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ALLERGIES AND THE ENVIRONMENT (M HERNANDEZ, SECTION EDITOR)

Impact of Climate Change on Pollen and Respiratory Disease

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Abstract

Purpose of Review A warming world will impact everyone and everything. The practice of allergic and respiratory disease will not be excepted. All the impacts will be impossible to anticipate. This review is intended to discuss significant factors related to individuals with allergic and respiratory disease.

Recent Findings Recent findings include the increased growth of allergenic plants in response to higher carbon dioxide levels and warmer temperatures. This also contributes to the increased production of pollen as well as the appearance of allergenic species in new climactic areas. Stinging insects will extend their ranges into northern areas where they have not previously been a problem. The shift and extension of pollen seasons with warmer springs and later frosts have already been observed. Recent severe hurricanes and flooding events may be just the harbinger of increasing damp housing exposure related to sea level rise. Evidence is accumulating that indicates the expected higher number of ozone alert days and increased pollution in populated areas is bringing increases in pollen potency. Finally, increased exposure to smoke and particles from wild fires, resulting from heat waves, will contribute to the general increase in respiratory disease.

Summary The practice of allergy being closely aligned with environmental conditions will be especially impacted. Allergists should consider increasing educational activities aimed at making patients more aware of air quality conditions.

Keywords Pollen · Climate change · Global warming · Heat wave · Wild fire smoke · Damp housing · Sea level

Introduction

The evidence for climate change is all around. Just in the USA, daily high temperature records are being set much more frequently than daily low temperature records [1]. For example in the past year, there have been 46 maximum high temperature records and 124 maximum daily low temperature records. But only 9 minimum low temperature and 12 maximum low temperature records were set. Most glaciers around the world are receding as ice melts faster than it is formed [2]. Ice men and frozen mummies, centuries old, have been emerging from their tombs in mountainous areas. Sea levels have risen 4 to 8 in. in the past 100 years. As more glaciers melt, the salinity of the oceans decreases [3]. As more scientists look into the warming climate, the evidence continues to grow. No one of these observations or series of observations is definitive, but when taken all together, they build a very convincing body of evidence. So, as much as we wish it is not true, and no matter what our political inclination might be, we are in the middle of a global warming climate change. It is most likely caused by human activities. And, the probability that human political institutions will successfully reverse the current trend is very low.

The American sociologist Robert K. Merton is generally given credit for popularizing the law of unintended or unanticipated consequences. These consequences basically encompass all of the outcomes that are not foreseen or intended, but nonetheless, they result from a purposeful action. A good example is all the ecological consequences of introducing Nutria into the Southern USA. So, it will be nearly impossible to anticipate all of the ways in which global climate change, and the purposeful actions humans will take to live with it, will impact allergy in the future. The purpose of this article is to review the published evidence that documents the elements of climate change predicted to impact allergists and their patients. These include the increased growth of allergenic plants, the increased production of pollen, the increases in pollen

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potency, the appearance of allergenic species in new climactic areas, the shift in pollen seasons with warmer springs and later frosts, increasing damp housing exposure related to sea level rise, a higher number of ozone alert days in populated areas, increased flooding exposures, increased exposure to smoke and particles from wild fires, and the general increase in respiratory disease related to increasing heat waves.

It is very difficult to anticipate what actions societies will take in response to predicted climatic changes. Alterations will likely evolve in an adaptive manner. Humans will make small changes to relieve the stresses of the moment without giving much thought to any collateral problems these changes might elicit. Much of this adaptation will be driven by near past experiences while little of it will be driven by anticipatory assessment of future conditions. Human adaptation is usually motivated by economic or safety concerns. Individuals and countries will change to meet their own collective goals. And Darwin's rules will apply. Those that adapt wisely will survive, and those that adapt poorly will perish. There will be many unanticipated results of climate change. We have endeavored to discuss those that are most anticipated. Climate change will impact all aspects of allergen exposure including both indoor and outdoor allergens as well as communicable diseases related to allergies and asthma [4].

Impact of Climate Change

The most obvious impact that a warming climate will have on those with allergies is plants that release allergenic pollen, which is likely to alter their growth and pollen release timing. There is experimental evidence that plants will have increased growth with higher carbon dioxide levels. The most easily demonstrated element of climate change is the increase in carbon dioxide. Many have personally experienced this. When the Allergy Section first procured a carbon dioxide detector in Kansas City, about 20 years ago, routinely measured carbon dioxide levels were in the 380 ppm range (microliters of carbon dioxide per liter of air). Today, the outdoor carbon dioxide level readings typically exceed 400 ppm. And, readings are higher in the city than they are in rural areas. But the most often quoted values are monitored in Hawaii at the Mauna Loa Observatory. These readings taken far from heavily populated areas have been rising year over year since they were first recorded.

A higher carbon dioxide level is not necessarily bad for all earthly organisms. For any organism that gains energy through photosynthesis, carbon dioxide is basically a nutrient. As such, we expect higher carbon dioxide levels would produce greater amounts of growth among plants. In a demonstration of how higher carbon dioxide levels will impact growth of allergenic plants, researchers grew short ragweed plants in climate-controlled greenhouses [5]. Ragweed plants were grown from seed at ambient and twice-ambient carbon dioxide levels (350 vs 700 ppm). Researchers reported outcomes including stand-level total pollen production and end-of-season measures of plant mass, height, and seed production. The doubling of carbon dioxide increased ragweed pollen production by 61%. This indicates there will be a significant increase in ragweed exposure and possibly an increased exposure to all allergenic pollen with global warming. In a later but similar study in Europe, where ragweed pollen is a growing problem, the actual ragweed allergenic proteins were evaluated [6]. Plants were grown in greenhouses at 380 and 700 ppm carbon dioxide. RNA was isolated from the ragweed pollen. Of the identified sequences, those encoding allergenic ragweed proteins (Amb a) increased under elevated carbon dioxide and drought stress scenarios.

A confirming real-world experiment was conducted by growing equivalent ragweed plots in urban and rural conditions. Urban carbon dioxide concentrations were about 30% higher than rural concentrations [7]. In the urban environment, the ragweed grew faster, flowered earlier, and produced significantly greater above-ground biomass and ragweed pollen. Therefore, urbanization-induced temperature/carbon dioxide increases simulate conditions associated with expected global climatic change scenarios and confirm the experimentally demonstrated increase in ragweed allergenic potential. Additional studies of ragweed under earlier spring germination and higher carbon dioxide scenarios have indicated both timing and carbon dioxide interacted to increase pollen production. The earlier cohort of ragweed plants had a greater biomass, a higher average flower weight, a larger number of flowers, earlier flowering, and 54.8% greater pollen production [8]. The high carbon dioxide cohort had greater biomass, greater overall reproductive effort, and increased pollen production for the later cohorts. This and many additional studies predict an increased overall ragweed pollen production under predicted future climate warming.

It is not surprising that ragweed is the plant of choice when studying allergy and climate change in the USA. However, in much of the world, birch pollen is the most significant allergen in the air. In a study that examined the impact of urbanization on the proteome of birch pollen and its chemotactic activity on human granulocytes, researchers reported that extracts from pollen collected in urban areas had higher chemotactic activity on human neutrophils compared to pollen from rural sites [9]. An investigation into the temporal patterns in the start dates of Betula (birch) pollen seasons at selected sites for a 30-year period was conducted in Europe. Data from London, Brussels, Zurich, and Vienna show trends towards earlier start dates. Extrapolation produced an estimation that start dates at these sites will advance by about 6 days over 10 years [10]. Research into the onset and duration of several allergenic pollen types in the USA indicates that allergenic pollen seasons for spring-flowering birch, oak, and grass start from the south and then shift gradually to the north [11]. This would predict that as climate warming trends occur earlier in northern latitudes, as indicated by the shifting hardiness zone maps [12], start dates for the appearance of significant allergens would move earlier in the year. A review of changing allergenic pollen types, concentrations, and distributions in the USA that may be occurring as a result of increasing greenhouse gasses in the atmosphere and global climate change found increased levels of birch allergen at warmer temperatures [13]. They also found warmer temperatures resulted in earlier flowering for many spring-flowering species in many countries around the world. In many instances, an accompanying increase in season total pollen was documented.

Not only has it been demonstrated that total plant biomass and total pollen production will increase under a global warming scenario, but it has also been shown that greenhouse gasses and total pollutant exposure often produce pollen with altered allergenic profiles or increased allergenicity. In a study of high environmental ozone levels and birch pollen allergenicity, pollen collected from several areas was analyzed for allergen content. Both allergen content and immunostimulatory potential were evaluated. The study revealed that ozone exposure produced changes in both the chemotactic and the immune modulatory potential of the pollen. In addition, increased ozone exposure produced enhanced allergen content and skin prick test reactivity [14]. In a study of greenhouse grown rye grass under differing ozone concentrations, rye grass pollen was evaluated for allergen content by microscopy and immunoblotting methods. The results demonstrated an increased content for each of the allergen groups tested and clearly demonstrated that increased ozone levels during the growth phase of grasses result in a higher allergen content [15]. A European study examined tree pollen including birch when exposed to common atmospheric pollutants expected to increase under a global warming scenario. Low-level exposure of the pollen to carbon monoxide, ozone, and sulfur dioxide evaluated by immunodetection assays indicated higher IgE recognition by sera of allergic patients. This indicates that tree pollen exposed to higher levels of pollutants will produce enhanced allergic reactions in sensitized individuals [16]. However, experiments that exposed ragweed pollen to increased levels of ozone produced differences in expressed proteins, but seemed to have little impact on the total Amb a1 level or allergenicity when evaluated by polyclonal rabbit sera [17]. Studies with another very allergenic species, Arizona cypress, reported that expression of allergenic protein under polluted conditions produced an increase in pollen allergenicity demonstrated by skin tests and in vitro tests [18]. And similar increases in allergenic potential related to pollution exposure are reported for *Parietaria* ssp. [19]. These and many more reports indicate that under an expected global warming climate change scenario, and the expected increase in airborne pollutants, the potency of major airborne environmental allergens is likely to increase.

Under a global warming scenario, the geographic range of major allergenic pollen-producing species is expected to shift. The United States Department of Agriculture (USDA), Agricultural Research Service (ARS), has provided plant hardiness zone maps since 1960. Plant hardiness zone designations estimate the average annual extreme minimum temperatures at given locations during particular time periods. Each zone on the map represents a 10 °F band and in recent years an "A" and "B" designation to represent a 5° band within each zone. The zones are set using the average minimum temperature in a region (hardiness zones). The maps have evolved over 50 years as data has accumulated. But, it is very clear from an examination of Fig. 1 (maps from 1960 and 2012) that the zones have moved northward [20, 21]. These hardiness zone changes additionally suggest that allergy sufferers will be exposed to new pollens or to familiar pollens at times that vary from historical norms.

One of the best worldwide examples of allergenic plants moving into new territory is the story of ragweed in Europe. Short ragweed *Ambrosia artemisiifolia* was likely introduced into Europe on numerous occasions probably as a result of commercial activities [22, 23]. There are reports of *A. artemisiifolia* in Budapest as early as 1888 [24]. From current pollen maps, there appear to be two centers of ragweed in Europe. One area centered in Hungary extending north almost to the Baltic, and the other centered in northern Italy extending into southeast France [25]. The most abundant ragweed pollen count in Europe is usually found in Ukraine. It is expected, as Europe warms due to climate change, ragweed will spread north and northeast with populations eventually reaching northern France, Germany, the Czech Republic, Poland, the Baltic states, Belarus, and Russia [26]. Published estimates suggest that through expansion related to climate change ambrosia pollen allergy will become a common health problem throughout Europe, even in areas where it is not currently found [27••].

Another example of an allergenic plant changing its range with changing climate is in the *Cupressaceae* family. Although junipers in some areas of the southwest are experiencing dye off as a result of prolonged climate-related droughts [28], respiratory disease will likely be more impacted as juniper trees extend their ranges into the populated areas of the South and upper Midwest. In a study of savanna ecological areas in the USA, *Juniperus virginiana* was the only major tree that was not adversely impacted by a climate scenario of warming and intensified summer drought. Climate warming and altered precipitation are expected to accelerate juniper encroachment [29]. *Juniperus* is a very large allergenic genus whose major species are somewhat sensitive to both overly hot and overly cold temperature and weather ranges. It is thus restricted to fairly well-defined geographical regions. A study was conducted in Alto Tajo Natural Park (Central Spain) where from 1951 to 2007 the mean annual temperature increased at a rate of + 0.2 °C per decade. The researchers studied *Juniperus thurifera*, a major species in the area. They documented that growth was positively related to current April temperature, July rainfall, and September rainfall of the year prior to ring formation. There was greater early wood

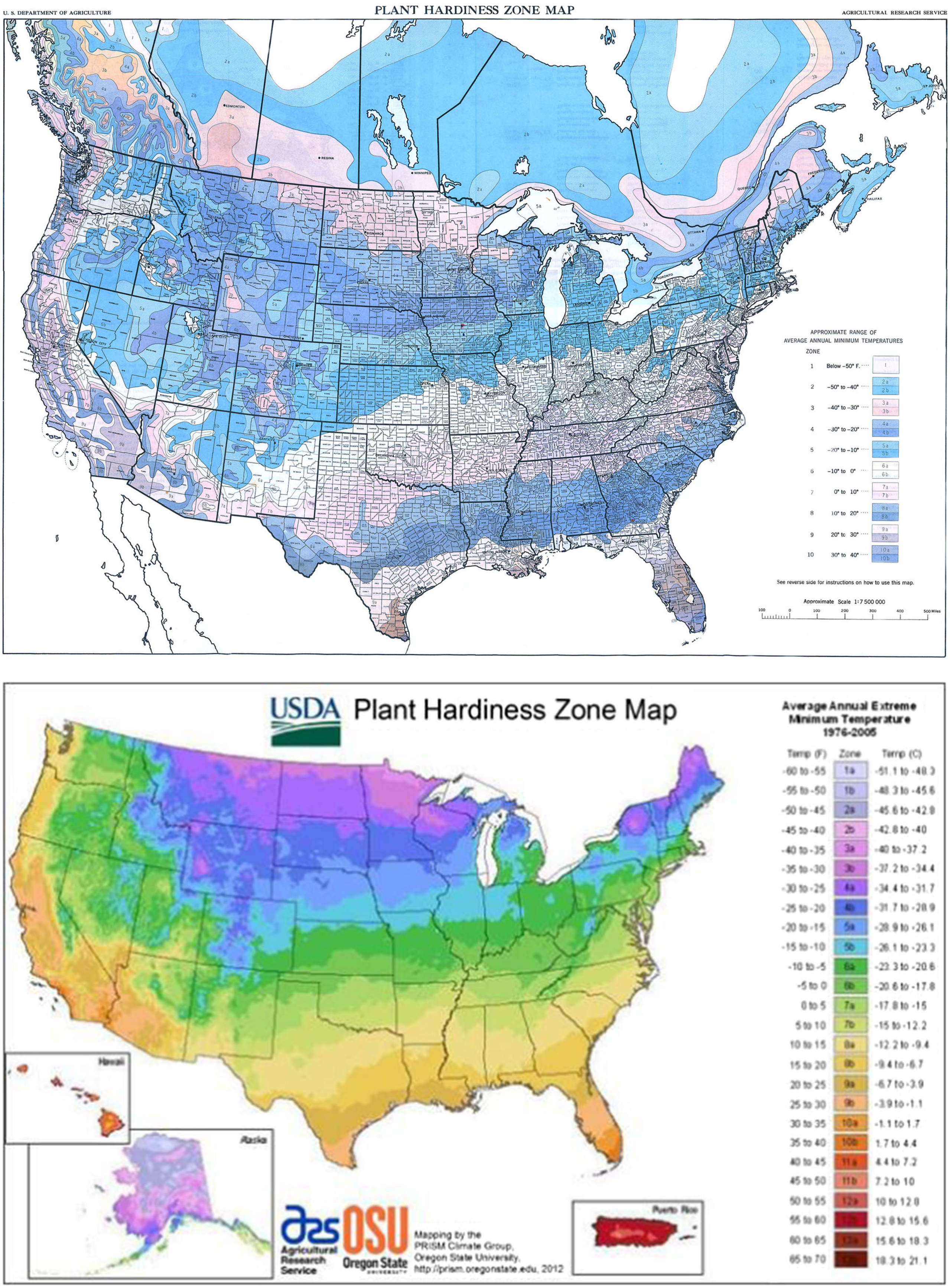


Fig. 1 USDA plant hardiness zones for 1960 (above) and 2018 (below)

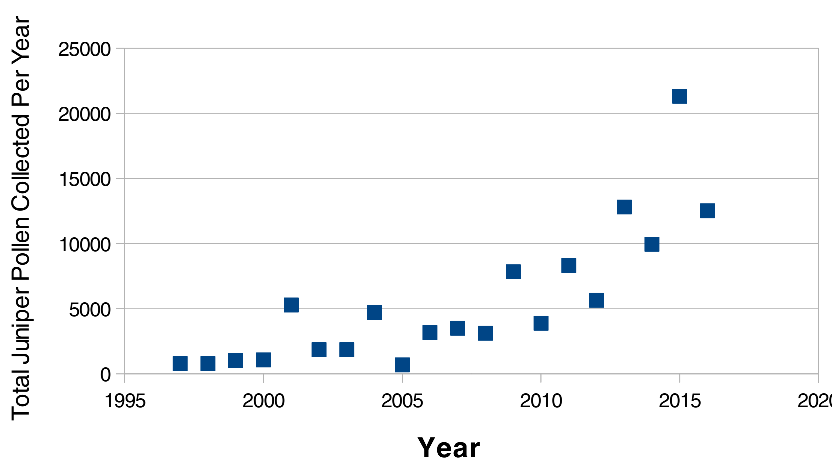
formation in response to warmer temperatures in late winter and early spring. Their climate-growth relationship studies demonstrated that *J. thurifera* growth was favored by warm spring (April) temperatures [30].

Kansas City, MO, is located in the central USA just north of large populations of juniper (*virginiana* and *ashei*) in the Ozark mountains of southern Missouri and northern Oklahoma. Over the past 20 years, there has been a noticeable increase in the population of juniper trees in the fields and along the sides of the roads. This increase is likely related to the decreased incidence of very cold temperatures and devastating ice storms. As in the findings of the Spanish researchers above, the increase is also likely to be related to the warmer spring temperatures and later cold temperatures in the fall. This increase is also reflected in the annual amount of juniper pollen collected by the local National Allergy Bureau station in Kansas City (Fig. 2). In the early 1990s, Juniper was not considered to be a major allergen in Kansas City. Currently, juniper is one of the major tree pollens seen in the spring, and if fall conditions are just right, juniper pollen appears in the fall air also. The Kansas City data mirrors reports of data from Tulsa, OK, there were significant increases from 1987 to 2016 in the seasonal pollen index and in peak concentrations of airborne juniper pollen [31••].

A warming climate will lead to shifts in the yearly pollination cycles of allergenic plants. Earlier warm weather in the spring and later first frosts in the fall can have a myriad of impacts on pollen exposure for sensitized individuals. If an allergenic plant starts to release pollen as soon as temperatures are warm enough in the spring and continues for a set period, the impact will be earlier exposure. For the type of plant that begins to pollinate on a given date every year and continues until the plant is killed by frost in the fall, the impact is likely to be increased pollen exposure over an extended period of time. The latter is the case for ragweed pollen in the USA. Work done by the USDA indicates that the duration of ragweed season in the USA increased over a 15-year period due to delayed first frost date especially in northern latitudes. USDA scientists compiled aerobiological data collected for 15 years from many stations around the USA. They concluded that from 1995 to 2009, the duration of ragweed season in North America increased in association with an increasing delay in the first frost of the fall season. This was more pronounced in northern areas. Some cities in Canada experienced three additional weeks of ragweed exposure [32].

In addition to longer exposure to ragweed, there is also evidence of an earlier start for the spring tree pollen season for many species including birch and oak [33]. In the USA, the National Phenology Network tracks key seasonal changes in plants and animals from year to year through their network of volunteers. When researchers analyzed this large-scale citizen science data, they found not only earlier but also more variable flowering in recent years giving further evidence supporting a changing climate [34]. These observations are supported by data from National Allergy Bureau pollen counting stations. In addition, several European studies indicate pollen cycles are advancing into the early spring. In Britain, a large analysis of 385 plant species found the average first flowering date advanced 4.5 days during the last decade of the twentieth century. This indicates a strong biological signal for climate warming [35]. Perhaps, fortunately for allergy sufferers, anemophylous species overall tended to be somewhat less effected than entomophilous-pollinated species. In a study of 27 years of pollen data from northwestern Italy, researchers reported there was a progressive increase in the duration of the pollen seasons for their major allergenic plants, parietaria, olive, and cypress. Also, the total pollen load for all studied species except grass increased over the time period [36]. Their results paralleled increases in sunlight, temperature, and days with temperature greater than 30 °C. Similar results were reported when aerobiological data collected in Poland from 1996 to 2011 was analyzed. They reported an increased duration of pollen seasons for analyzed taxa including Urticaceae, Rumex, and Artemisia. They attributed most changes to a delay in pollen season end dates [37]. These and many other reports indicate pollen seasons are either starting earlier, ending later, or both [38–41].

Fig. 2 Total juniper pollen collected at the NAB station in Kansas City over a 20-year period



Another element of change related to climate change is rising sea level. As sea level rises and rainfall patterns change, mold allergies are expected to increase [42]. About 56 million years ago, the earth was in the Paleocene-Eocene Thermal Maximum. Much of the Earth's natural carbon stores were released into the atmosphere and temperatures were on average nearly 5 °C warmer than today. Nearly all of the ice trapped in the polar ice caps was converted to liquid water. Sea level estimations at that time are about 250 m higher than they are today [43]. Under that scenario, most major world capital cities including Beijing, London, Rio de Janeiro, and Berlin would be under the ocean. In the USA alone, there continues to be population growth in low-lying coastal areas and along the ocean fronts. This increases the potential impact of a warming planet [44••]. There is a program on the internet that allows a person to run a simulation of what would be inundated for most areas in the world under varying warming scenarios [45]. Hours could be spent on the internet watching simulated projections of rising sea level. Under all of these scenarios, sea level rise would increase flooding frequency and expose up to 3.3 billion people around the world to damper conditions favorable for fungal growth.

Damp buildings are clearly associated with respiratory disease [46], and a rising sea level will expose a large percentage of the US population living in ocean front and riparian environments to wet housing conditions. Mold exposure studies in New Orleans after Hurricane Katrina demonstrated that the heat and wet debris produced by the storm provided excellent growth conditions for mold. A CDC investigation a few months after the hurricane recorded visible mold growth in 44% of impacted sampled homes with 19% of homes having heavy mold growth. Extrapolating, based on 2000 US census data, the CDC estimated that 282,000 homes in the greater New Orleans area experienced flooding; 308,000 homes had roof damage; and 194,000 homes had visible mold growth, with 70,000 homes having heavy mold growth [47]. However, two studies designed to discover any increased long-term fungal-related health consequences were unable to document significant increases.

Much work has been done evaluating species-specific responses in insects to changes in climate. Commonly used methods involve assessing distribution/range shifts or changes in abundance. Most work has been done on Lepidoptera, whereas Hymenoptera are of more concern for allergists. It will be difficult to predict future trends accurately, but many current trends are documented in the literature. The climate change most likely to impact the relationship of insects and allergy is temperature. Changes in temperature are likely to impact insect populations not only by allowing additional growth or expansion due to cold regions getting warmer [48] but also by causing extinction events due to warm regions becoming too hot to support the population. Although they are not directly related to allergy, it is not unusual that environmentally related disease from ticks and mosquitoes will be seen in an allergist office. Communicable diseases like Zika and dengue fever are moving north as warmer temperatures allow longer growing seasons for their vectors [49]. In May 2018, the U.S. Centers for Disease Control and Prevention reported the number of cases resulting from mosquito, tick, and flea bites nationally tripled over 13 years—from 27,388 cases in 2004 to 96,075 in 2016. And, the frequency of these environmentally related diseases is expected to increase even further.

Specifically of direct concern for allergists, increased warming in the Northern Hemisphere has resulted in Hymenoptera allergic exposures occurring in areas that were previously free of those exposures. For example, Fairbanks, AK, had its first ever reported Hymenoptera sting anaphylaxis death in 2006 [50]. A retrospective review of Alaska Medicaid records for the 8 years from 1999 through 2006 showed increases in claims for insect reactions in all regions, with the largest percentage increases occurring in the most northern areas [50].

Ozone is already a regulated pollutant in the USA. Most ozone concerns occur in cities and urban areas on hot, sunny days in the summertime. Under a global warming scenario, increasing temperatures and increased sunlight exposure are expected to increase air quality concerns related to ozone. Although ozone is very much needed in the upper atmosphere, it is not desirable to have in the human breathing zone. It is a potent oxidizer much stronger than regular oxygen. When exposed to ozone, people reported irritation of the mucous membranes and difficulty breathing [51]. As early as 1911 [52], it was understood that exposure to any appreciable (> 5 ppm) concentration of ozone caused edema of the lungs and death [53]. Ozone in the lower atmosphere is formed from the interaction of molecular oxygen and UV radiation (sunlight). Ozone participates in a complex equilibrium whose actors include volatile hydrocarbons, sunlight, high temperature, nitrogen oxides, atmospheric particulates, and other pollutants. Pollutants emitted by cars, trucks, buses, lawn mowers, back yard barbecues, power plants, industries, refineries, and chemical plants interact with ozone to produce poor-quality outdoor air. Since sunlight and temperature are in the mix, ozone concerns are most frequent on hot sunny days in the summertime [54].

The EPA regulates ozone in the lower atmosphere as part of Title 1 of the Clean Air Act Amendments of 1990. The current levels of ozone attainment were set in 2015 at 0.070 ppm as an 8-h averaged concentration. To help understand ozone exposure, the EPA publishes an air quality index. The index grades ozone exposure in six levels from Good to Very Unhealthy. Under Very Unhealthy levels, all people are advised to limit outdoor activities [55]. The EPA recommends to physicians that patients with heart or lung diseases, patients with diabetes, older adults, and children be educated concerning air quality. Allergists should encourage awareness of daily air quality (Airnow.gov has forecasts as well as links to the email notification and an app for smartphones). This education becomes more and more of a necessity each year. With future climate change and increasing urbanization, there will be rising ozone concentrations in the next decades [14].

Ozone does not only have a direct impact on human respiratory problems. But it also is implicated in the chemical alteration of airborne pollen allergens. The combined mixture of traffic-related air pollutants interacts with pollen to intensify respiratory allergy symptoms. For many years, it has been known that diesel exhaust particles have an adjuvant or aggravating effect on sensitization and ragweed allergic immune responses [56]. Also, air pollutants impact the pollen itself. Ozone exposure has been demonstrated to be an important factor in enhancing the allergenicity of birch pollen. Studies on birch pollen collected from the area of Munich, Germany, highlighted ozone as a prominent factor influencing allergenicity. Ozone also induced changes in lipid composition and in the chemotactic and immune modulatory potential of pollen. These authors speculated that with increasing temperatures and increasing ozone levels, symptoms of pollen allergic patients will increase [49].

A global warming future will have increased smoke exposure from increasingly prevalent wildfires. On August 13, 2018, the National Inter-agency Fire Center reported 110 fires burning in the USA—all in the western states. So far in 2018, there have been over 40,000 fires with nearly 6 million acres burned. This is fairly typical for recent years but is about 20% higher than the 20-year average. In 2006, an article in Science reported that warmer temperatures appeared to be causing an increase in duration and intensity in the wild fire season in the western USA. They reported a fourfold increase from 1986 to 2006 in major fires and a sixfold increase in the number of acres burned [57]. This increase was attributed to a number of factors including human-caused climate change [58•].

In the USA, the CDC distributes specific warnings about the exposure to smoke from wildfires [59]. They advise that wildfire smoke can hurt your eyes, irritate your respiratory system, and worsen chronic heart and lung diseases. Those who have diseases including heart disease, chest pain, lung disease, or asthma are at higher risk from wildfire smoke. Older adults are more likely to be affected due to their increased risk of heart and lung diseases. Children are more likely to be affected because their airways are still developing and they breathe more air per pound of body weight than adults. Information that can assist people in avoiding exposure to wildfire smoke can be found at Airnow.gov. A check of conditions on August 13, 2018, indicates much of the state of Washington and large areas of northern California are under red alert for unhealthy air quality.

Wildfire smoke contains many different hazardous air pollutants. Some of the general contents of wildfire smoke include particulate matter, carbon monoxide, carbon dioxide, nitrogen dioxide, ozone, polycyclic aromatic hydrocarbons, and volatile and semi-volatile organic compounds. Of course, additional toxic compounds will be produced when wildfire consumes manmade structures. Since no institutional review board would even consider allowing an experimenter to expose subjects to such a toxic mix, all of the studies of wildfire smoke and health impacts are retrospective. Health impacts and documented population health studies are reported in a recent review [60]. The critical review listed evidence from recent, adequately statistically powered studies establishing associations between wildfire smoke exposure and all-cause mortality. However, studies that specifically addressed respiratory mortality and asthma were not sufficiently powered to demonstrate associations [60]. Two epidemiological studies reported significant associations between wildfire smoke exposure and declines in lung function among non-asthmatic children. Four studies reported increases in physician visits for respiratory problems. Four studies reported increases in respiratory emergency department visits. And, eight studies reported an increase in respiratory-related hospitalizations associated with exposure to wildfire smoke. At least 17 studies reported evidence that wildfire smoke exposure contributed to exacerbations of asthma as evidenced by increased physician visits, increased emergency department visits, or increased hospitalizations, while only 4 studies reported insignificant increases [60].

In one of the longest duration studies of wildfire exposure, researchers in Australia studied the relationship of air pollution events from forest fires and emergency department visits for a 10-year period [61]. The authors defined a smoke event day whenever PM10 or PM 2.5 exceeded the 99th percentile level of the daily citywide average concentration for the entire study period. They adjusted for weather, influenza epidemics, and holidays. They compared emergency department visits on event days with non-event days for all non-trauma ED attendances and selected cardiorespiratory conditions. In the 46 smoke event days, non-trauma emergency visits increased (OR 1.03, CI 1.02–1.04), respiratory conditions increased (OR 1.07, CI 1.04–1.10), asthma related visits increased (OR 1.23, CI 1.15–1.30), and COPD-related visits increased (OR 1.12, CI 1.02–1.24). There were also increases for several related cardiac conditions. They concluded that smoke events were associated with an immediate increase in presentations for respiratory conditions and a lagged increase in attendances for ischemic heart disease and heart failure.

Wildfire in the news seems to be a western US problem, but it is actually a problem around the world. It has been estimated that worldwide 339,000 deaths annually may be attributable to landscape fire smoke [62]. These are attributed to respiratory and cardiovascular events, and these wildfire-related deaths will only increase as wildfire smoke exposures occur more frequently as the climate changes [63].

Climate change through global warming implies that at least certain areas of the world will see ever increasing temperature maximums over the next centuries. Since many areas of the world do not have a nearby temperature buffer like an ocean, we can expect increased occurrences of extreme high temperatures. These predicted events are being documented yearly. A brief literature search was able to find articles documenting 10 extreme temperature events associated with multiple deaths during the past 25 years in the USA alone. The worst US event so far as deaths seems to be the heat wave in Chicago in 1995 [64]. Worldwide, the Russian heat wave in the summer of 2010 is estimated to have caused around 55,000 heat-related deaths [65]. Under a global warming scenario, both the frequency and the intensity of heat waves are expected to increase. The twenty-first century is expected to see more intense, more frequent, and longer lasting heat waves [66]. Heat waves are associated with excess mortality and morbidity. Many scientists have studied exposure metrics designed to trigger heat wave and health warning systems related to potential dangerously hot days [67]. Epidemiological studies have shown that hot weather is associated with mortality, hospital admissions, heat stroke, heat exhaustion, and cardiovascular and respiratory diseases [68]. In 2003, a heat wave caused over 70,000 excess deaths in 12 European countries. It is expected that summer temperatures as high as those during 2003 will be the norm by 2150 [69]. Extensive analysis of the relationship of heat and respiratory disease indicated during heat extremes, the risk of premature death among respiratory patients is higher than in the rest of the population [68, 70]. Extreme heat events also impact the bread and butter of allergy, hay fever. By linking National Health Interview Survey (NHIS) data from 1997 to 2013 ($n = 505{,}386$ respondents), investigators established a link between hay fever and extreme heat events. They reported that with extreme heat, adults in the highest quartile of heat exposure had a 7% increased odds of hay fever compared with those in the lowest quartile of heat exposure (odds ratios, 1.07; 95% confidence interval, 1.02–1.11) [71•]. The expectation is that extreme heat events will likely increase in frequency, intensity, and duration under a global warming scenario. Since respiratory diseases from asthma to hay fever are related to extreme heat events, the current documented increase in respiratory disease is expected to continue for the foreseeable future.

Conclusion

In the future climate change and the associated heat, ozone, carbon dioxide, and pollution problems will result in an increase in respiratory disease. It is also expected to significantly worsen health inequities within and among countries. This will inevitably put additional stress on poorer groups. These same factors will also have more impact on the most vulnerable patient populations such as elderly, children, patients with chronic diseases, and those in distressed socioeconomic conditions [72•]. There are multiple and complex links between air quality, increasing temperature, increasing sea level, global climate change, and respiratory disease. It is not possible to predict all the impacts global climate change will have on respiratory disease. There will likely be consequences humans have never faced before. However, it is likely that changes related to increased growth of allergenic plants, increased pollen production, increased pollen potency, allergenic species in new climactic areas, shift in pollen seasons, increasing damp housing, increased ozone alert days, increased smoke exposure from wild fires, and increasing heat waves will all potentially increase respiratory disease. It can be assumed that humans will adapt to face these new challenges in ways that have not been conceived yet. The practicing allergist must adapt along with their patients to face these developing challenges. And, as much as possible, allergists should anticipate and prepare for expected changes. As the field of medical practice most associated with environmental exposure and respiratory disease, the practicing allergist should also be in the forefront of environmental advocacy. As a specialty that relies heavily in patient education, the practice of making patients aware of air quality issues could be a centerpiece of allergy practice. Finally, what can allergists do to help mitigate the impact of global climate change. The WHO has put together a course for healthcare professionals entitled "Protecting Our Health from Climate Change: WHO Training Course for Public Health Professionals." The course and materials are available on the internet [73•]. Becoming familiar with the course and perhaps even presenting to community groups would be a very positive step.

Compliance with Ethical Standards

Conflict of Interest The author declares no conflicts of interest relevant to this manuscript.

Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by any of the authors.

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experimental data amassed over many years and examines the relationship between allergic respiratory diseases, asthma and the environmental factors including meteorological variables, airborne allergens, and air pollution.

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