

Global Climate Change and Pollen Aeroallergens

A Southern Hemisphere Perspective



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KEYWORDS

• Aeroallergens • Carbon dioxide • Climate change • Biodiversity

KEY POINTS

- Climate change is having an impact on pollen distributions and aeroallergen seasonal exposure globally.
- Distinctions in anthropogenic climate change between hemispheres and unique plant biogeography suggest that the southern hemisphere aeroallergen biology and clinical consequences differ from those of the northern hemisphere.
- Directions that could aid research to better monitor and evaluate climate shifts and aerobiology in the southern hemisphere are suggested.

INTRODUCTION

Pollen proteins can act as antigens for the human immune system and are capable of exacerbating allergic rhinoconjunctivitis (pollinosis) and allergic asthma. Allergic reactions are mediated by aberrant overproduction by the immune system of allergen-specific IgE that trigger an inflammatory response on re-exposure to the eliciting substance. Exposures to pollen aeroallergens are seasonal. For the southern hemisphere,

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depending on climatic region, trees may contribute to pollen in late winter to early spring; grasses from several subfamilies dominate throughout spring into summer and autumn, and weeds contribute in summer and autumn. Health impacts of pollen allergy can be significant; approximately 10% to 40% of the global population is affected by allergic rhinitis due to seasonal pollen exposure.^{1,2} Allergic diseases are increasingly recognized as one of the most prevalent and important noncommunicable diseases worldwide.³

Given the known influential effects of weather and climate on plant phenology and pollen per se, and the subsequent health impacts, the consequences of projected environmental and climatic changes on aeroallergen production are likely to be significant. Yet, although the sources and physical consequences of greenhouse gas emissions on weather and climate have been well reviewed,⁴ the potential linkages related to seasonality of pollen exposure, magnitude of pollen production, pollen allergenicity, and thresholds of pollen exposure that lead to allergic diseases are still under investigation.

One of the most fundamental factors influencing pollen biology is temperature. Although "global warming" is generally interpreted as an average increase in surface temperature, differential increases in surface temperatures are occurring. In general, these differential temperature increases are occurring because of the relative concentration of water vapor, an important greenhouse gas. For example, in the tropics, where water vapor (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, less water vapor).⁵ Hence, observed changes in surface temperature are greater at the poles and desert areas, where water vapor is low.

Such geographic changes, large and small, in daily and seasonal temperatures will have obvious biological consequences for floral phenology and pollen release. Shifts in phenology are among the most consistent findings in studies of global climate change and warming temperatures.^{6,7} Such shifts, in turn, will affect the timing and duration of flowering with consequences for both pollen production and seasonal exposure. Climatic studies also suggest that extreme heat and precipitation events are likely to increase in frequency, intensity, and duration in coming decades in response to changing climate, potentially exacerbating pollen and fungal spore season duration and exposure.⁸

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 maximize growth and reproduction; consequently, the rapid increase in atmospheric CO₂, in addition to its role in climate change, likely will stimulate growth and flower production of many known allergenic plants. At present, there also is limited evidence that rising CO₂ concentrations also may advance flowering time, although the degree of advancement appears to be species specific.^{9,10}

Although Whilst additional information is needed, there is a clear prospective association between climatic change, aerobiology, and allergic disease.¹¹ It seems likely that ongoing changes in CO₂ concentration, temperature, and other climate variables will intensify these associations, especially in regard to seasonality of pollen exposure and amount of pollen produced by a given plant species during a season.

A HEMISPHERIC PERSPECTIVE

Currently, the foremost locus of research regarding climate change and pollen aerobiology has been in the northern hemisphere, primarily in North America and Europe.

But how relevant or applicable are these data to the southern hemisphere? To address this fundamental question, it is important to consider some unique geographic and biological hemispheric distinctions.

For example, increases in atmospheric 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 higher; 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 northern and southern hemispheres.^{12,13} In one of the longest analyses of surface temperature trends (1931–2015), however, Kruger and Nxumalo¹⁴ note a general increase in extreme warm events and a general decrease in extreme cold events across South Africa. 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 (Fig. 1).

In addition to the rate of warming, there also are unique flora associated with the southern hemisphere. These flora also are capable of producing allergenic pollen; but there are prolific plant species of northern origin that have established and become widespread in the southern hemisphere. One of the most egregious is *Parthenium hysterophorus* (false ragweed or star weed) originating from northeast Mexico. *Parthenium* weed is present in South America and has been introduced to Australia. It can be toxic to animals and humans and cause hypersensitivity responses like 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.^{15,16}

Of particular importance to the subtropical regions of the southern hemisphere is the effect of elevated CO₂ on grass pollen. Grasses use either a 3-carbon (C₃) or 4-carbon (C₄) photosynthetic pathway. The C₄ pathway utilizes more carbon and loses less water than C₃ in the process. In the absence of deciduous trees (birch, ash, poplar, and hazel) from subtropical regions of southeast Queensland, Australia, the contribution of grass pollen to the total annual pollen load is elevated relative to northern

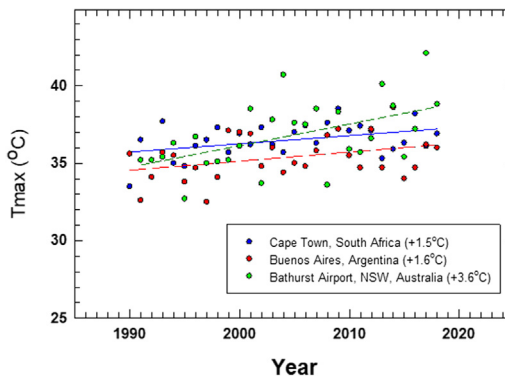


Fig. 1. Time series of highest recorded temperature for 3 locations in the southern hemisphere: Cape Town, South Africa; Buenos Aires, Argentina; and Bathurst, New South Wales, Australia. The number next to the location is the increase in maximum temperature (Tmax) recorded between 1990 and 2018.

temperate climate zones.¹⁷ As CO₂ increases, changes in relative competition and demography are likely between C₃ temperate and C₄ tropical grasses associated with relative photosynthetic stimulation by CO₂ as well as potential changes in water loss and desiccation, suggesting that ecological niches for subtropical grasses may be altered with climate change.¹⁸

Grass pollens are the major cause of pollinosis in many parts of the world.¹⁹ For South America, Panicoideae and Chloridoideae are C₄ grasses typical of tropical and subtropical arid habitats and are well represented in Argentina, Brazil, and Uruguay.²⁰ In seasonal climates, C₃ grasses increase in winter and flower in spring, whereas C₄ grasses grow and flower in summer and early autumn.²¹ Across the continent of Australia, there is a latitudinal gradient in the distribution of subtropical C₄ and temperate C₃ grass species,²² with Panicoideae and Chloridoideae species dominating at latitudes closer to the equator and temperate Pooideae dominating at higher latitudes with temperate climates.²³

Climatic global change, with an increase in atmospheric CO₂ concentration and temperature, habitat transformation, and biodiversity loss, may lead to an expansion of the C₄ grasses over typical C₃ grass areas.^{24,25} The change in the proportion of C₃ and C₄ grasses may, in turn, be a factor that alters the number of allergic patients.¹⁸ Recently, it was demonstrated that subtropical grass pollens are significantly important in the skin sensitization of patients with allergic rhinitis in the city of Bahia Blanca, in southern Argentina,²⁶ and in South Africa²⁷ as well as in subtropical regions of Australia.²⁸ Representation of pollen allergen extracts, however, relevant to the southern hemisphere, such as for standardized subtropical grass pollens, are not all commercially available for clinical diagnosis and therapy in these regions.²¹

Although plant species, the rate of warming, and the concentration of CO₂ may vary hemispherically, the consequences, in terms of climate change, and the need to monitor subsequent changes in pollen phenology and health impact still are present. As emphasized by Haberle and colleagues,²⁹ aerobiology in the southern hemisphere is complex. Changes in temperature, rainfall, and the environment generally will span from the tropics to temperate zones.

SOUTHERN HEMISPHERE AEROALLERGEN MONITORING AND CLIMATE CHANGE: CHALLENGES

Regardless of location, the impacts of aeroallergens on human health are consequential. For example, allergic rhinitis affects approximately 19.3% of people in Australia³⁰ and approximately 26% of people in New Zealand.³¹ Australia also has a high occurrence of allergy relative to a range of common and important aeroallergens.³² Limited site-specific studies on the prevalence of sensitization to pollens in Australia, however, may not represent the complete picture of sensitization rates over the whole continent. For example, the prevalence of allergic sensitization to timothy grass pollen was 29% of 552 adults by skin prick test in Melbourne, but this grass is rare in the Victoria environment.³³ Ryegrass pollen would have been more relevant to test and although timothy and ryegrass are both temperate Pooideae grasses, there can be differences in level of allergic sensitization.³⁴ In Western Australia, the frequencies of serum IgE reactivity with ryegrass and Bermuda grass pollen were 41% and 36%, respectively, in a group of 1380 teenagers from an unselected birth cohort study.³⁵ Elsewhere, the frequency of grass pollen-positive skin prick tests in Australian school children ranged from 10% to 20%, depending on the region and the grass pollen tested.^{36,37} Studies of adolescents in Cape Town, South Africa, from 1995 to 2002, indicated significant increases in asthma, allergic rhinitis, and atopic eczema.³⁸

There is an existing need to monitor pollen and to determine likely or potential health outcomes of pollen exposure in diverse phytogeographical and climatic regions of the southern hemisphere. Climate change imposes another challenge: to begin to integrate and compare measurements of pollen aerobiology across southern hemisphere locations to determine current impacts and to identify countries or geographic regions that may be at greater risk. Pollen monitoring for much of the southern hemisphere (**Fig. 2**), however, remains limited to monitoring in urban areas with diverse aerobiological signatures observed in diverse biogeographical regions.²⁹ Few long-term (eg, decadal) attempts have been made to determine general patterns for allergen seasonality or determine variation in pollen composition.^{39–41} Progress, however, is ongoing.

Since 2013, Australia has demonstrated a surge of pollen monitoring, reporting, forecasting, and research. Initial funding from the Australian Center for Ecological Analysis and Synthesis facilitated the formation of the Australian Aerobiology Working Group, which developed into the collaboration known as AusPollen Aerobiology Collaboration Network. This collaboration has advanced understanding of pollen seasonality and diversity throughout Australia significantly.^{22,23,29,42,43} A key strength of this collaboration has been its broad interdisciplinary team and transdisciplinary approach.^{23,44} The team has received further support from the Australian National Health and Medical Research Council, the Australian Research Council, and the Victoria Government in response to the deadly Melbourne epidemic thunderstorm asthma event of November 21, 2016. Following this 2016 thunderstorm asthma epidemic,^{45–47} the largest ever globally, a review of aerobiological, meteorologic, and individual susceptibility factors associated with thunderstorm asthma⁴⁸ was commissioned by the Victoria Department of Health and Human Services. A rapid public health response and emergency service preparedness program (<https://www2.health.vic.gov.au/public-health/environmental-health/climate-weather-and-public-health/thunderstorm-asthma>) was initiated, including the Victoria

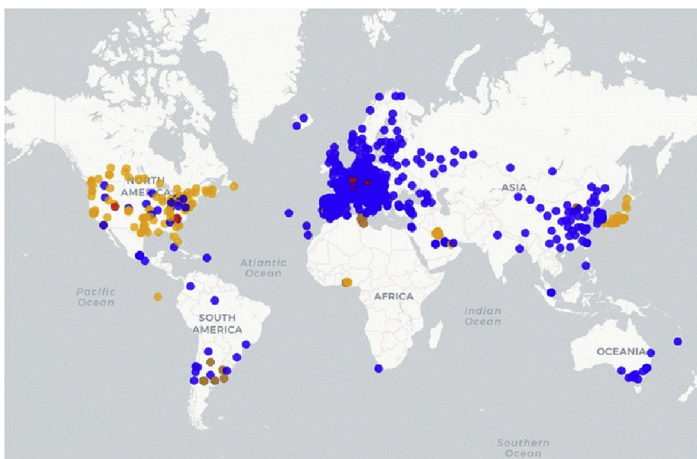


Fig. 2. Interactive map of pollen monitoring stations ([blue dots] Burkard Hirst traps; [red dots] automated; and [orange dots] Rotorod). Note variation in monitoring sites between hemispheres. (From Buters JTM, Antunes C, Galveias A, et al. Pollen and spore monitoring in the world. *Clin Transl Allergy*, 2018;8:9-14; with permission.)

Thunderstorm Asthma Pollen Surveillance Project managed by the Bureau of Meteorology. The AusPollen collaboration has developed an Australian Standard,⁴⁹ engaged in international collaboration,^{43,50} instigated quality control exercises,⁵¹ evaluated perceived benefits and uses of pollen information by community,²² and integrated with other Australian (eg, AirRater, University of Tasmania) and international initiatives, such as AutoPollen and the International Association for Aerobiology.

Similarly, in South Africa, long-term pollen records only exist for Cape Town, where pollen profiles and seasonal differences have been mapped from 1984 to 2014,⁵² with sporadic pollen records for other cities, such as Johannesburg and Durban.⁵³ In KwaZulu-Natal, a study compared fossil pollen with modern pollen to identify changes in the vegetation over time.⁵⁴ Fortunately, the situation has new impetus, with a network of pollen monitoring stations recently established in August 2019, the South African Pollen Network (SAPNET). The SAPNET team includes aeropalynologists, clinicians, climate scientists, statisticians, and air quality scientists based at 7 universities and research centers. Pollen concentrations now are measured daily in 7 cities within 6 different vegetation biomes using volumetric spore traps. Early results highlight large regional differences and have even brought the presence of the highly allergenic weed *Ambrosia artemisiifolia* (ragweed) to the attention of allergists. This is consequential, because, despite knowledge of its presence known to local plant scientists, ragweed has not been incorporated into skin prick tests or specific IgE testing panels prior to 2019.

In Argentina, attempts to develop a network of pollen monitoring through the Asociación Argentina de Alergia e Inmunología Clínica (AAAeIC) commenced in 2006 but sustaining this network has been challenging due to economic fluctuations and limited resourcing. Despite its discontinuity, throughout these 14 years, the AAAeIC was able to monitor the pollen of almost 12 different cities with the presence of different species of pollen. Within this network, different pollen collectors, Rotorod (IQVIA, PA, USA), Burkard (Burkard Manufacturing, UK), and Lanzoni (Lanzoni SRL, Italy), have been used. The AAAeIC recently published the *Atlas Alergopalinológico de la República Argentina*.⁵⁵ This atlas attempts to unify practical monitoring methods and offers content to develop aerobiology for the purpose of providing allergy information.

Unfortunately, at present, few attempts have been made to incorporate climatic and/or CO₂ influences on studies of aeroallergen exposures and allergic disease within the southern hemisphere.⁵⁶ 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; changes in pollen season start date, end date, and length; changes in pollen allergenicity; and changes in seasonal pollen integral, or pollen load.

Are there lessons that can be learned from allergists, botanists, and aerobiologists in the northern hemisphere that would be of value for southern hemisphere research efforts? Yes, but as with all lessons, a value can be attached—some aspects are worth doing and others are to be avoided.

There are shortcomings in efforts to monitor pollen regardless of hemisphere. For example, there is no widespread, consistent set of guidelines for pollen collection, assessment, and reporting. Europe has advanced in recent years with the publication of a Technical Specification and now Standard for Sampling And Analysis Of Airborne Pollen Grains and Fungal Spores.^{57,58} Quality control assessments of individuals involved in pollen counting from Spanish and European Union pollen monitoring networks⁵⁹ informed the AusPollen quality control assessments.⁵¹

Effort is being made to compile and analyze regional or continental responses that could be associated with climate change, or rising CO₂^{50,60–62}; yet, such attempts

remain uncoordinated and sporadic. Limitations and biases due to technical differences in collection site, instrumentation, and counting procedures are not well considered or accounted for.

Unstandardized pollen monitoring practices reflect, in part, the autonomy of allergists and pollen counters as well as inadequate financial resourcing. The independence of those who take responsibility for counting pollen is understandable. It is labor intensive and requires extensive training to identify and enumerate pollen. To do so on a continuous basis requires expertise and fortitude of character that not everyone possesses.

But such independence can be a stumbling block for cooperation. There are loose affiliations (eg, National Allergy Bureau) and business interests (eg, IQVIA) associated with training and certification of pollen identification and counting in the United States and Europe. There are few regulations or metrics, however, that are standardized across locations. How pollen is collected is site specific and can vary considerably (Rotorod, Burkard Spore Traps, and gravimetric methods), yet different sampling methods have different efficiencies,⁶³ and concentrations obtained by different sampling methods not always are directly comparable.^{64,65} The Rotorod device may have advantages in very windy regions, such as coastal regions of Argentina, near the Atlantic, and to the south, which have significantly high average daily wind speeds (Ramón, personal communication 2020). The amount of area counted on the impaction surface (slide or Melinex tape) affects the accuracy of pollen concentration estimates but confidence intervals for pollen concentration values are not routinely provided with pollen records.⁶⁶

In addition to different sampling methodologies, there are no consistent benchmarks used to define features of the pollen season. 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 total pollen for a given year.⁶⁷ This can be referred to as the annual pollen integral (ie, seasonal pollen integral, or pollen load) or yearly cumulative count (some locations use 1% and 99% values). Aerobiology Canada uses a different seasonal definition—that of pollen persistence, that is, season is initiated with 3 days to 5 days of continuous pollen and ends with the last 3-day to 5-day period of continuous pollen. New metrics for the pollen season characteristics are emerging but none is accepted as standard, hampering comparability of reported study outcomes.^{50,68,69} To be effective, globally harmonized terminology for pollen season metrics, as suggested by Pfaar and colleagues and Galán and colleagues,^{68,70} need to be well communicated, adopted, and implemented.

Finally, there is a fundamental issue of the sparsity of sampling sites in the southern hemisphere. Airborne pollen concentrations are reported as if they were ubiquitously representative across a local geographic area, and few guidelines exist for interpreting them.⁶⁴ For example, there is substantial physical and biological heterogeneity within an urban landscape with consequences for spatial and seasonal variability of airborne pollen concentrations.³⁹ Yet, for many large urban areas, 1 or 2 rooftop pollen samplers provide pollen information for an entire city. Lack of funding, and lack of resourcing more generally, is a primary driver of the inadequate spatial density of pollen monitoring. There often is inadequate temporal coverage, with many sites unable to monitor year-round and having to stop monitoring for significant periods of time (often years) while further funding is sought.

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

NEXT STEPS

There is no doubt that pollen monitoring has been longer and more spatially extensive in the northern hemisphere relative to the southern hemisphere (see Fig 2), yet it also is clear that all pollen monitoring efforts, although notable, fall short of assessing or preparing for climate change impacts. Can current efforts in the southern hemisphere to incorporate the impact of CO₂ and climate on plant biodiversity and pollen aerobiology benefit from the northern hemisphere's oversights? It can be argued that southern resources are newer, and less available; yet, it also can be maintained that adaptation is more likely for smaller groups and younger associates. If adaptation is possible, what steps should be taken?

Plant Biogeographical Diversity

There is an immediate need to understand and document the role of climate and CO₂ in changing biogeographical diversity and evolutionary potential of known allergenic plant taxa. Understandably, airborne pollen records are based on what has been observed in the past; yet, it also is evident that as climate changes, or new species are introduced, pollen sources will remain in flux. Such sources may include highly invasive species (eg, *Ambrosia* and *Parthenium*) that are significantly allergenic; alternatively, native species unique to the southern hemisphere may remain uncharacterized in regard to their contribution to allergic diseases.^{36,71,72}

Observation and documentation of new (and old) pollen sources may benefit from citizen science and remote sensing as a means to maintain up-to-date biogeographical distributions.^{43,73} Application of DNA meta-barcode techniques can enable documentation of pollen aerobiome diversity; however, this information only now is being applied to environmental air samples collected by cyclonic samplers or routine Hirst-style pollen and spore traps.^{74,75} Yet, such information would provide valuable insight into biogeographical distribution and phenological patterns of pollen release and distribution and how these spatiotemporal patterns, in turn, respond to current and future climatic change.

Standardization of Pollen Metrics

At present, there is no uniform standard for collecting pollen. The 2 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 size⁶⁴; similarly, site pollen collection often is listed as rooftop, with less detail about height above ground level or surrounding vegetation. Similarly, there is no uniform standard as to what constitutes a pollen season with different groups applying different metrics. Yet, acceptance of a uniform standard would be invaluable in evaluating climate impacts. The "5%" approach to mark beginning of a pollen season can result in temporal anomalies; that is, if the total pollen accumulations for 2 consecutive years were 2000 and 5000, then the start of the season would not be noted until counts reached 100 and 250, respectively. Using this system to mark beginning and end of a pollen season would mask any season length trends associated with climate/temperature. In contrast, a consecutive day metric, as described previously, would be more sensitive to climate-induced changes in start and end times, especially if springs arrived earlier or if falls were delayed.⁵⁰

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). Such a need

contrasts, however, with the number of trained counters and site availability. For example, Sydney, Australia, with an estimated metropolitan population of more than 4 million, has 2 urban pollen monitoring sites.

Automated pollen monitoring using recognition software has been suggested as a means to bridge the gap. In 1 report, a comparison of a Burkard system with a fully automated image recognition-based pollen monitoring system (BAA500 Helmut Hund Gmb, Germany) for daily pollen concentrations was highly correlated ($r = 0.98$); however, some specific pollen sources (eg, *Salix*) were not identified satisfactorily.⁷⁶ Šaulienė and colleagues⁷⁷ have similarly evaluated the capabilities of another automated pollen monitor based on fluorometric detection. The latest innovation incorporated fluorometry and holographic image recognition.⁷⁸ Moves toward automation are accelerating rapidly, particularly in Europe, where the AutoPollen program represents large potential for progress that automatic pollen observations provide, from the actual observation through to the final end-user-defined product.⁷⁹

Such sensors are low maintenance and do not require certified (human) pollen counters, making data comparisons across space and time more consistent. In addition, they can be disseminated in greater numbers as a means to help quantify heterogeneous pollen variability. For example, urban areas typically are warmer than surrounding rural areas, with documented effects of microclimate on pollen release and load.⁸⁰ Yet, at present, there are insufficient pollen monitoring sites to document urban-rural differences in pollen exposure.

Environmental Interactions

Airborne pollen reflects 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 need to be modeled and incorporated into pollen forecasts; certainly large-scale changes, such as the El Niño Southern Oscillation or Indian Ocean Dipole, should be considered.⁸¹

But what is the role of other climatic consequences? Australia, during the summer of 2019 to 2020, experienced an unprecedented wildfire season with significant health impacts,⁸² which was exacerbated by climate change, with an estimated affected area of 110,000 km² (11 million hectares). How will this have an impact on the biogeography of anemophilous plant species? Could pollen levels decline? Alternatively, fires produce fine particulate pollution, known as particles that measure less than 2.5 μm across, that can be transported long distances. Such particles may exacerbate pollen sensitivity and related asthma.⁸³ How will concurrent changes in fire outbreaks and climate alter biodiversity, plant distributions, and pollen seasonality for Australia? Thunderstorms have been linked to asthma epidemics, especially during the grass pollen seasons.⁴⁷ Such extreme meteorologic events are projected to increase in frequency and/or severity in the future,^{84,85} yet the public health consequences remain unknown.

There are, in effect, several probable means by which climate change could affect air quality; a better understanding of the risks of coexposure to both pollen and air pollutants is needed to inform and respond to likely health threats. Similarly, a more integrated approach to assessment, forecasting, and public communication of air quality, which considers the physical, chemical, and biological components and the interactions between them, is now being called for.⁸⁶

Modeling

Understanding and documenting the complex interactions between disparate meteorologic variables, plant physiology, and their interactions with human activities (eg, air

pollution and climate change) and the subsequent consequences on pollen production, seasonality, and health outcomes is a daunting task. Although individual, reductionist experiments are necessary and vital to understanding these linkages, modeling 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.⁸⁷ 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, and social sensing as well as data from symptom trackers or personal monitors.^{88,89} Potentially, improved aeroallergen forecasts could be developed that provide detailed pollen information specific to a given population (eg, urban or rural). Overall, it is hoped that allergists, plant scientists, climatologists, and mathematicians can be encouraged to work together and assimilate their expertise for model frameworks that not only address vulnerabilities but also provide insight into research priorities, especially in regard to climate change.

SUMMARY

The relationships between weather, climate, and pollen and the resulting consequences for human health are universally acknowledged. Pollen-induced allergic rhinitis affects 10% to 40% of populations; it can predispose people to more frequent sinus infections, contribute to poor sleep quality, impair learning, and reduce productivity, and, for the people who suffer from allergic rhinitis with comorbid asthma, it can make asthma more difficult to control.⁷²

Given these links, the role of ongoing 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 can have an impact on aeroallergen metrics, from taxa distribution to pollen production and atmospheric concentration to allergenicity, and that these changes appear to be happening in real time.^{62,80} Yet, it is clear that to continue this work, coordinated multidisciplinary research involving allergists, health care professionals, ecologists, and aerobiologists is necessary for success.^{23,44,48} There are both enablers and barriers, however, to multidisciplinary and intersectoral partnerships as outlined by Davies and colleagues.²³ Enablers include access to diverse skills and knowledge, amplification of productivity, influence beyond the usual arena, and incubation of new solutions to shared problems. Barriers include field specific language and concepts, time pressures, and publication challenges as well as facing autonomously managed infrastructure already in place; the lack of consistent standards for monitoring and recording pollen among locations; nonappreciation of climate change impacts; and lack of recognition or funding sources necessary to further coordination.

Better understanding of the health and socioeconomic impacts of pollen allergen exposure and associated allergic respiratory as well as other chronic inflammatory diseases is needed in relevant populations of the southern hemisphere.⁹⁰ In particular, given the unique geographic, climatic, and biological diversity of pollen aerobiomes in the southern hemisphere, understanding the clinically relevant local thresholds of pollen exposure that are associated with ocular, nasal, and lower respiratory symptoms is needed.

In summary, new opportunities for southern hemisphere research focused on standardized pollen monitoring are needed to enable the generation of long-term data sets necessary to assess broad-scale trends in pollen aerobiology with climate change. In the absence of high-density, manual pollen monitoring stations, integration of airborne

pollen records with innovative landcover, and greenness indices informed by near-ground automated, fixed-site time-series digital camera photography of vegetation (phenocam) monitoring and satellite remote sensing are being applied to advance this field of research. There remains a challenge to understand and respond to the consequences of rising CO₂ and climate change on aeroallergen exposure in the southern hemisphere and the corresponding influence on allergic respiratory diseases. There are unique opportunities, and challenges, for scientists in current or emerging networks, such as the SAPNET, AAAelC, and AusPollen, to accomplish these goals.

Threat recognition and unity of purpose, justifiable concern regarding climate change, uniform standards, cooperation, and support from governments all are necessary to address the health challenges posed by climate change, not simply those of aeroallergens and air quality. These emerging threats are of significant public concern, and it is hoped that southern nations will be able to monitor, prepare, and evaluate the effects and health impacts of climate change on pollen exposure.

CLINIC CARE POINTS

Pearls

Climate change almost certainly will influence aeroallergen exposure seasonally and temporally throughout the southern hemisphere.

Interactions between aeroallergens and other environmental events (thunderstorms and storms) may exacerbate existing pollen-based allergies, for example, in Australia.

Clinical increases in aeroallergen associated illness, pollinosis, allergic rhinitis, and asthma can be anticipated.

Pitfalls

Allergenic plant species within the southern hemisphere that may be impacted by climate and/or rising levels CO₂ have not been fully identified.

At present, there is a need for consolidation and uniformity among southern hemisphere countries in relation to methodology, reporting, and clinical response to climate and/or CO₂-induced changes in aeroallergen biology.

DISCLOSURE

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