

Allergenic Pollen Season Variations in the Past Two Decades Under Changing Climate in the United States



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KEYWORDS

• Climate change • Pollen • Pollen indices • Allergy

KEY POINTS

- Climate change has contributed to an increase in prevalence of allergic airway diseases.
- Climate factors (increasing temperature and carbon dioxide levels) increase production of pollen, which also exhibit increased allergenicity.
- Climate change has contributing to shift in flowering phenology (trees and ragweed) and pollen initiation, thus causing longer pollen exposure.

INTRODUCTION

Allergic airway diseases (AADs) are common chronic diseases affecting one-third of the population in the United States.¹ Estimated costs of care are approximately \$21 billion annually.² Among these, allergic rhinoconjunctivitis, allergic sinusitis, and asthma are associated with aeroallergen exposure. The prevalence of these allergic diseases has been increasing over the past 3 decades.³ This has been related to multiple factors, including obesity, hygiene hypothesis, altered gene-environment interactions, climate change, and pollutants.⁴ Overall, there appears to a multifaceted interaction of the various factors that has culminated in the transformations in phenology, production of pollen, distribution of floristic zones, and sensitivity to aeroallergens and may even include the development to new allergens.

Climate change has had and continues to have impact on various allergenic plants. Specific climate factors, including humidity, rising temperatures, and increasing carbon dioxide (CO₂) levels, have resulted in increased production of

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pollen, mold, and allergenic plant species for example, toxicodendron.⁵ In addition to increased quantity, pollen from trees grown under increased temperatures exhibit increased allergenicity.⁶ Increasing levels of greenhouse gases (CO_2 and ozone [O_3]) have led to alterations in normal flora (allergen content, geographic distribution, and genetics of plants) and fauna (changes in habitat and allergen content of stinging insects) that provide the basis for increased sensitization and exacerbation of existing AADs (Fig. 1). Increased pollen levels in the air increases the efficiency of wind-borne pollination, resulting in dispersion of the pollen over long distances. Over time this will result in increase in aeroallergen burden and an increase in inhalant allergy.^{7,8} Climate change is expected to have dual effect on the allergic diseases—on one hand, it affects pollen indices, including the start, duration, and intensity of the pollen season; on the other hand, it affects frequency of AAD, including asthma exacerbations. The presence of allergic sensitization of the nasal and bronchial mucosa also may lead to increased propensity of developing viral respiratory infections, such as coronavirus disease (COVID 19).⁹

Studies have shown climate change (milder winters, warmer air temperatures, and higher CO_2 concentrations) globally is resulting in shifting of plant phenology.¹⁰ Global warming hastens flowering of the plants and early blooming. Compared with the early 1960s, there has been advancement of spring events (flowering of trees) by 6 days and delay of fall season events by 5 days.¹¹ Prolonged ragweed season in the past 2 decades has been shown to be associated with increase in number of frost-free days and delayed fall frosts.¹² This increases allergic sensitization and increased prevalence of allergic diseases. Patients also experience longer duration as well as increased severity of symptoms.³ Also, increased outdoor allergen levels results in pollen influx into the house, which results in increased personal exposure. Increased CO_2 levels have been shown to have fertilizing effect on plants.¹³ Pollen from ragweed increases 30% to 90% when CO_2 levels double.¹⁴ Similar effect has been seen on other plants including poison ivy.¹⁵

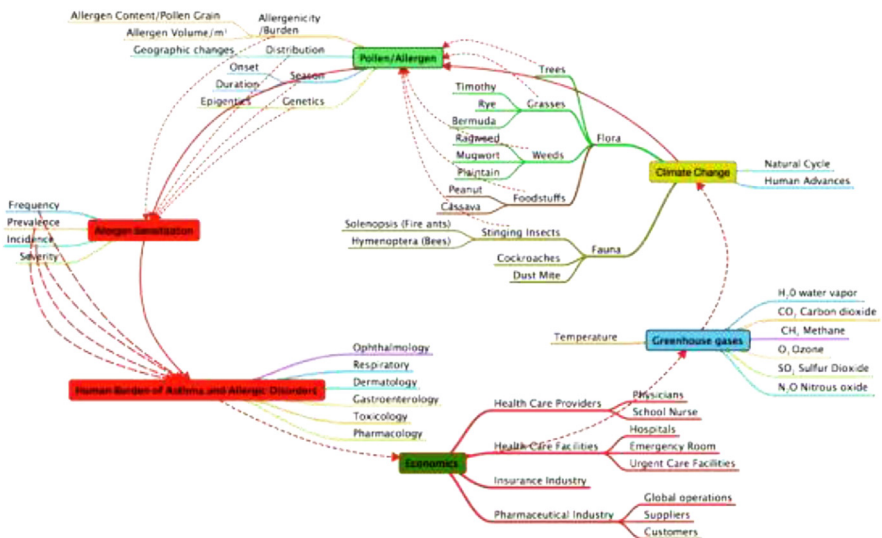


Fig. 1. The cycle of climate and allergic disease. (From Bielory L, Lyons K, Goldberg R. Climate change and allergic disease. *Curr Allergy Asthma Rep.* 2012;12(6): 485-494; with permission.)

AEROBIOLOGY OF NORTH AMERICA

Plants of various species release pollen into the air causing allergy symptoms but only some of these cause significant allergic symptoms (**Table 1**).¹⁶ Epidemiology of allergic diseases is determined by regional pollen distributions, which also is essential for diagnosis and treatment of allergic diseases.

There are 3 distinct plant-based aeroallergen seasons experienced through most of the temperate zones of the United States: tree pollen during spring season, grass pollen in early summer, and weed pollen during end of summer and fall season. Tree and weed pollens can be transported easily over long distances.¹⁶ A variety of weed plants are known to produce very large amount of pollen grains during a season, with ragweed the most commonly sensitized weed in the United States.^{16,17} Cutaneous reactivity to ragweed has been reported up to 70% of the US population in the Centers for Disease Control and Prevention National Health and Nutrition Examination Survey studies.¹⁸ Pollen production from trees in various section of the United States, however, may extend beyond spring (*Ulmus* may produce pollen in late summer and early fall; Cupressaceae may produce pollen in fall and winter) and grass pollen may be emitted beyond summers (Poaceae pollen may be released March through November).¹⁶

Climate change can affect pollen seasons in all of the floristic zones. Floristic zones include the native vegetation found in a particular area and are affected by temperature and mean precipitation. Hardiness zones are characterized by mean annual minimum temperatures. **Fig. 2** depicts difference in hardiness zones from 1990 to 2015.¹⁹

Table 1
Important pollen in North America

Name	Type of Pollen	Percent	Characteristics
Oak (<i>Quercus</i>)	Tree	19.6	Produce heavy pollen load. Found in residential areas, forests, parks
Cyper, juniper, cedar (Cupressaceae)	Tree	19.4	Produce profuse amounts of pollen. Reactions often are severe to Cupressaceae pollen.
Ragweed (<i>Ambrosia</i>)	Weed	7.2	Most important cause of rhinitis symptoms in late summer, early fall
Mulberry (<i>Morus</i>)	Tree	6.7	Often causes severe reactions
Pine (Pinaceae)	Tree	4.5	Produces large amount of low allergenic pollen
Elm (<i>Ulmus</i>)	Tree	4.6	Produces heavy load of allergenic pollen
Ash (<i>Fraxinus</i>)	Tree	3.7	Produces heavy load of allergenic pollen
Birch (<i>Betula</i>)	Tree	3.8	Short pollen season.
Grass (Poaceae, Gramineae) (bluegrass, timothy, Bermuda, ryegrass)	Grass	3.7	Poaceae pollen is highly allergenic.
Maple (<i>Acer</i>)	Tree	3.7	Most species are allergenic.
Poplar, aspen, cottonwood (<i>Populus</i>)	Tree	2.5	Large deciduous trees

Adapted from Lo F, Bitz CM, Battisti DS, et al. Pollen calendars and maps of allergenic pollen in North America. *Aerobiologia* 2019; 35(4): 613–633; with permission.

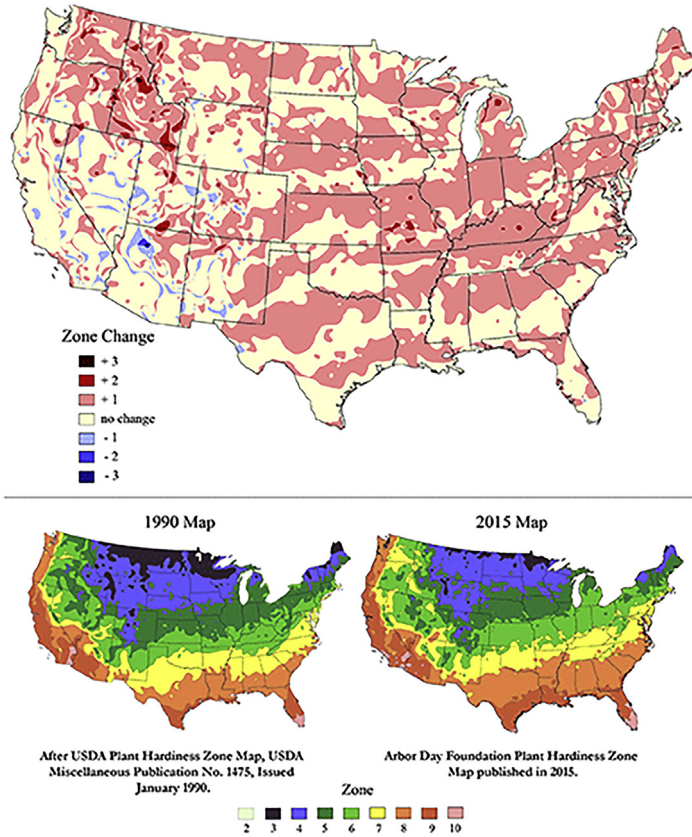


Fig. 2. Differences between 1990 US Department of Agriculture hardiness zones and 2015 [Arborday.org](https://www.arborday.org) hardiness zones. (From Differences between 1990 USDA Hardiness Zones and 2015 [Arborday.org](https://www.arborday.org) Hardiness Zones. Arbor Day Foundation. 2015 Available at: https://www.arborday.org/media/map_change.cfm With permission.)

Migration of these zones has happened due to global warming, thereby affecting the type of flora in a given area. Within the United States, there has been 2-zone shift in some areas in the past 2 decades. Over time, there has been a change in distribution of trees. Boreal trees (fir, larch, and alder) have shifted south with cooling, while replaced by oak and white pine (northward shift) with subsequent warming.²⁰ Lo and colleagues¹⁶ conducted a study to generate data on pollen distribution in the United States and Canada. The investigators used data from 31 National Allergy Bureau (NAB) pollen stations from 2003 to 2017 to develop pollen calendars for specific pollen taxa. It was noted that in most areas, a majority of the total pollen is contributed by only a small number of taxa. For tree and grass pollen season, start date strongly correlates with latitude, which in turn correlates with temperature and length of the day. Earlier start date was noted for lower latitudes. Also, earlier start date correlated with longer pollen season duration.¹⁶

Various environmental factors contribute to pollen allergy, such as climate and local plantations.²¹ Pollen concentrations in a given area correlate with the local weather conditions and vegetation and usually reflect pollen emissions locally,²² although sometimes they might be transported to farther places.²³

Pollen calendars are created using daily average pollen concentrations. They help to determine distribution, timing, and concentration of different pollen at a particular location. This allows physicians and patients to identify their allergen triggers and initiate appropriate testing and treatment.²⁴

POLLEN SEASON INDICES

Pollen season indices (annual pollen integral [API_n], duration of the pollen season, and start and end dates) are used to describe prominent features of the main pollen season. API_n is defined as the integral of the pollen concentration for a particular taxon measured daily over the pollen year. A pollen year is a year that includes 1 full pollen season, starting when the plant is still dormant. Start date of the pollen season usually is considered when the integral of pollen concentration approaches 50 pollen grains/m³ during a pollen year. In cases of plants with high API_n (>2000 pollen grain/m³), end date of the pollen season is defined as the date when the integral of pollen concentration up to the end of the pollen year is less than 50 pollen grain/m³. In cases of plants with API_n less 2000 pollen grain/m³, the end date threshold is the date when accumulated pollen concentration approaches 97.5% mean API_n. Most sensitive patients tend to experience symptoms even at low airborne pollen concentrations (50 pollen grains/m³). This could be related to priming effect of allergens, wherein daily exposure to the allergen results in increased allergic response.²⁵

Pollen sensitization occurs when a genetically predisposed individual is exposed to their individual threshold. This varies with geographic location, CO₂ and O₃ levels, climate variations, and air pollution. Pollen levels increase during warm and dry days whereas levels fall during cool and moist days. In recent decades, ragweed pollen season has increased in North America and is related to latitude and linked to warming temperatures in those regions.¹² Over a period of 20 years, from the 1990s to 2010, daily average airborne allergen has increased by 46%.²⁶ Elevated CO₂ levels have been shown to have increased ragweed pollen production.²⁷ Additional factors that have an impact on allergenic pollen production include pollution and diesel exhaust.^{28,29}

MODELS FOR POLLEN DISPERSAL

AADs comprise a complex medical problem that often is triggered by air pollutants and bioaerosols, but, due to the inability to obtain precise information regarding spatial distribution of bioaerosol emissions, it is difficult to predict their combined effect. Currently, however, there are no standardized methods across the United States that allow estimation of such emissions. Various numerical models have been developed to assess the effect of climate change on pollen emission and transport and the impact on AADs. These models are based on phenological observations or use meteorologic principles.

Pollen Emissions Module

The pollen emissions module provides estimate of pollen particle emissions from common allergenic trees and plants in the United States based on biogenic gas emissions used in the Biogenic Emission Inventory System. Several factors influence pollen emission that include humidity, temperature, speed of wind, and total growing degree days. The Intergovernmental Panel on Climate Change (IPCC) concluded that milder temperatures affect pollen production resulting in early release as well as increased allergenicity.³⁰ Various remote sensing sources and local surveys were used to develop a spatiotemporal vegetation map, which was coupled with the mesoscale

meteorologic model to develop emission rates of various pollens.³¹ Strong correlations were noticed between predicted pollen emissions and measured pollen counts across wide geographic region using this approach.

Atmospheric Pollen Transport Module

Different models have been developed for analysis of transport of pollen and transformation of other air pollutants (Table 2).³² Among these, models commonly used in the United States include (1) the Hybrid Single-Particle Lagrangian Integrated Trajectory (HYSPLIT) model and (2) the modified version of US Environmental Protection Agency Community Multiscale Air Quality (CMAQ) model. The CMAQ model offers advantage of being more flexible. The CMAQ model includes 3 different models—meteorologic model, emission model, and air transport model. The meteorologic model represents weather conditions; the emission model represents emissions from man-made as well as natural sources; and the air transport model is used to predict air pollutants transmission based on atmospheric conditions. The CMAQ provides prompt and accurate information regarding O₃, particulate material, toxics, and acid deposition. The CMAQ pollen model uses a single model simulation to predict transport of multiple air pollutants and pollens.

The HYSPLIT model commonly is used to compute atmospheric transport and dispersion of allergens and pollutants. It has been used in simulations models describing transport, chemical transformation, and deposition of bioaerosols and hazardous materials, including radioactive material, wildfire smoke, and volcanic emissions. It often is used for back trajectory analysis, which involves establishing source-receptor relationship to determine origin of these particles. In general, CMAQ estimated profiles correspond with the pollen transport trajectories as estimated by HYSPLIT.³²

Table 2 Various models developed for large-scale emissions and long-range transport of pollen			
Model for Pollen Transport	Model for Pollen Emission	Species of Plant	Location and Year of the Study
CMAQ model	Meteorologic parameterization	Birch and ragweed	USA (2010)
Aerosols and reactive trace gas (ART) model	Meteorologic parameterization	Birch	Switzerland (2008)
Mesoscale atmospheric meteorology (METRAS) model	Meteorologic parameterization	Oak	Germany (2006)
System for Integrated Modeling of Atmospheric Composition (SILAM)	Phenological observations	Birch	Finland (2006)
HYSPLIT model	Uniform diurnal profile	Oak	USA (2005)
DRAIS chemistry transport model (CTM)	Meteorologic parameterization	Hazel, alder	Germany (2004)
Gaussian model	Meteorologic parameterization	Cedar	Japan(1999)

EFFECT OF CLIMATE CHANGE ON TREE POLLEN

In a study that was conducted to examine the effect of climate change on spatiotemporal patterns of *Betula* (birch) and *Quercus* (oak) tree pollen, data were collected from 6 NAB stations from 1994 to 2011 in order to assess the effect of climate change on trends of annual pollen production (AP), season start, and season length.³³ Comparing data from 1994 to 2000 to 2001 to 2010, birch and oak trees began to pollinate 1 week to 2 weeks earlier during 2000 to 2010. The annual mean pollen concentrations and the daily peak values (PVs) increased at most of the stations for birch and oak trees. Season length for birch was noted to be shorter whereas season lengths for oak varied according to the location.³³

The growing degree hour model has been used for developing spatiotemporal profiles of pollen emissions and to produce simulated data on future start dates and season lengths for birch and oak tree pollen (year 2050). Simulation results indicated that responses of birch and oak pollen seasons to climate change are projected to vary for different regions based on regional climate variations. As an example, the birch pollen season in 2050 in the Northeastern United States is projected to start earlier and last longer, and in the Northwestern United States, it is projected to start later and end sooner; whereas the oak pollen season in 2050 in Northeastern United States is projected to be longer and, in the Northwestern United States, the season is expected to start earlier. Earlier start dates and longer pollen seasons for both birch and oak pollen in Northeastern United States are linked to increasing temperatures and regional warming.³³

Bayesian models were used by Zhang and colleagues³⁴ to study the effect of multiple climate factors on different pollen indices (AP, PV, start date, and peak date) of birch (*Betula*) tree. The model used variable selection-parameterization-evaluation-prediction factors.

The model was developed to assess the impact of climate change related to anthropogenic activities on future pollen indices. It was based on 3 IPCC scenarios (based on economic, demographic, and technological factors): (1) A2—economic development, (2) A1B—economic growth with balanced emphasis on energy sources (A1B), and (3) B1—globally and environmentally oriented development. Each scenario was associated with different projections of CO₂ concentrations (853 parts per million [ppm], 709 ppm, and 533 ppm) and temperature (17.7°C, 17.0°C, and 16.1°C) in 2100. Spatiotemporal emission profiles were developed for birch tree pollen for the Northeastern United States for the years 2002 and 2040 by incorporating predicted pollen integral into the emission model. Among different climate factors, mean spring temperature, annual mean (CO₂) and pollen counts of the prior year had significant effect on the pollen indices. The investigators used the output of these models to formulate birch pollen emissions for future years (from 2020 to 2100), as shown in [Table 3](#).

The start and peak dates of birch pollen season are expected to occur 2 weeks to 4 weeks earlier than usual. Climate change, thus, is expected to have significant effects in pollen production, timing, and intensity and subsequently will have a significant impact on patients that suffer from AAD.³⁴ Pollen release from trees including birch has been earlier and more pronounced across North America.³⁵ In New England, pollen as well as mold spore counts were highest during a warmer, wetter El Niño year compared with other years.³⁶ In the San Francisco Bay area, California, pollen counts for oak tree were strongly associated with total rainfall during the preceding year.³⁷ Over the years, there has been a significant increase in seasonal pollen levels of *Juniperus*, *Quercus*, *Carya*, and *Betula* spp. Certain trees (*Juniperus*, *Ulmus*, and *Morus*) have been having early start dates during pollen season. This was significantly related

Table 3

Comparison of mean pollen counts and related indicators of annual pollen production, peak pollen count values, pollen release start date, and peak pollen count date between 2020 and 2100 starting with the base year 2000

Pollen Index	Scenario	2000	2020	2040	2060	2080	2100
AP (pollen.m ⁻³)	B1	8455	11,413 (1.3)	18,286 (2.2)	23,872 (2.8)	26,913 (3.2)	27,621 (3.3)
	A2	8455	12,019 (1.4)	21,047 (2.5)	33,005 (3.9)	47,778 (5.7)	67,831 (8.0)
	A1B	8455	12.673 (1.5)	21,735 (2.6)	31,950 (3.8)	41,518 (4.9)	49,889 (5.9)
PV (pollem.m ⁻³)	B1	1684	1844 (1.1)	3121 (1.9)	4187 (2.5)	4768 (3.2)	4918 (3.3)
	A2	1684	1951 (1.2)	3622 (2.2)	5851 (3.5)	8601 (5.1)	12,334 (7.3)
	A1B	1684	2067 (1.2)	3758 (2.2)	5671 (3.4)	7468 (4.4)	9056 (5.4)
Start date (days from January 1)	B1	105	86 (−19)	86 (−19)	85 (−20)	84 (−21)	84 (−21)
	A2	105	86 (−19)	86 (−19)	84 (−21)	83 (−22)	81 (−24)
	A1B	105	86 (−19)	86 (−19)	84 (−21)	83 (−22)	83 (−22)
Peak date (days from January 1)	B1	122	99 (−23)	99 (−23)	98 (−24)	98 (−24)	97 (−25)
	A2	122	99 (−23)	99 (−23)	98 (−24)	97 (−25)	96 (−26)
	A1B	122	99 (−23)	98 (−24)	98 (−24)	97 (−25)	96 (−26)

The ratio to or differences from base year are in parentheses. The model has predicted a dramatic increase in AP (1.3–8.0×) and PVs (1.1–7.3×) of birch pollen. For 2040, AP and PV for 3 scenario A2/A1B/B1 increase to 21,047 (2.4×)/21,735 (2.4×)/18,286 (2.1×) and 3622 (2.3×)/3758 (2.3×)/3121 (1.9×), respectively. For 2100, AP and PV for A2/A1B/B1 increase to 67,831 (7.6×)/49,889 (5.6×)/27,621 (3.1×) and 12,334 (7.7×)/9056 (5.6×)/4918 (3.1×).

From Zhang Y, Isukapalli S, Bielory L, et al. Bayesian Analysis of Climate Change Effects on Observed and Projected Airborne Levels of Birch Pollen. Atmos Environ. 2013; 68: 64–73 with permission.

to warmer temperatures increasingly seen during winters.¹⁴ A significant increase has been seen in *Juniperus* spp pollen counts in Oklahoma due to encroachment of *Juniperus* spp trees into the native grasslands along with earlier start dates for tree pollen season. The rise in pollen counts of Cupressaceous and *Ulmus* spp correlates with daily temperatures. On the other hand, pollen levels were negatively associated with daily precipitation, because rain washes away the pollen particles.³⁸ Preseason weather parameters, including temperature and precipitation, also showed significant correlations with pollen parameters. Preseason temperature has been shown essential for maturation and release of pollen from spring-pollinating tree species. This is related to the accumulated temperature above the threshold. As a result, warmer winters are associated with earlier pollen season start dates.³⁹

EFFECT ON RAGWEED

The duration of the ragweed (*Ambrosia* spp) pollen season has been increasing in past few years.¹² Increasing duration of ragweed pollen season in North America has been correlated to latitude and thus warming temperatures. The increase in surface temperature has not been uniform all over, rather has been more toward the poles or with increase in altitude.⁴⁰ Since 1995, the ragweed pollen season has been longer by 13 days to 27 days at latitudes above 44°N. Ziska and colleagues¹² collected and analyzed data pertaining to ragweed pollen as collected by NAB in the United States and Aerobiology Research Laboratories in Canada. The aim was to analyze the effect of latitude on the ragweed pollen production in regards to frost-free days as surrogate for temperatures changes related to climate change. The data were collected from 8 NAB locations from latitude of 30.63°N (Austin, Texas) to 46.88°N (Fargo, North Dakota) and 2 locations in Canada from latitude 50.1°N (Winnipeg, Manitoba) to 52.1°N (Saskatoon, Saskatchewan) over a duration of 15 years (Fig. 3). The data obtained were statistically analyzed for each location. The investigators noted that the length of the duration of ragweed season was significantly associated with latitude.¹² The investigators then analyzed data for each location. They compared duration of ragweed season against seasonal variations in temperature for each location. They

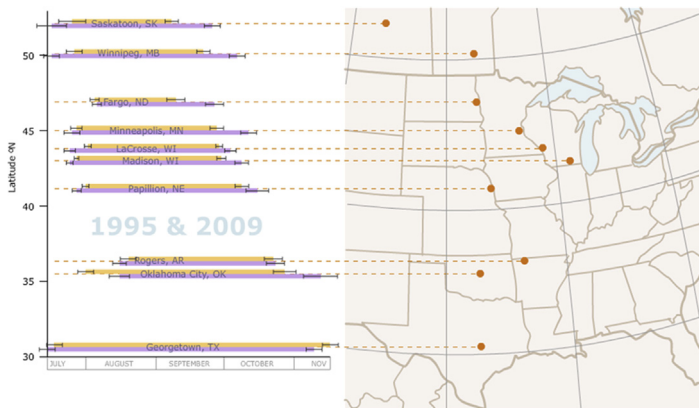


Fig. 3. NAB locations in the United States and Canada used for data collection. (From Ziska L, Knowlton K, Rogers C, et al. Recent warming by latitude associated with increased length of ragweed pollen season in central North America. PNAS 2011;108(10): 4248-5; with permission.)

noticed that over the past 15 years, increase in the duration of ragweed season was associated with an increase in number of frost-free days as well as delayed onset of fall frosts (Fig. 4), which in turn was noted to have a clear correlation with latitude of each location. There was no correlation between latitude and other weather phenomenon, such as precipitation.¹² In another study, it was determined that same-day total precipitation significantly affects ragweed pollen levels. Changes in daily pollen levels were noted to be inversely related to total precipitation. Rainfall tends to wash away pollen particle and also prevents further dehiscence of the pollen particle.⁴¹

Ziska and colleagues²¹ conducted a study to assess the impact of climate change on ragweed pollen production using a temperature-CO₂ gradient between urban and rural areas to assess the impact for year 2000 and 2001. Average daily CO₂ concentration and air temperature in an urban area were 30% to 31% and 3.4°F to 3.6°F, respectively, more than the rural area. They noticed that the higher temperature and CO₂ concentration in the urban area led to faster growth of ragweed (*Alternaria artemisiifolia*) and earlier and increased pollen production and produced large amounts of above-ground biomass compared with rural areas.²¹ In Tulsa, total *Ambrosia* spp pollen levels decreased significantly from 1987 to 2006.⁴² Warmer temperatures during August were shown to be a contributing factor, in addition to urbanization. Wan and colleagues showed, however, that warmer temperatures increased *A psilostachya*

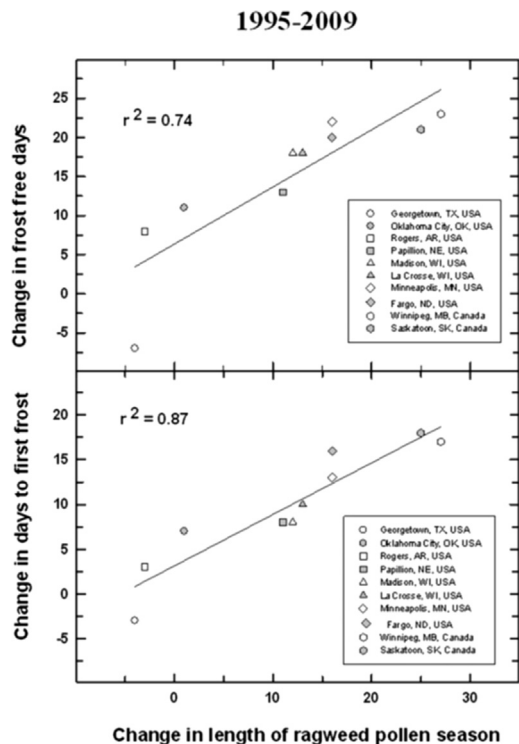


Fig. 4. Change in the length (days) of ragweed pollen season from 1995 to 2009 as a function of frost-free days and delays in the time of first frost during the fall, as a function of latitude. (From Ziska L, Knowlton K, Rogers C, et al. Recent warming by latitude associated with increased length of ragweed pollen season in central North America. PNAS 2011;108(10): 4248-5; with permission.)

pollen counts.⁴³ *A psilostachya* is perennial whereas *A artemisiifolia* is annual. Thus, there might be a difference in the response of perennial versus annual ragweed spp. Response of ragweed pollen season to climate change was analyzed in 9 climate regions across the United States. Spatiotemporal distributions of ragweed pollen were simulated during 2001 to 2004 and 2047 to 2050 to study the effect of climate change on ragweed pollen season timing and levels in the different climate region. As shown in **Table 4**, the pollen season length was short in all climate regions across the United States. The mean hourly concentration decreased in 6 of the 9 regions. The maximum hourly concentration increased in 5 of the 9 regions, with the effect being most pronounced in the East North Central region (34.7% increase). The pollen season was predicted to start late in 7 of the 9 regions.⁴⁴

Zhang and colleagues²⁵ conducted a study to analyze the effect of climate change on the pollen season for trees (birch and oak), grasses (Poaceae), and weeds (ragweed and mugwort weed). The investigators described the spatiotemporal patterns of changes in the levels and timing of pollen belonging to multiple taxa that are exposed to different climate across the United States. They obtained daily pollen counts from all 50 NAB stations across the United States from 1994 to 2010, expressed as pollen grains per cubic meter.²⁶ Analysis of the data showed that of the 50 stations, early start dates were seen at a majority of the stations for all different taxa. Season length was shorter for birch and oak stations but longer for ragweed, mugwort, and grass at more than half of the stations. Also, PV and AP showed increasing trend for spring-flowering taxa (birch, oak, and grass) at 62% stations whereas for summer flowering (ragweed and mugwort) taxa, a decreasing trend was more common.²⁶ Pollen indices during the period 2000 to 2010 were compared with those of 1990s. Pollen season was noted to start earlier by an average of 3 days for all different taxa (trees, grasses, and weeds) during 2001 to 2010 in most of the climate regions. Also, pollen levels increased to a

Table 4

Regional average and SD of the changes in mean and maximum hourly concentrations, start date, season length, and exceedance hours for ragweed (*Ambrosia*) pollen

Regions	Mean Hourly (%)	Maximum Hourly (%)	Start Date (Days) – = Earlier, + = Later	Season Length (Days)	Exceedance Hours (>30 Grains/m ³) (%)
NW	–8.7 ±26.2	–10.6 ±41	1.2 ±1.3	–1.1 ±1	–5.5 ±25.7
WNC	0.8 ±22.2	0.9 ±45.3	1.7 ±1	–2 ±0.9	3.5 ±47.1
ENC	–3.4 ±16.5	34.7 ±98.3	1.8 ±1.2	–3.7 ±0.9	–3 ±17.3
NE	–9.3 ±43.8	–19.3 ±74.7	–0.9 ±1.5	–0.9 ±0.8	–6.2 ±111.8
W	–36.4 ±19.1	–30.5 ±23	0.5 ±1.2	–0.3 ±1	–11 ±25.7
C	2 ±30.7	13.8 ±91	1 ±1.1	–3.8 ±1	4.1 ±81.1
SW	15.2 ±39.7	13.1 ±78	0.1 ±1.1	–0.7 ±0.8	6.2 ±42.7
SE	–9.6 ±34.3	–23 ±59.6	–1.1 ±0.7	–0.2 ±0.5	–8.6 ±46.2
S	–1.8 ±30.3	17.7 ±128.7	0.3 ±1	–1.4 ±0.7	–2.8 ±28.9

Abbreviations: C, Central; ENC, East North Central; NE, Northeast; NW, Northwest; S, South; SE, Southeast; SW, Southwest; W, West; WNC, West North Central.

These changes were calculated using the simulation data between periods of 2001 to 2004 and 2047 to 2050 in 9 climate regions across the United States (mean ±SD).

From Zhang Y. Climate Change and Airborne Allergens[dissertation]. New Brunswick, Rutgers. 2015. Available at: <https://rucore.libraries.rutgers.edu/rutgers-lib/46460/>.

great extent compared with 1990s. The average peak pollen count and annual airborne pollen production increased by 42.4% and 46.0%, respectively. Length of the pollen season, however, was noted to vary: in the northeastern regions, the pollen season lasted longer whereas in southern region, the pollen season was shorter than in 1990s. Pollen seasons were shorter for spring flowering plants by 3.1 days to 4.8 days and longer for summer flowering taxa (ragweed and mugwort) by 1.3 days to 10 days.²⁶ The investigators also noticed that these changes in pollen levels and season timing were related to latitude. At higher latitudes, the pollen seasons were noted to start earlier and also the length of the pollen season increased. Higher latitudes also experienced larger changes in average AP but only smaller changes in average peak pollen levels.²⁶ Thus, recent climate change, especially enhanced warming and precipitation at higher latitudes, has resulted in longer and more intense pollen exposure, thereby increasing the prevalence of AAD. These climate changes have resulted in a similar shift in plants and animal distribution.⁴⁵ Changes in precipitation have resulted in dual effects. Increased precipitation washes away airborne pollen resulting in decreased peak airborne pollen levels. Larger increase in precipitation, however, seen at higher latitudes, has been more favorable for growth of plants, thereby resulting in higher levels of pollen. This dual effect is seen to be more prominent on the higher latitudes, which, if it continues, can lead to increased prevalence of AADs and increased morbidity related to early start dates and increased exposure to airborne pollens.

Climate change and higher CO₂ concentrations have resulted in increased spore production of *Alternaria alternata* (common allergenic mold), contributing to increased occurrence of asthma and other allergic diseases.⁴⁶ A study conducted in Denver, Colorado, analyzed the relationship between certain climate factors (humidity, temperature, sunshine, and wind) and observed tree, grass, and weed pollen levels. Weed pollen levels were more affected by temperature and were noted to be low after an early fall frost in Denver. On the other hand, tree pollen and grass pollen were affected more by precipitation. Association between climate factors and pollen level, however, was not consistent and varied from year to year.⁴⁷ Experimental warming has been shown to induce flowering earlier in plants that flower in spring and early summer whereas delayed flowering was seen in late summer and fall flowering plants. *Ambrosia* spp exhibited delayed flowering related to a prolonged bud stage. There was a significant change in flowering time of 2 summer flowering grasses—advanced flowering in *Panicum* spp (17 days early) whereas delayed flowering in *Andropogon* spp (10 days later).⁴⁸ Climate change can have a significant impact on AADs through exposure to new allergens or higher concentrations of indigenous aeroallergens. Both pollen and dust can be dispersed over long distances. In Tulsa, Oklahoma, *Juniperus ashei* pollen gets dispersed over long distances and contributes to increased allergic symptoms in the area.⁴⁹

SUMMARY

Climate change, over the years, has contributed significantly to an increase in prevalence of AADs. Effect of climate change also has been seen on plant distribution as seen in widespread expansion of *Juniperus* spp in central and the southwest United States. Future research needs to focus on collecting long-term integrated data series on different allergenic pollen species. The results also can be extrapolated to document future changes in pollen production and distribution with assessment models that would integrate socioeconomic factors, climate factors, and technological changes. Research can help develop more sustainable and effective measures for control of aeroallergens.

CLINICS CARE POINTS

- Climate change globally has contributed to an increase in prevalence and severity of AADs related to altered pollen production as well as timing and duration of pollen season.
- Complex interaction between increasing pollen levels and air pollutants can increase the burden of asthma and other allergic diseases further.
- Anthropogenic activities have resulted in increased production of greenhouse gases (CO₂ and O₃), which in turn have led to global warming and climate change.
- Climate change (increasing temperatures and CO₂) have contributed to increased allergenicity of plants.
- Climate change also has affected the distribution and type of trees and other vegetation over recent years in a geographic area.

DISCLOSURE

The authors have nothing to disclose.

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