

IMPACT OF CLIMATE CHANGE ON AEROALLERGENIC POLLEN METRICS: A HEMISPHERIC PERSPECTIVE

LH Ziska¹

D Berman²

¹ Mailman School of Public Health, Columbia University, United States

² Allergy Immunology Unit, UCT Lung Institute, South Africa

Email | Lhz2103@cumc.columbia.edu

ABSTRACT

The recognition and documentation of climatic change effects on human health remains one of the most important challenges of the 21st century. While myriad in scope, one of the most recognised impacts is related to pollen, specifically its production, release and duration, and the consequences for allergic diseases, including asthma and allergic rhinitis. At present, the bulk of efforts to understand and document these links have been conducted by scientists in the Northern Hemisphere. However, the link between climate change and aeroallergenic pollen is global and international in scope. For this reason, more recent efforts to provide similar evaluations have been initiated by scientists in the Southern Hemisphere. The current review acknowledges northern enquiries, but also emphasises research gaps and inconsistencies which should be avoided by southern investigators. To remedy these deficiencies, some suggestions are offered, including a greater emphasis on plant demographics, the standardisation of pollen metrics, automation and environmental integration. It is hoped that this perspective will be able to provide support to efforts of scientists in the Southern Hemisphere to evaluate better climate shifts and aeroallergen consequences. Overall, there is a clear and pressing need to understand these likely changes while simultaneously comprehending their impact on pollen-related health outcomes – for both hemispheres.

Keywords: climate change, impact, aeroallergenic pollen metrics, hemispheric perspective

INTRODUCTION

Pollen proteins can act as antigens for the human immune system and are capable of exacerbating pollinosis, asthma and allergic reactions. Such reactions, however, are seasonal for the Northern Hemisphere: trees dominate in the spring, grasses and weeds in the summer and ragweed in the autumn. These impacts can be significant; approximately 10–30% of the global population is affected by allergic rhinitis (AR) as a result of seasonal pollen exposure.¹ Indeed, allergic diseases are increasingly being recognised as one of the most prevalent and important non-communicable diseases worldwide.²

Plant species that produce copious amounts of pollen are anemophilous or ‘wind-pollinated’. Such pollination is inefficient relative to insect pollination (entomophily), and to compensate, anemophilous species must produce large quantities of pollen to ensure fertilisation and seed production. Consequently, in addition to wind, other factors, such as temperature, humidity and rainfall, are also important in pollen production and seasonal distribution.

Given the known influential effects of weather and climate on pollen, and the subsequent health impacts, the consequences of projected environmental and climatic changes on aeroallergen production are likely to be significant. Yet, while the sources and physical consequences of greenhouse gas emissions on weather and climate have been well reviewed,³ the potential linkages related to seasonal exposure, pollen production, aeroallergens and allergic disease are still under investigation.

One of the most fundamental associations with pollen biology is that of temperature. The term ‘global warming’ is generally understood in the context of an average increase in surface temperature; yet, in reality, differential increases in surface temperatures are occurring. In general, these differential temperature increases are occurring because of the relative concentration of water vapour, an important greenhouse gas. For example, in the tropics, where water vapour (humidity) is an important greenhouse gas, rising levels of carbon dioxide (CO₂, another greenhouse gas) are not expected to result in as great an increase in surface temperature as in regions where the air is dry (ie there is less water vapour). Observed changes in surface

temperature are accordingly greater at the poles and in desert areas where water vapour is low.

Such geographical changes, both large and small, in daily and seasonal temperatures will have obvious biological consequences for floral phenology and pollen release. Shifts in phenology are, in fact, among the most consistent findings in studies of global climate change and warming temperatures.^{4,5} Such shifts, in turn, will affect the timing and duration of flowering, with consequences for both seasonal exposure and pollen production. In addition, studies suggest that the extreme heat and precipitation events associated with climate change are likely to increase in frequency, intensity and duration in coming decades in response to changing climate,⁶ potentially exacerbating pollen or fungal spore duration and exposure.

A second, more obscure link to pollen biology is that CO₂, in addition to being a greenhouse gas, is the singular supplier of carbon for photosynthesis and plant growth. At present, more than 90% of all plant species (including all tree species) function below the optimal CO₂ concentration needed to maximise growth and reproduction; consequently, the rapid increase in atmospheric CO₂, in addition to its role in climate change, will probably stimulate the growth and flower production of many known allergenic plants. At present, there is also limited evidence that rising CO₂ concentrations may accelerate flowering time too, although the degree of advancement appears to be species-specific.⁷

While additional information is needed, there is a clear prospective association between climate change, aerobiology and allergic disease.⁸ It seems likely that ongoing changes in temperature, climate and CO₂ concentration will intensify these associations, especially with regard to the seasonality of pollen exposure and the amount of pollen produced by a given plant species during a season.

A HEMISPHERIC PERSPECTIVE

At present, the primary focus of research regarding climate change and pollen characteristics has been in the Northern Hemisphere, mainly in North America and Europe. But how relevant or applicable are these data to the Southern Hemisphere? To respond to this fundamental question, it is important to overlay some geographical and biological metrics that are unique to the Southern Hemisphere.

For example, it should be noted that CO₂ concentrations in the Southern Hemisphere typically trail those in the north. The higher Northern Hemisphere levels occur because CO₂ sources (eg fossil-fuel emissions) are greater; and, in addition, CO₂ 'sinks', such as oceans, are predominant in the Southern Hemisphere. Similarly, greater CO₂-induced increases in temperature are associated with greater land area relative to areas with open water, as with the Northern Hemisphere. The greater ocean-to-land ratio in the south may be useful in understanding delayed responses to global temperature changes between the Northern and Southern hemispheres.^{9,10} However, in one of the longest analyses of surface temperature trends (1931–2015), Kruger

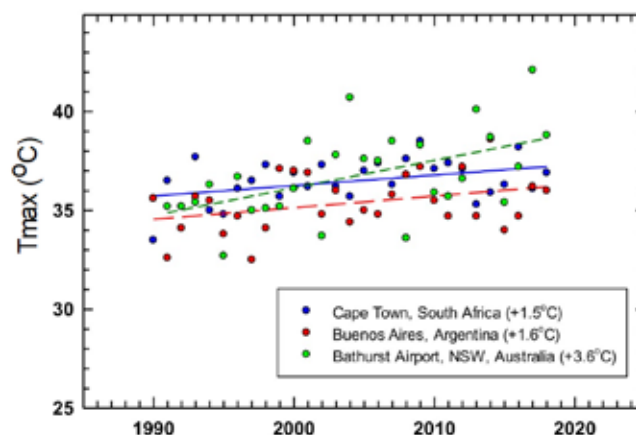


Figure 1: Time series of highest recorded temperature for three locations in the Southern Hemisphere; (a) Cape Town, South Africa; (b) Buenos Aires, Argentina; (c) NSW, Australia. (The number next to the location is the increase in maximum temperature recorded between 1990 and 2018.)

and Nxumalo note a general increase in extreme warm events and a general decrease in extreme cold events across South Africa.¹¹ Changes in maximum temperatures may vary by location (as in the Northern Hemisphere), but there is a distinct increase in maximum temperatures across diverse locations (see Figure 1).

In addition to changes in the rate of warming, unique flora are associated with the Southern Hemisphere. These flora, like their Northern counterparts, are also capable of producing allergenic pollen (eg kikuyu grass and eucalyptus in South Africa). But there are, in addition, unique and prolific new plant species which, while of Northern origin, have established and become widespread. One of the most egregious is *Parthenium hysterophorus* (false ragweed, congress grass, star weed), originating from northeast Mexico. *Parthenium* can cause allergy-type responses such as hay fever, photodermatitis, asthma, skin rashes, peeling skin, puffy eyes, excessive water loss, swelling and itching of mouth and nose, constant cough, running nose and eczema.¹²

Although the rate of warming and the concentration of CO₂ may vary hemispherically, the consequences for climate change and the need to monitor subsequent changes in pollen phenology and health impact are still present. As emphasised by Haberle et al,¹³ aerobiology in the Southern Hemisphere is as complex as that in the Northern Hemisphere, and changes in temperature, rainfall and environmental change will also span from the tropics to the temperate zones.

CLIMATE CHANGE AND AEROALLERGENS: CHALLENGES

While complex, the impacts on human health are still consequential. For example, AR affects approximately 18% of people in Australia and New Zealand with predispositions to increased sinus infections and asthma-related AR.¹³ Studies

of adolescents at Cape Town from 1995 to 2002 indicated significant increases in asthma, AR and atopic eczema.¹⁴

There is a need, then, as with the Northern Hemisphere, to monitor pollen and to determine likely or potential health outcomes. But the imposition of climate change imposes another challenge: to begin to integrate and compare measurements of pollen aerobiology across Southern Hemisphere locations in order to determine current impacts, and to identify countries or geographical regions that may be at greater risk.

Pollen monitoring throughout the Southern Hemisphere remains isolated, limited as it is to monitoring urban areas and their unique aerobiological signatures.¹³ Few attempts have been made to determine general patterns for allergen seasonality or to determine any variation in pollen composition. Unfortunately, even fewer attempts have been made to incorporate climatic and/or CO₂ influences on aeroallergens and allergic disease.¹⁵ Yet it can be argued that the Southern Hemisphere is likely to encounter similar consequences as the north – for example, changes in the distribution of known allergenic plant taxa and changes in pollen-season length, pollen distribution and pollen load.

Can lessons be learned from allergists and botanists in the Northern Hemisphere that would be of value for future Southern Hemisphere efforts? Yes, but as with all lessons, a value can be attached – some aspects are worth doing, others are to be avoided.

For there are also deficiencies in Northern efforts to monitor pollen. Overall, there is no widespread, consistent set of guidelines for pollen collection, assessment and reporting. Some effort is being made to compile and analyse pollen data for regional or continental responses that could be associated with climate change or rising CO₂ levels;^{16,17,18} however, such efforts remain uncoordinated and sporadic.

This reflects, in part, the autonomy of allergists and pollen counters. The independence of those who count pollen for a living is understandable. It requires extensive training to identify pollen, and to do so on a continuous basis requires a fortitude of character that not everyone possesses.

But such independence can be a stumbling block to cooperation. There are loose affiliations (eg National Allergy Bureau) and business interests (eg IQVIA™) associated with counting and reporting pollen concentrations in the United States and Europe. However, few regulations or metrics are standardised across locations. For example, how pollen is collected is site-specific and can vary considerably (Rotorod; Burkard Spore Traps; gravimetric methods). But different sampling methods have different efficiencies, and numbers obtained by sampling method are not always directly comparable.^{19,20}

In addition to different sampling methodologies, no consistent benchmarks are associated with pollen seasons.²¹ For some locations, the 'start' of a pollen season can be defined when the

cumulative pollen count reaches 5% and ends when it reaches 95% of the annual pollen integral (API), the yearly cumulative count (some locations use 1% and 99% values). Aerobiology Canada uses a very different seasonal standard – that of pollen persistence; that is, the season is initiated with 3–5 days of continuous pollen and ends with the last 3–5-day period of continuous pollen.

Finally, there is a fundamental issue of the number of sampling sites. Pollen counts are ubiquitous and few guidelines exist for interpreting them.¹⁹ For example, there is substantial physical and biological heterogeneity within an urban landscape, with consequences for the spatial and seasonal variability of pollen concentrations. Yet, in many large urban areas, one or two rooftop pollen samplers provide pollen information for an entire city.

Overall, even as rising CO₂ levels and climate change necessitate a greater need to assess spatial and temporal changes in pollen, and the consequences for human health, fundamental flaws in the current monitoring system make meeting this challenge more difficult.

NEXT STEPS

There is no doubt that pollen monitoring has been conducted for longer and has been more extensive in the north relative to the Southern Hemisphere (see Figure 2); yet it is also clear that these Northern efforts, while notable, may fall short of assessing or preparing for climate change, rising CO₂ levels and health outcomes.

Can current efforts in the Southern Hemisphere to incorporate the impact of rising CO₂ levels and climate on pollen biology benefit from the Northern Hemisphere's oversights? It can be argued that Southern resources are newer, and less available; yet it can also be maintained that adaptation is more likely for smaller groups and younger associates. If adaptation is possible, what steps should be taken?

PLANT DEMOGRAPHICS

There is an immediate need to understand and document the role of climate or CO₂ in the changing demography and evolutionary potential of known anemophilous plant taxa. Understandably, pollen collection is based on what has been observed in the past; but it is also evident that as climate changes or new species are introduced, plant-pollen sources will remain in flux. Such sources may include highly invasive species (eg *Parthenium*) that are significantly allergenic; alternatively, native species unique to the Southern Hemisphere may remain uncharacterised regarding their contribution to allergic diseases.²² The observation and documentation of new (and old) sources may benefit from citizen science and remote sensing as a means of maintaining up-to-date demographic distributions.²³ Such information would provide valuable insights into the biogeographical distribution and phenological patterns of pollen release and distribution. It would also provide insights into the manner in which these patterns, in turn, respond to current and future climatic change.

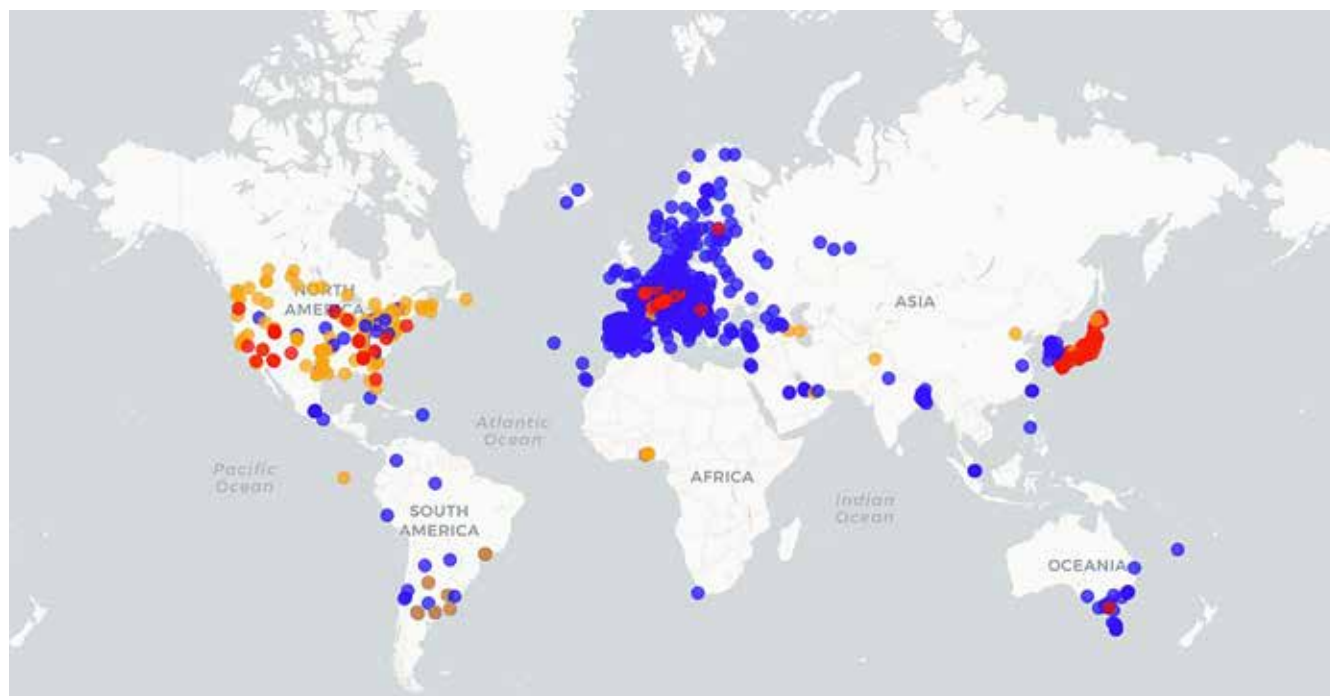


Figure 2: EAACI map of active pollen-monitoring stations, showing massive differences between the Northern and Southern hemispheres. Available at <https://www.eaaci.org/19-activities/task-forces/4342-pollen-monitoring-stations-of-the-world.html> (accessed 24 December 2019) (Used with permission of Jeroen Buters.)

Blue dots (Hirst trap), red (Automatic station), orange (other manual) (Buters JTM, Antunes C, Galveias A, et al. Pollen and spore monitoring in the world. *Clin Transl Allergy* 2018;8:9. <https://doi.org/10.1186/s13601-018-0197-8>)

STANDARDISATION OF POLLEN METRICS

At present, there is no uniform standard for collecting pollen. The two most widely applied collection methodologies – a Burkard Hirst-type volumetric pollen trap and a Rotorod volumetric sampler – can differ in their sensitivity, depending on particle size.¹⁹ Similarly, site pollen collection is often listed as 'rooftop', with less detail being provided about height or surrounding vegetation. In addition, there is no uniform standard as to what constitutes a pollen 'season', with different groups applying different metrics. Acceptance of a uniform standard would, however, be invaluable in evaluating climate impacts. For instance, the '5%' approach often used to mark the beginning and end of a pollen season can result in temporal anomalies; that is, if the total pollen accumulation for two consecutive years was 2 000 and 5 000, then the 'start' of the season would not be noted until counts reached 100 and 250, respectively. Using this system to mark the 'beginning' and 'end' of a pollen season would mask any climate or temperature trends associated with season length. In contrast, a consecutive day metric, as described previously, would be more sensitive to climate-induced changes in start and end times, especially if spring seasons arrived earlier or if autumn seasons were delayed.¹⁸

AUTOMATION AND SAMPLING SITES

There is an obvious need to provide relevant pollen information in the context of changing climate or population demographics (eg city vs rural). However, such a need contrasts with the number of trained counters and site availability. For example,

New York City, with an estimated metro population of 20 million, has two pollen collection sites.

Automated pollen monitoring using recognition software has been suggested as one means of bridging the gap. In one report, a comparison of a Burkard system with a fully automated pollen-monitoring system based on image recognition (BAA500) for daily pollen counts was highly correlated ($r = 0.98$); however, some specific pollen sources (*Salix*) were not identified satisfactorily.²⁴ There is therefore obvious potential for upgrading software and automation for such systems (see www.pollensense.com).

Such sensors are low-maintenance and do not require certified (human) pollen counters, which makes data comparisons across space and time more consistent. In addition, they can be disseminated in greater numbers as a means of helping to quantify heterogenic pollen variability. For example, urban areas are heat sinks with documented effects of micro-climate on pollen release and load;²⁵ but at present there are insufficient pollen-monitoring sites to document urban–rural differences in pollen exposure.

ENVIRONMENTAL INTERACTIONS

Airborne pollen is a sensitive surrogate of the current climate and flora for a given region. But anthropogenic climate change is complex, and there are likely to be other concurrent disturbances that may interact with pollen to exacerbate – or improve – human health outcomes. Climate-induced changes in temperature and

rainfall will be consequential and will need to be modelled and incorporated into pollen forecasts; certainly, large-scale changes such as the El Niño Southern Oscillation (ENSO) or the Indian Ocean Circulatory Patterns should be considered.

But what is the role of other climatic consequences? During the summer of 2019–2020, Australia experienced an unprecedented wildfire season exacerbated by climatic change, with an estimated loss of approximately 103 600 km² of vegetation. How will this affect the demography of anemophilous plant species? Could pollen levels decline? Alternatively, fires produce fine particulate pollution, known as PM_{2.5} (particles that measure less than 2.5 microns across), that can be transported long distances. Such particles may act as a 'platform' for pollen collection, and exacerbate pollen sensitivity and related asthma.²⁶ How will concurrent changes in fire outbreaks and climate alter pollen seasonality and load? Thunderstorms have been linked to asthma epidemics, especially during the grass-pollen seasons. If climate change results in more weather extremes, how will they affect thunderstorm frequency or intensity? And what could be the public health consequences?

There are, in effect, a number of probable means by which climate change could affect air quality; a better understanding of the risks of co-exposure to both pollen and air pollutants is needed to inform and respond better to likely health threats.

MODELLING

Understanding and documenting the complex interactions between disparate meteorological variables, plant physiology and their interactions with human activities (ie air pollution, climate change) and the subsequent consequences for pollen production, seasonality and health outcomes is a daunting task. Whereas individual reductionist experiments are necessary and vital to understanding these linkages, modelling approaches to integrate physical and biological changes, especially in the context of problematic climatic shifts, will be necessary to encompass a full range of outcomes, including those related to public health.²⁷ Such efforts will need to incorporate myriad sources of pollen data into numerical forecast systems. Examples of these data could include phenological observations, demographic changes in plant-pollen sources, social sensing and data from symptom trackers or personal monitors.²⁸ Potentially, improved aeroallergen forecasts could be developed that provide detailed pollen information of relevance to a given population (ie urban or rural).

In general, it is hoped that allergists, plant scientists, climatologists and mathematicians can be encouraged to work together to assimilate their expertise towards generating model frameworks that address vulnerabilities but also provide insight into research priorities, especially in regard to climate change.

FINAL THOUGHTS

The association between weather and climate and its effect on pollen and the resulting consequences for human health are universally acknowledged. Pollen-induced AR affects 10–20% of sensitive populations; it can predispose people to more

frequent sinus infections, contribute to poor sleep quality, impair learning, and/or reduce productivity for the approximately 80% people who suffer from AR. And it can lead to asthma being more difficult to control.²⁸

Given these links, the role of continuing environmental and climatic change on aeroallergen production and spread is likely to be substantial. Northern Hemisphere efforts have provided sufficient information to confirm that climate change and/or rising CO₂ levels can have an impact on aeroallergen metrics – from taxa distribution and pollen release to allergenicity. This information has also confirmed that these changes appear to be happening in real time.^{17,25} Yet, it is also clear that, while there is interest in continuing this work, efforts to coordinate the research among allergists, healthcare professionals, botanists, etc, have met with limited success. This may be due, in part, to the autonomous infrastructure already in place; or to the lack of consistent standards for monitoring and recording pollen between locations, a lack of appreciation of the impacts of climate change or a lack of recognition or funding sources necessary to enable further coordination to take place.

In summary, research in the Northern Hemisphere among allergists and environmentalists, modellers and doctors to understand and integrate the consequences of rising CO₂ levels and climate change on aeroallergens and allergic respiratory diseases has resulted in useful insights. But the same research should not serve as a complete model for similar efforts in the Southern Hemisphere. Rather, there are unique opportunities – and challenges – for Southern Hemisphere scientists to accomplish these goals.

Finally, the analysis and the recommendations provided here are by no means inclusive. Threat recognition and unity of purpose, justifiable concern regarding climate change, uniform standards, cooperation, and government support are all necessary to address the health challenges posed by climate change, not simply those of aeroallergens and air quality. It is, in effect, a public concern, and it is hoped that, overall, the Southern nations will learn from the efforts of the Northern Hemisphere and prepare themselves accordingly.

DECLARATION OF CONFLICT OF INTEREST

The authors declare no conflict of interest.

This article has been peer reviewed.

REFERENCES

1. Sarfaty M, Bloodhart B, Ewart G, Thurston GD, et al. 2015. American Thoracic Society member survey on climate change and health. *Ann Am Thorac Soc* 2015;12(2):274–278.
2. Ozdoganoglu T, Songu M. 2012. The burden of allergic rhinitis and asthma. *Ther Adv Respir Dis* 2012;6(1):11–23.
3. Pachauri RK, Allen MR, Barros VR, Broome J, et al. Climate change 2014: Synthesis report. Contribution of Working Groups I, II and III to the fifth assessment report of the Intergovernmental Panel on Climate Change. IPCC 2014:151.

4. Cleland EE, Chuine I, Menzel A, Mooney HA, Schwartz MD. Shifting plant phenology in response to global change. *Trends Ecol Evol* 2007;22(7):357–365.
5. Rafferty NE, Nability PD. A global test for phylogenetic signal in shifts in flowering time under climate change. *J Ecol* 2017;105(3):627–633.
6. Horton RM, Mankin JS, Lesk C, Coffel E, Raymond C. A review of recent advances in research on extreme heat events. *Current Climate Change Reports* 2016;2(4):242–259.
7. Springer CJ, Ward JK. Flowering time and elevated atmospheric CO₂. *New Phytol* 2007;176(2):243–255.
8. Ziska LH, Beggs PJ. Anthropogenic climate change and allergen exposure: The role of plant biology. *J Allergy Clin Immunol* 2012;129(1):27–32.
9. Goosse H. 2017. Reconstructed and simulated temperature asymmetry between continents in both hemispheres over the last centuries. *Clim Dyn* 2017;48(5–6):1483–1501.
10. Stouffer RJ, Manabe S, Bryan K. Interhemispheric asymmetry in climate response to a gradual increase of atmospheric CO₂. *Nature* 1989;342(6250):660–662.
11. Kruger AC, Nxumalo M. Surface temperature trends from homogenized time series in South Africa: 1931–2015. *Int J Climatol* 2017;37(5):2364–2377.
12. Adkins S, Shabbir A. Biology, ecology and management of the invasive parthenium weed (*Parthenium hysterophorus* L.). *Pest Manag Sci* 2014;70(7):1023–1029.
13. Haberle SG, Bowman DM, Newnham RM, Johnston FH, et al. The macroecology of airborne pollen in Australian and New Zealand urban areas. *PloS one* 2014;9(5):e97925.
14. Zar HJ, Ehrlich RI, Workman L, Weinberg EG. The changing prevalence of asthma, allergic rhinitis and atopic eczema in African adolescents from 1995 to 2002. *Pediatr Allergy Immunol* 2007;18:560–565.
15. Berman D. Climate change and aeroallergens in South Africa. *Curr Allergy Clin Immunol* 2011;24(2):65–71.
16. Van Vliet AJ, Overeem A, De Groot RS, Jacobs AF, Spijksma T. The influence of temperature and climate change on the timing of pollen release in the Netherlands. *Int J Climatol: RMetS* 2002;22(14):1757–1767.
17. Ziska L, Knowlton K, Rogers C, Dalan D, et al. Recent warming by latitude associated with increased length of ragweed pollen season in central North America. *Proc Natl Acad Sci USA* 2011;108(10):4248–4251.
18. Ziska LH, Makra L, Harry SK, Bruffaerts N, et al. Temperature-related changes in airborne allergenic pollen abundance and seasonality across the northern hemisphere: A retrospective data analysis. *The Lancet Planetary Health* 2019;3(3):e124–e131.
19. Frenz DA. Comparing pollen and spore counts collected with the Rotorod Sampler and Burkard spore trap. *Ann Allergy Asthma Immunol* 1999;83(5):341–349.
20. Frenz DA. Interpreting atmospheric pollen counts for use in clinical allergy: Allergic symptomology. *Ann Allergy Asthma Immunol* 2001;86(2):150–158.
21. Jato V, Rodríguez-Rajo FJ, Alcázar P, De Nuntis P, et al. May the definition of pollen season influence aerobiological results? *Aerobiologia* 2006;22(1):13.
22. Access Economics. The economic impact of allergic disease in Australia: Not to be sneezed at. Australasian Society of Clinical Immunology and Allergy (ASCIA). 2007.
23. Ziska LH, Bradley BA, Wallace RD, Barger CT, et al. Climate change, carbon dioxide, and pest biology, managing the future: Coffee as a case study. *Agronomy* 2018;8(8):152.
24. Oteros J, Pusch G, Weichenmeier I, Heimann U, et al. Automatic and online pollen monitoring. *Int Arch Allergy Immunol* 2015;167(3):158–166.
25. Ziska LH, Gebhard DE, Frenz DA, Faulkner S, et al. Cities as harbingers of climate change: Common ragweed, urbanization, and public health. *J Allergy Clin Immunol* 2003;111(2):290–295.
26. Gleason JA, Bielory L, Fagliano JA. Associations between ozone, PM_{2.5}, and four pollen types on emergency department pediatric asthma events during the warm season in New Jersey: A case-crossover study. *Environ Res* 2014;132:421–429.
27. Watts N, Amann M, Arnell N, Ayeb-Karlsson S, et al. The 2019 report of The Lancet Countdown on health and climate change: Ensuring that the health of a child born today is not defined by a changing climate. *The Lancet* 2019;394(10211):1836–1878.
28. D'Amato G, Rottem M, Dahl R, Blaiss MS, et al. Climate change, migration, and allergic respiratory diseases: An update for the allergist. *World Allergy Organ J* 2011;4(7):121–125.