observed seasonal trends, with TA events confined to mid-spring to early summer for Australasia, and to late spring to mid-summer for England, Spain, Italy

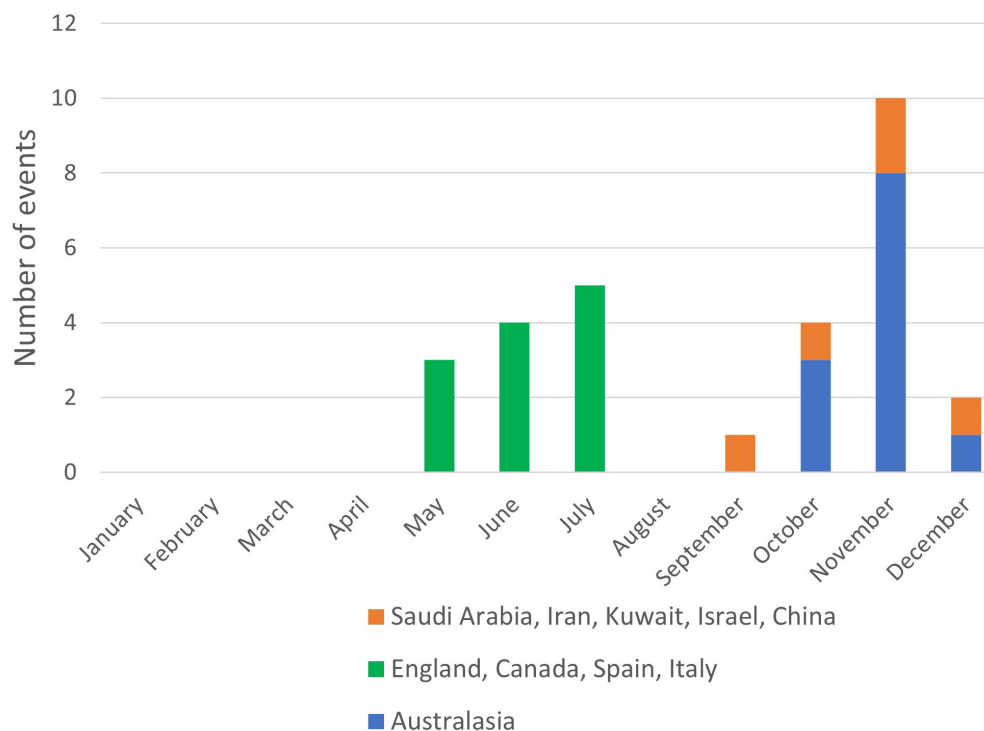
and Canada, are expected on the basis that this time of year is the peak of the pollen and outdoor mould seasons and the summer storm season.²⁰ Peak pollen concentrations typically occur earlier in the season than peak fungal spore concentrations. Within England, Spain, Italy and Canada, TA events in May (late spring) are dominated by pollen triggers, moving to fungal spore dominance for events in July (mid-summer). This knowledge is useful as a basis for location-specific predictions of future events.

Patient characteristics

Allergen sensitivity, histories of seasonal allergic rhinitis and asthma

Sensitivity to the triggering allergen is considered essential for developing TA symptoms.^{14,15,20,21} However, patient allergen sensitivity has been reported for just three of the 29 TA events to date (Table 1), using skin-prick tests and/or IgE serology. While there is no clear common allergen globally,¹⁴ patient sensitivity to ryegrass pollen has been a near-universal feature of TA events in Australia.^{10,15,22} Of 85 patients tested for allergen sensitivity from the November 2016 Melbourne TA epidemic, 100% were sensitised to ryegrass pollen, as were 96% of 138 patients in a TA event in Wagga Wagga, inland New South Wales, in October 1997.^{15,22} However, in the UK, allergen tests carried out on patients from a TA event in Cambridge in July 2002 showed that 23

Figure 2: Reported thunderstorm asthma events by month (from Table 1).



(88%) of the 26 cases were sensitive to *Alternaria* species, 22 (85%) sensitive to grass pollen, and 16 (62%) sensitive to *Cladosporium* species.²³ Grass pollen was considered unlikely to be the primary trigger as airborne concentrations were relatively low at the time of the event. Based on a timeline of meteorological conditions, asthma admissions and aerobiological monitoring, the authors propose that the following sequence of events may have led to the TA event: 1) a prolonged, earlier grass pollen season may have caused bronchial hyperresponsiveness in people sensitised to both grass pollen and *Alternaria*; 2) forecasted thunderstorms caused farmers to increase harvesting activity of barley crops, which host *Alternaria*; 3) combine harvesting liberated large numbers of fragmented *Alternaria* spores; 4) asthma symptoms triggered in sensitised individuals. The authors also noted that high ground-level ozone concentrations and a sudden reduction in temperature, both associated with thunderstorm conditions, may have also contributed to bronchial hyperresponsiveness.

Patient histories of seasonal allergic rhinitis (SAR) are reported for 16 TA events (Table 1): proportions of cases with a history of SAR ranged from 29–100%, with a weighted mean of 74%. Interestingly, proportions of cases with previous histories of SAR were much higher in Australian TA events (84–100%), but were lower in the Hamilton, New Zealand event (48%). Clinical SAR was one of three key “trifecta” risk factors for TA in Melbourne, and for other areas globally where ryegrass is cultivated.¹⁵ It is less clear that SAR is an important risk factor for TA triggered by other aeroallergens.

Patient histories of asthma were recorded for 18 TA events (Table 1). Proportions of cases with a history of asthma ranged from 39–100%, with a weighted mean of 49%. A substantial proportion of people affected by TA have no prior history of asthma and may be at higher risk because they do not have prior education to recognise asthma symptoms and seek medical attention, and also because they do not have ready access to reliever bronchodilator inhalers.⁵ However, while pre-existing asthma is not a strong risk factor for TA susceptibility, it is associated with severity of outcome and increases the risk of hospital admission (odds ratio 1.9).⁹ All 35 critically ill patients admitted to ICU during the 2016 Melbourne TA epidemic had a previous diagnosis of asthma.¹⁴ Of these, 66% were not on preventer (inhaled corticosteroid) therapy, suggesting suboptimal control of asthma and treatment adherence.

Age, gender and ethnicity

The ages of those affected by TA was reported in 16 of the 29 events (Table 1). For the largest and most thoroughly documented TA epidemic to date in Melbourne in November 2016, 1,435 TA cases were followed up; the mean age was 32.0 years.¹⁰ These authors noted a dominance of patients aged 20–59 and noted the departure from a typical U-shaped age distribution. Similarly, of 2,000 ED presentations in Ahvas, Iran, 61% were aged between 20–40, and 85% between 20–60.²⁴ Other reports of mean or median age of TA cases are generally consistent with this observation and range from a median age of 24¹¹ to a mean age of 44.²⁵ There is limited evidence that outcomes of TA cases may worsen with increasing age: while the mean age of TA cases was 32.0 years, the median age of adult patients admitted to ICU was 42 years, and the mean age of the 10 deaths was 38.5 years.¹⁰ TA has also been documented in pediatric patients (age range 3–14 years, median age 7) in Yulin City, China.¹⁷

Reporting of gender of TA sufferers is inconsistent across studies. The percentage of males varies from 37–74% (Table 1). For the studies involving the largest numbers of people, there is no clear gender dominance, with 56% male of 1,435 TA cases followed up in Melbourne,¹⁰ but 46% male of 2,000 ED presentations in Ahvas, Iran.²⁴ There is limited evidence that males may have more severe outcomes; in Melbourne, 63% of the 35 patients admitted to ICU were male and seven of the 10 deaths were male.¹⁰ Similarly, in Kuwait, 10 of 17 (59%) patients admitted to hospital were male, but all 11 people diagnosed with fatal asthma (prior to arrival at hospital) were male.²⁶

Few studies report ethnicity of TA sufferers (Table 1), but of those that do a striking finding is that individuals of Asian or Indian ethnicity were over-represented in ED admissions.^{5,10} For the Melbourne event, 39% of 1,435 cases followed up were of Asian or Indian descent, compared to 25% in the general population.¹⁰ Patients with Asian/Indian ethnicity were also over-represented in ICU admissions and deaths.^{10,14} For the December 2017 TA event in Hamilton, New Zealand, 39% of ED presentations were of Asian or Indian ethnicity, compared to 18.5% of the Hamilton population from 2018 census data.⁵ Atopy and asthma are more prevalent amongst migrants in high-income countries, with possible mechanisms including exposure to novel allergens and vitamin D deficiency (who died prior to arrival at hospital) impairment to immunoregulation, and of further note is a significantly higher prevalence of allergic rhinitis in Asians living in Australia.¹⁰ Cultural factors

such as poor knowledge of asthma in migrant populations may also contribute. As TA events are rare globally, these mechanisms remain poorly understood.

Limitations of analysis

While 29 TA events have been documented worldwide from 1983 onwards, we acknowledge that this is likely to be an incomplete record as we did not attempt to search any non-English language databases. Thus, TA may have a much longer history and widespread distribution than described here. It would be surprising if the true global footprint of TA was restricted to the 11 countries with documented TA events (Table 1). Consequently, we emphasise that our findings may not be fully representative. For example, a greater range of aeroallergen triggers may exist, and other ethnicities than described here may be at higher risk of TA.

Further, increases in milder asthma cases following thunderstorms may not result in hospital or other healthcare presentations; and small rises in presentations may not exceed the twofold increase that defines an epidemic TA event.^{10,11}

Projected impacts of global warming on frequency and severity of TA events

TA has recently been described as a global health problem that is likely to be exacerbated by climate change, with future events likely to become more common, more catastrophic and more unpredictable.⁴ The frequency and severity of thunderstorms is projected to increase in response to rising global temperatures.²⁷ Furthermore, climate change may exacerbate pollen allergies, including TA, with rising temperatures and atmospheric CO₂ concentrations collectively causing higher pollen production in certain plants due to a “CO₂ fertilisation effect”, earlier and longer pollen seasons, and shifts in ranges.²⁸

Implications for Aotearoa New Zealand Potential aeroallergen triggers

For the single recorded TA event in New Zealand to date, in Hamilton in December 2017, suspected aeroallergens were not reported.⁵ Newnham²⁸ has pointed out that New Zealand does not have an airborne pollen monitoring programme and lags well behind other regions in not instigating routine aeroallergen monitoring in major population centres. While the primary purpose of such monitoring would be to inform management of seasonal allergic rhinitis, which has a high prevalence in New Zealand, it would also be critical for identifying triggering aeroallergens in any future TA events. We therefore support Newnham’s call for routine aeroallergen monitoring in New Zealand.

Of note is that perennial ryegrass is widely distributed across New Zealand in high-producing grasslands that support dairying, and is also used widely in sports grounds, golf courses, school playing fields and residential lawns. Ryegrass pollen is strongly implicated as the triggering aeroallergen in TA events in Australia,^{4,14,15} and more generally, grass pollen is considered the major outdoor aeroallergen source in Australasia.²⁹ High-producing grasslands are concentrated in the Waikato, Taranaki, the Manawatu, Wairarapa/southern Hawke’s Bay, Canterbury and Southland.³⁰ In some regions there is high potential for priming for grass pollen allergens by prior exposure to tree pollen allergens.²⁸

Fungal spores should also be considered as potential TA triggers. While there is very limited information available for New Zealand, high airborne fungal spore levels were recorded for some locations, notably Kaikohe, Hamilton and Christchurch, in a survey of seven population centres.⁴⁹

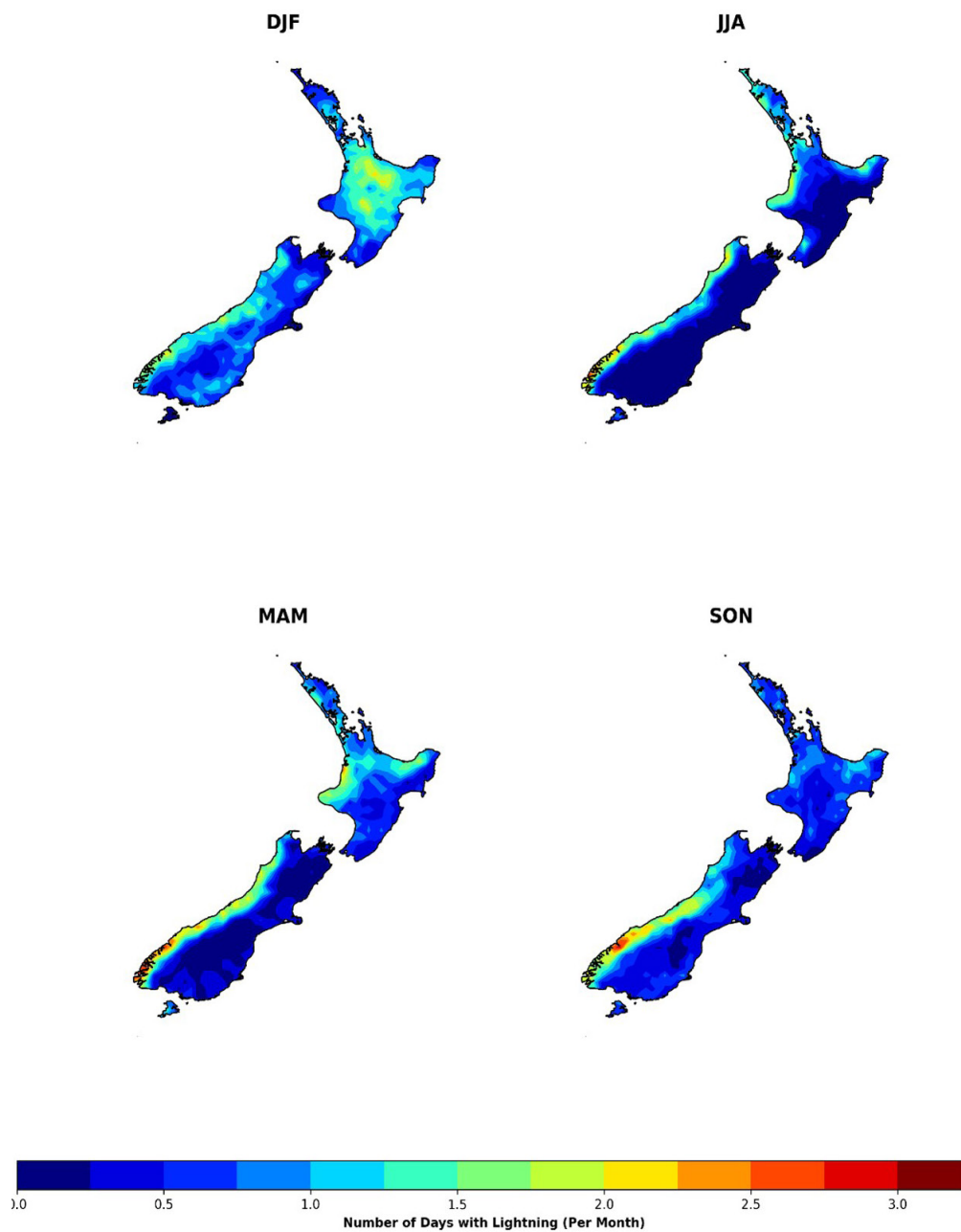
Risk of TA events across New Zealand

The New Zealand grass pollen season runs from November to the end of February, peaking strongly in December in most regions, while fungal spore concentrations peak in January/February.^{28,49} Although they can occur anywhere, summer thunderstorms most commonly originate in inland areas and the ranges of the North Island, and the South Island high country and West Coast (Figure 3, which shows expected days per month with lightning by season as a proxy for thunderstorm activity).^{31,50} The Waikato therefore emerges as an area at particular risk of TA events due to its extensive pastoral farming, substantial population and inland location associated with a greater probability of summer thunderstorms. However, we emphasise that thunderstorms can, and do, occur anywhere in New Zealand. An investigation of statistical relationships between acute asthma presentations and thunderstorm occurrence may inform a more quantitative assessment of TA risk for New Zealand.⁵⁰

Healthcare services preparedness for future TA events

During TA events, many patients presenting simultaneously may overwhelm local healthcare services thus it is important to consider the capacity of these services, particularly as TA events are expected to become more frequent and severe in future. Treatments provided in intensive care units (ICUs), such as intubation and mechanical ventilation, can be lifesaving for acute asthma cases, thus New Zealand’s ICU capacity is an important determinant of preparedness.¹² A recent assessment found that as of

Figure 3: Geographical distribution of predicted number of days per month with lightning for summer (DJF), autumn (MAM), winter (JJA) and spring (SON).



October 2021, there were just 176 staffed ICU beds in public hospitals, with surge capacity (based on the ICU nursing workforce availability) for a further 67 beds.³² While the current total ICU capacity of 243 ICU beds (4.8 per 100,000 population) is substantially lower than Australia's, which varies by state from six to 10.8 per 100,000, it seems unlikely that this will be a limiting factor in New Zealand's preparedness for a TA event, unless ICU capacity were to become overwhelmed by, for example, current or future pandemics or a mass casualty event.

Health emergency management considerations

A key role for the emergency management sector is preparing for and responding to "rare" events. In rapidly evolving adverse events, there is typically a high level of uncertainty about the nature of the event and likely outcomes, especially in the initial stages.^{33,34} Health and emergency management personnel will be called upon to act quickly and provide advice during these periods of major uncertainty.

We suggest that an effective preparedness strategy for "rare" events such as thunderstorm asthma would be to develop evidence-based public messaging in a form ready to be disseminated when required, to help proactively manage a surge in demand for information rather than attempting to develop messaging during an unfolding event. As an example, outdoor exposure to aeroallergens is a critical trigger for TA.^{9,15} Therefore, public messaging advising people to remain indoors with doors/windows closed and air conditioners turned off during and after thunderstorms could be a simple, effective risk reduction measure. Messaging could also emphasise the importance of diagnosed asthmatics adhering to regular preventer use and keeping reliever medications at hand.⁵¹ Such messaging should be developed in partnership with the health emergency management sector. Care would need to

be taken to deploy messaging only during the high-risk period of ryegrass pollen season to avoid potential warning fatigue.

In conclusion, here we have reviewed reported thunderstorm asthma events worldwide and identified causative factors. TA is globally rare, with 29 recorded events since 1983, but is expected to increase in frequency as Earth warms. Where reported, pollen was the most common suspected trigger in 83% (and fungal spores in 39%) of events. Strong seasonality of TA events is observed in some countries but not others. In Australia, which has experienced the highest number of TA events (11) of any country, all events occurred during October and November, peaking in November. In terms of individual susceptibility, major risk factors are outdoor exposure, sensitivity to the triggering allergen and a history of seasonal allergic rhinitis. Pre-existing asthma does not appear to be a strong risk factor for TA but is associated with severity of outcome. People with no prior history of asthma may be at higher risk as they are unlikely to have access to reliever bronchodilator inhalers and may not recognise symptoms and seek medical attention. Available data on age, gender and ethnicity is limited, but points towards a dominance of patients aged between 20 and 60. In Australasia, people of Asian/Indian ethnicity appear to be at higher risk.

The triggering aeroallergen for the single recorded TA event in Hamilton in Dec 2017 is unknown, but likely to be ryegrass pollen. Much of New Zealand may be at risk of future TA events given that ryegrass pastures are widely distributed across New Zealand and summer thunderstorms (coinciding with ryegrass pollen season) can occur anywhere. We suggest that an effective preparedness strategy for this rare but consequential phenomenon would include the development of rapidly deployable public messaging to support the health and emergency management response, supported by the instigation of routine aeroallergen monitoring.

COMPETING INTERESTS

Nil.

AUTHOR INFORMATION

Carol Stewart: School of Health Sciences,
College of Health, Massey University Wellington.
Nicole L Young: School of Health Sciences,
College of Health, Massey University Wellington.
Nicholas D Kim: School of Health Sciences,
College of Health, Massey University Wellington.
David M Johnston: Joint Centre for Disaster Research,
Massey University Wellington.
Richard Turner: National Institute of Water
and Atmospheric Research, Wellington.

CORRESPONDING AUTHOR

Carol Stewart: School of Health Sciences,
College of Health, Massey University Wellington.
c.stewart1@massey.ac.nz

URL

www.nzma.org.nz/journal-articles/thunderstorm-asthma-a-review-risks-for-aotearoa-new-zealand-and-health-emergency-management-considerations-open-access

REFERENCES

1. Kevat A. Thunderstorm Asthma: Looking Back and Looking Forward. *Journal of Asthma and Allergy* 2020, 13:293-299. <https://doi.org/10.2147/JAA.S265697>
2. Idrose N S, Dharmage S C, Lowe A J, et al. A systematic review of the role of grass pollen and fungi in thunderstorm asthma. *Environmental Research* 2020, 181:1-14 108911. <https://doi.org/10.1016/j.envres.2019.108911>
3. Zou E, Worsham C, Miller N H, et al. Emergency visits for thunderstorm-related respiratory illnesses among older adults. *JAMA Internal Medicine* 2020, 180(9):1248-1250. <http://doi.org/10.1001/jamainternmed.2020.1672>
4. Price D, Hughes K M, Thien F, Suphioglu C. Epidemic thunderstorm asthma: lessons learned from the storm down-under. *J Allergy Clin Immunol Pract*. 2021, 9(4):1510-1515. doi:10.1016/j.jaip.2020.10.022
5. Sabih A, Russell C, Chang C L. Thunderstorm-related asthma can occur in New Zealand. *Respirology Case Reports* 2020, 8(7):1-3. <https://doi.org/10.1002/rcr2.655>
6. Emmerson K M, Silver J D, Thatcher M, et al. Atmospheric modelling of grass pollen rupturing mechanisms for thunderstorm asthma prediction. *PLOS ONE* 2021, 16(4) <https://doi.org/10.1371/journal.pone.0249488>
7. D'Amato G, Baena-Cagnani C E, Cecchi L, et al. Climate change, air pollution, and extreme events leading to increasing prevalence of allergic respiratory diseases. *Multidisciplinary Respiratory Medicine* 2013, 8(1):12-22. <http://www.mrmjournal.com/content/8/1/12>
8. D'Amato G, Annesi-Maesano I, Vaghi A, et al. How do storms affect asthma? *Current Allergy and Asthma Reports* 2018, 18(4):24-31. <https://doi.org/10.1007/s11882-018-0775-9>
9. Chatelier J, Chan S, Tan J A, et al. Managing exacerbations in thunderstorm asthma: current insights. *Journal of Inflammation Research* 2021, 14:4537-4550.
10. Thien F, Beggs P J, Csutoros D, Darvall J, et al. The Melbourne epidemic thunderstorm asthma event 2016: an investigation of environmental triggers, effect on health services, and patient risk factors. *The Lancet Planetary Health* 2018, 2(6):255-263. [https://doi.org/10.1016/S2542-5196\(18\)30120-7](https://doi.org/10.1016/S2542-5196(18)30120-7)
11. Davies J M, Erbas B, Simunovic M, et al. Literature review on thunderstorm asthma and its implications for public health advice: Final Report. 2017. <https://eprints.qut.edu.au/110102/1/110102.pdf>
12. Fergeson J E, Patel S S, Lockey R F. Acute asthma, prognosis, and treatment. *Journal of Allergy and Clinical Immunology* 2017, 139(2):438-447. <https://doi.org/10.1016/j.jaci.2016.06.054>
13. Mahmoudi M, Craig T, Ledford D K. Allergy and asthma: The basics to best practices. 2019. Springer.
14. Harun N S, Lachapelle P, Douglass J. Thunderstorm-triggered asthma: What we know so far. *Journal of Asthma and Allergy* 2019, 12:101-108. <http://doi.org/10.2147/JAA.S175155>
15. Lee J, Kronborg C, O'Hehir R E, Hew M. Who's at risk of thunderstorm asthma? The ryegrass pollen trifecta and lessons learned from the Melbourne thunderstorm epidemic. *Respiratory Medicine* 2017, 132:146-148. <http://dx.doi.org/10.1016/j.rmed.2017.10.012>
16. Packe G E, Ayres J. Asthma outbreak during a thunderstorm. *The Lancet* 1985, 326(8448):199-204. [http://doi.org/10.1016/s0140-6736\(85\)91510-7](http://doi.org/10.1016/s0140-6736(85)91510-7)
17. Xu Y Y, Xue T, Li H R, Guan K. Retrospective analysis of epidemic thunderstorm asthma in children in Yulin, northwest China. *Pediatric Research* 2020, 1-4. <https://doi.org/10.1038/s41390-020-0980-9>
18. Wardman A E, Stefani D, MacDonald J C. Thunderstorm-associated asthma or shortness of breath epidemic: a Canadian case report. *Canadian Respiratory Journal* 2002, 9(4), 167-270. <https://doi.org/10.1155/2002/728257>
19. Yair Y, Yair Y, Rubin, B et al. First reported case

- of thunderstorm asthma in Israel. *Nat Hazards Earth Syst Sci* 2019, 19:2715-2725. <https://doi.org/10.5194/nhess-19-2715-2019>
20. D'Amato G, Holgate S T, Pawankar R et al. Meteorological conditions, climate change, new emerging factors, and asthma and related allergic disorders. A statement of the World Allergy Organization. *World Allergy Organization Journal* 2015, 8(1):1-52. <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4499913/>
 21. Galán I, Prieto A, Rubio M et al. Association between airborne pollen and epidemic asthma in Madrid, Spain: A case-control study. *Thorax* 2010, 65(5):398-402. <http://doi.org/10.1136/thx.2009.118992>
 22. Girgis S T, Marks G B, Downs S H et al. Thunderstorm-associated asthma in an inland town in south-eastern Australia: Who is at risk?. *European Respiratory Journal* 2000, 16(1):3-8. <http://doi.org/10.1034/j.1399-3003.2000.16a02.x>
 23. Pulimood T B, Corden J M, Bryden C et al. Epidemic asthma and the role of the fungal mould *Alternaria alternata*. *Journal of Allergy and Clinical Immunology* 2007, 120(3):610-617. <http://doi.org/10.1016/j.jaci.2007.04.045>
 24. Forouzan A, Masoumi K, Haddadzadeh Shoushtari M et al. An overview of thunderstorm-associated asthma outbreak in southwest of Iran. *Journal of Environmental and Public Health* 2014, 504(17):1-4. <https://doi.org/10.1155/2014/504017>
 25. Losappio L, Heffler E, Contento F et al. Thunderstorm-related asthma epidemic owing to *Olea Europaea* pollen sensitization. *Allergy* 2011, 66(11):1510-1511. <http://doi.org/10.1111/j.1398-9995.2011.02699.x>
 26. Ali F, Behbehani N, Alomair N, Taher A. Fatal and near-fatal thunderstorm asthma epidemic in a desert country. *Annals of Thoracic Medicine* 2019, 14(2):155-160. http://doi.org/10.4103/atm.ATM_258_18
 27. Trapp R J, Diffenbaugh N S, Brooks H E, et al. Changes in severe thunderstorm environment frequency during the 21st century caused by anthropogenically enhanced global radiative forcing. *Proceedings of the National Academy of Sciences* 2007, 104(50):19719-19723. <http://doi.org/10.1073/pnas.0705494104>
 28. Newnham R M. Monitoring airborne pollen in New Zealand. *Journal of the Royal Society of New Zealand* 2021, <https://doi.org/10.1080/03036758.2021.1967414>
 29. Medek D E, Beggs P J, Erbas B, et al. Regional and seasonal variation in airborne grass pollen levels between cities of Australia and New Zealand. *Aerobiologia* 2016, 32(2):289-302.
 30. Amies A C, Dymond J R, Shepherd J D et al. National mapping of New Zealand pasture productivity using temporal Sentinel-2 data. *Remote Sensing* 2021, 13:1481. <https://doi.org/10.3390/rs13081481>
 31. Aich V, Holzworth R, Goodman S J, Kuleshov Y, Price C, Williams E. Lightning: a new essential climate variable. *Eos* 2018. <https://eos.org/science-updates/lightning-a-new-essential-climate-variable>
 32. Young P J, Psirides A, Streat S. New Zealand's staffed ICU bed capacity and COVID-19 surge capacity. *New Zealand Medical Journal* 2021, 134:8-10.
 33. Endsley M R. (1997). The role of situational awareness in naturalistic decision making. In: Zsombok CE, Klein G (eds) *Naturalistic Decision Making*. Lawrence Erlbaum Associates, Mahwah, NJ, pp 269-284.
 34. Doyle E E H, Johnston D M, Smith R, & Paton D. Communicating model uncertainty for natural hazards: A qualitative systematic thematic review. *International Journal of Disaster Risk Reduction* 2019, 33:449-476. <http://doi:10.1016/j.ijdr.2018.10.023>
 35. Alderman P M, Sloan J P, Basran G S. Asthma and thunderstorms. *Archives of Emergency Medicine* 1986, 3(4):260-262. <http://doi.org/10.1136/emj.3.4.260>
 36. Egan P. Weather or not. *The Medical Journal of Australia* 1985, 142(5):330-331. <https://www.mja.com.au/>
 37. Lindstrom S J, Silver J D, Sutherland M F, et al. Thunderstorm asthma outbreak of November 2016: A natural disaster requiring planning. *The Medical Journal of Australia* 2017, 207(6):235-237. <http://doi.org/10.5694/mja17.00285>
 38. Bellomo R, Holmes P, Gigliotti P, et al. Two consecutive thunderstorm associated epidemics of asthma in the city of Melbourne: the possible role of ryegrass pollen. *Medical Journal of Australia* 1992 156(12): 834-837. <http://doi.org/10.5694/j.1326-5377.1992.tb136994.x>
 39. Waters J, Corbett S, Gibson P, Hensley M, Włodarczyk J. Epidemic asthma surveillance in the New England Region 1990-1992. *New South Wales Public Health Bulletin* 1993, 4(9):100-101. http://doi.org/10.1071/NB9304_9
 40. Davidson A C, Emberlin J, Cook A D, Venables K M. Thames region accident and emergency trainees association. A major outbreak of asthma associated with a thunderstorm. experience of accident and emergency departments and patients' characteristics. *British Medical Journal* 1996, 312(60):601-604. <http://doi.org/10.1136/>

- bmj.312.7031.601
41. Higham J, Venables K, Kupek E, et al. Asthma and thunderstorms: Description of an epidemic in general practice in Britain using data from a doctors' deputising service in the UK. *Journal of Epidemiology & Community Health* 1997, 51(3):233-238. <http://doi.org/10.1136/jech.51.3.233>
 42. Wark P A B, Simpson J, Hensley M J, Gibson P G. Airway inflammation in thunderstorm asthma. *Clinical & Experimental Allergy* 2002, 32(12):1750-1756. <http://doi.org/10.1046/j.1365-2222.2002.01556.x>
 43. Al-Rubaish A M. Thunderstorm-associated bronchial asthma: a forgotten but very present epidemic. *Journal of Family & Community Medicine* 2007, 14(2):47-51. <https://www.jfcmonline.com/>
 44. Erbas B, Akram M, Dharmage SC, et al. The role of seasonal grass pollen on childhood asthma emergency department presentations. *Clinical & Experimental Allergy* 2012, 42(5):799-805. <http://doi.org/10.1111/j.1365-2222.2012.03995.x>
 45. D'Amato G, Cecchi L, Liccardi G. Thunderstorm-related asthma: Not only grass pollen and spores. *Journal of Allergy and Clinical Immunology* 2008, 121(2):537-538. <http://doi.org/10.1016/j.jaci.2007.10.046>
 46. Levy ML, Bryden C. Thunderstorm asthma. *British Journal of Primary Care Nursing* 2007, 1:69-71.
 47. Elliot A J, Hughes H E, Hughes T C, et al. The impact of thunderstorm asthma on emergency department attendances across London during July 2013. *Emergency Medicine Journal* 2014, 31(8):675-678. <http://dx.doi.org/10.1136/emmermed-2013-203122>
 48. Spina M F, Banfi P I, Nicolini A. Thunderstorm-asthma, two cases observed in Northern Italy. *Multidisciplinary Respiratory Medicine* 2020, 15(1):1-6. <http://doi.org/10.4081/mrm.2020.679>
 49. Newnham R M, Fountain D W, Cornford C C, Forde M B. A national survey of airborne pollen and grass flowering in New Zealand, with implications for respiratory disorders. *Aerobiologia* 199, 11:239-252.
 50. Straub A, Fricke V, Olschewski P, et al. The phenomenon of thunderstorm asthma in Bavaria, Southern Germany: a statistical approach. *International Journal of Environmental Health Research* 2021: <http://doi.org/10.1080/09603123.2021.1985971>
 51. Thien F, Davies J M, Hew M, et al. Thunderstorm asthma: an overview of mechanisms and management strategies. *Expert Review of Clinical Immunology* 202, 16(10):1005-1017. DOI: 10.1080/1744666X.2021.1826310