



## Attachment B

# Global Warming & The Rise of Asthma

## How Climate Change Could Increase Pollution and Aeroallergens to Threaten Your Lung Health

**October 2008**

### **Author**

Nicole Esclamado

*BREATHE California of Los Angeles County*

### **About BREATHE LA**

BREATHE California of Los Angeles County (BREATHE LA) is an independent, non-profit organization dedicated to promoting clean air and healthy lungs through research, education, and technology. We are part of BREATHE California, a statewide organization with affiliates in Monterey, Sacramento, San Francisco-San Mateo and Santa Clara-San Benito Counties. Together with its affiliate offices, BREATHE LA works to advance lung disease prevention and advocate for policies that serve and involve local communities.

## **Introduction**

“Warming of the climate system is unequivocal.” According to the most recent Working Group 1 Report from the Intergovernmental Panel on Climate Change (IPCC), climate change provides a scientifically sound explanation for the global changes we have observed over the past few decades – such as increasing surface temperatures, melting glaciers, retreating ice caps, and rising sea levels (IPCC, 2007). The Earth’s average surface temperature has increased  $1.33 \pm 0.32^{\circ}\text{F}$  over the last 100 years, and global warming is continuing to speed up, tripling the rate observed in 1976 (Shannon et al., 2007). These changes are over 90% likely due to increasing atmospheric concentrations of greenhouse gases produced by human activity (IPCC, 2007). Carbon dioxide ( $\text{CO}_2$ ), the greenhouse gas contributing most to global warming, comes primarily from fossil fuel burning and deforestation.  $\text{CO}_2$  has increased from pre-industrial concentrations of 280 ppm to 383 ppm in 2007, and projected  $\text{CO}_2$  levels range from 541 to 970 ppm by 2100 (Beggs 2004).

Changes in climate directly and indirectly impact the environment and public health. Consequences of global warming include heat waves, droughts, floods, extreme weather, altered transmission of infectious disease, and declining air quality (EPA, 2008). The IPCC states that ground-level ozone pollution will likely increase, threatening respiratory health and potentially leading to premature death in people with heart and lung disease.

Furthermore, a growing number of studies provide evidence that climate-induced changes in temperature, concentration of atmospheric CO<sub>2</sub> and pollen seasons will increase the production and allergenicity of airborne allergens, effectively compounding the threat of deteriorating air quality (D'Amato and Cecchi, 2008). While more studies need to confirm this link, there has been substantial evidence that correlates the global rise in asthma with climate-induced changes in air pollution and aeroallergens, such as ragweed (Knowlton et al., 2007).

The aim of this report is to (1) review recent studies on how climate change affects traffic-related pollutants and aeroallergens, (2) discuss the risk that climate change presents to respiratory diseases such as asthma, and (3) offer recommendations for how to cope with these environmental changes and help reduce their negative effects.

## Global Rise in Asthma

The American Academy of Allergy, Asthma & Immunology (AAAAI) estimates that 36 million Americans suffer from seasonal allergy and 20 to 30% of the population suffers from seasonal *allergic rhinitis* ("hay fever") (Knowlton et al., 2007). As they induce inflammation and irritation of the nose, sinuses, throat, eyes, and ears, allergies significantly affect an individual's quality of life and a society's productivity. Seasonal ragweed pollen allergies are estimated to be responsible for 3.8 million days per year missed at schools and businesses.

Allergies are among a host of factors that can trigger an asthma attack. Asthma is a chronic and potentially life-threatening lung disease characterized by difficulty breathing (ALA, 2008). Worldwide asthma rates doubled between 1988 and 2003 and self-reported cases in the U.S. rose by 75% between 1980 and 1994. (Bunyavanich et al., 2003 and Knowlton et al., 2007). In addition to an increase in prevalence, there has also been an increase in the severity of asthma. Between 1986 and 1993, the number of hospitalized children in California who experienced a negative outcome, such as intubation or cardiopulmonary arrest, doubled. (Pandya, 2002).

**Climate change** refers to any significant change in measures of climate (such as temperature, precipitation, or wind) lasting for an extended period (decades or longer). Climate change may result from:

- natural factors, such as changes in the sun's intensity or slow changes in the Earth's orbit around the sun;
- natural processes within the climate system (e.g. changes in ocean circulation);
- human activities that change the atmosphere's composition (e.g. through burning fossil fuels) and the land surface (e.g. deforestation, reforestation, urbanization, desertification, etc.)

**Global warming** is an average increase in the temperature of the atmosphere near the Earth's surface and in the troposphere, which can contribute to changes in global climate patterns. Global warming can occur from a variety of causes, both natural and human induced. In common usage, "global warming" often refers to the warming that can occur as a result of increased emissions of greenhouse gases from human activities.

- *Environmental Protection Agency*

## Environmental Triggers of Asthma

**Asthma** is a chronic inflammation of the airways with reversible episodes of obstruction, caused by an increased reaction of the airways to various stimuli. Asthma breathing problems usually happen in "episodes" or attacks but the inflammation underlying asthma is continuous.

- *American Lung Association*

Such a rapid increase in the prevalence of asthma and severity of asthma attacks most likely precludes a genetic explanation (Beggs and Bambrick, 2005 and Pandya et al., 2002). Instead, a growing number of studies have indicated that the synergy of environmental triggers, such as traffic-related pollutants and aeroallergens, is responsible for the rise of asthma.

### *Aeroallergens*

Pollen is a potent environmental trigger for allergies and can have a severe impact on the respiratory health of people with asthma (Knowlton et al., 2007). Pollen grains are male reproductive structures of plants that measure over 10  $\mu\text{m}$  in diameter. These are the primary carriers of pollen allergens and explain the typical symptoms of hay fever, such as irritation of the eyes, nose and nasopharynx (D'Amato, 2005). While they are too small to see, these grains cannot enter lower airways due to their size. However, recent studies have revealed pollen allergens in microaerosol suspensions that are much smaller than pollen grains, allowing entry into peripheral airways. These findings may explain why peak asthma symptoms do not coincide with peak pollen counts. The microaerosol suspensions likely remain in the atmosphere before and after the "pollen season," extending the time of allergic symptoms (D'Amato, 2005).

A common allergenic plant used in climate change studies is ragweed, as it produces copious amounts of pollen, is the main cause of seasonal allergies according to the American College of Asthma, Allergy and Immunology (ACAAI), and has exhibited resistance to ozone. Furthermore, ragweed's pollen season in North America occurs between mid-August to October, coinciding with high ozone days. (Knowlton et al., 2007).

Other allergens include mold spores, house dust mites, and cockroach allergens (Beggs, 2004). These are common indoor triggers for asthma and allergies. During the proliferation of some mold types, toxic spores called mycotoxins are released that can weaken the immune system and cause an allergic reaction.

### *Ozone*

Ground-level ozone is considered to be a criteria pollutant by the Environmental Protection Agency (EPA) and World Health Organization (WHO), and presents a significant threat to respiratory health. Several studies show that asthma attacks, hospital admissions for asthma, and respiratory morbidity increase after days of high ambient ozone concentrations (Bayram et al., 2001 and D'Amato et al., 2005).

While 40 to 60% of inhaled ozone is filtered in nasal airways, the rest can access lower airways and affect the upper and lower respiratory tract. Breathing ozone causes bronchial epithelial cells

to release molecules that signal inflammation, such as interleukins 6 and 8, granulocyte macrophage colony-stimulating factor (GM-CSF), and fibronectin (D'Amato et al., 2005 and Devlin et al., 1991). This inflammation can cause chest pain and potentially scarring of lung tissue after repeated exposure.

### *How does ozone interact with allergens and affect asthma?*

Epidemiological, clinical, and laboratory studies have all indicated that pollutants and aeroallergens have a synergistic effect on asthma (D'Amato et al., 2005 and Pandya et al., 2002). For instance, people residing in areas with heavy traffic exhibited more severe symptoms to Japanese cedar pollen than people in rural areas, with lower levels of pollution and comparable levels of pollen. A clinical study found that a one-hour exposure to 0.12 ppm ozone was enough to induce a two-fold reduction in threshold concentration of allergen necessary to provoke bronchoconstriction in asthmatic subjects (Molfinio et al., 1991). Molecular studies have shown that ozone has a “priming” effect that enhances allergic reactions. Ozone stress increases intracellular reactive oxygen species to levels that can damage cell structures, facilitate deeper entry of allergens and toxins into airways, and further increase production of inflammatory molecules (D'Amato et al., 2005). These studies provide abundant evidence indicating that pollutants increase susceptibility to asthma attacks (D'Amato et al., 2005). Since ozone inflammation can last for several days, susceptibility to asthma attacks remains long after exposure.

## **Effect of Climate Change on Environmental Triggers of Asthma**

### *Effect of Climate Change on Ozone*

Ozone is composed of three oxygen atoms and forms by a photochemical reaction involving ultraviolet radiation on atmospheric nitrogen oxides (NO<sub>x</sub>) and volatile organic compounds (VOCs), which are largely derived from industrial and vehicular emissions (D'Amato et al., 2005). Ground level ozone is often referred to as “summer smog” because sunlight and hot temperatures cause it to accumulate in the air at harmful concentrations, especially in cities that enjoy a sunny Mediterranean climate, such as Southern California (D'Amato et al., 2005).

As many studies have found ground-level ozone generation to increase with temperature, global warming is expected to significantly change ozone chemistry (Denman et al., 2007). The IPCC predicts the global average temperature to rise 0.3 to 0.4 °F per decade for the next 20 years, for a range of scenarios of greenhouse gas emissions (Committee on the Environment and Natural Resources, 2008). This rise is predicted to be even greater for the U.S., as nearly all the models reviewed by the IPCC project that the temperature increase will exceed 3.6 °F by the end of the century. Furthermore, five out of 21 models project that average warming will even exceed 7.2 °F in the next 100 years. Due to its positive correlation with temperature, the IPCC expects regional and urban-scale ozone pollution to increase worldwide. By the 2050s, studies have projected that climate change could increase the number of summer days that exceed the 8-hour EPA standard by 68% in 50 U.S. cities (Bell et al., 2007).

Other climate-related factors responsible for an increase in ozone pollution include:

- temperature-dependent VOC emissions from soil and vegetation;
- NO<sub>x</sub> emissions from lightning and the thermal decomposition of peroxyacetylnitrate (PAN);
- changes in circulation patterns.

Soil and vegetation make up a significant source of VOC emissions that is positively correlated to temperature and, therefore, likely to release more of this pollutant due to global warming. According to the IPCC, such biogenic emissions are projected to increase 27 to 59% by 2090-2100 relative to 1990-2000, contributing to a 30 to 50% increase in ozone formation over northern continental regions (Meehl et al., 2007; Denman et al., 2007; Committee on the Environment and Natural Resources, 2008).

Global warming is expected to increase the global frequencies of lightning, a main source of nitrogen oxides (NO<sub>x</sub>) (Committee on the Environment and Natural Resources, 2008 and Price, 1993). In addition, high temperatures due to climate change can break down peroxyacetylnitrate (PAN) – a reservoir for NO<sub>x</sub> – causing it to release this important ozone precursor (Stevenson et al., 2005).

Scientists also expect climate change to alter current atmospheric circulation patterns. Global warming could result in the descent of ozone from the stratosphere, where it protects the Earth from excessive UV radiation, to the troposphere, where it becomes a ground-level pollutant (Committee on the Environment and Natural Resources, 2008).

---

Picture this: twenty years in the future, the "dog days" of August and September bring still, cloudless days that increase peak ozone concentrations. At the same time, years of heightened CO<sub>2</sub> emissions and blazing temp have created perfect conditions for ragweed pollen production. Particularly in and around cities, where the urban heat island effect boosts temp and ragweed thrives in disturbed soils of vacant lots and building sites, people who suffer from allergies and asthma will get sick with a host of debilitating symptoms. Thanks to the potential for weeds, grasses, and trees, to increase their pollen production; worsening air quality on hot days; increased asthma attacks from smog in the air and a prolonged allergy season, our health will likely suffer in a warmer world.

- Knowlton et al., 2007

---

### *Effect of Climate Change on Aeroallergens*

Environmental changes induced by global warming, such as longer spring seasons, increased temperatures and CO<sub>2</sub> concentrations, more severe thunderstorms, and deteriorating air quality, are expected to increase the potency and bioavailability of aeroallergens.

## Pollen season

Among the climate changes that have been observed is the lengthening of the spring season. According to global satellite data over the past 19 years, spring has been arriving 10 to 14 days earlier in temperate latitudes (Committee on the Environment and Natural Resources, 2007). Data from the International Phenological Gardens show that autumn events have been delayed 4.8 days since the early 1960s (Beggs and Bambrick, 2005). These observations have been confirmed by studies on allergenic plants, including birch, mugwort, urticaceae, grass, and Japanese cedar (Figure 1). The rate of these changes “provides some of the best evidence of the current impacts of recent climate change” (Gilmour et al., 2006). While this shift in pollen seasons may seem benign compared to an increase in severity of Atlantic hurricanes or an outbreak of malaria, it presents a very serious threat to respiratory health.

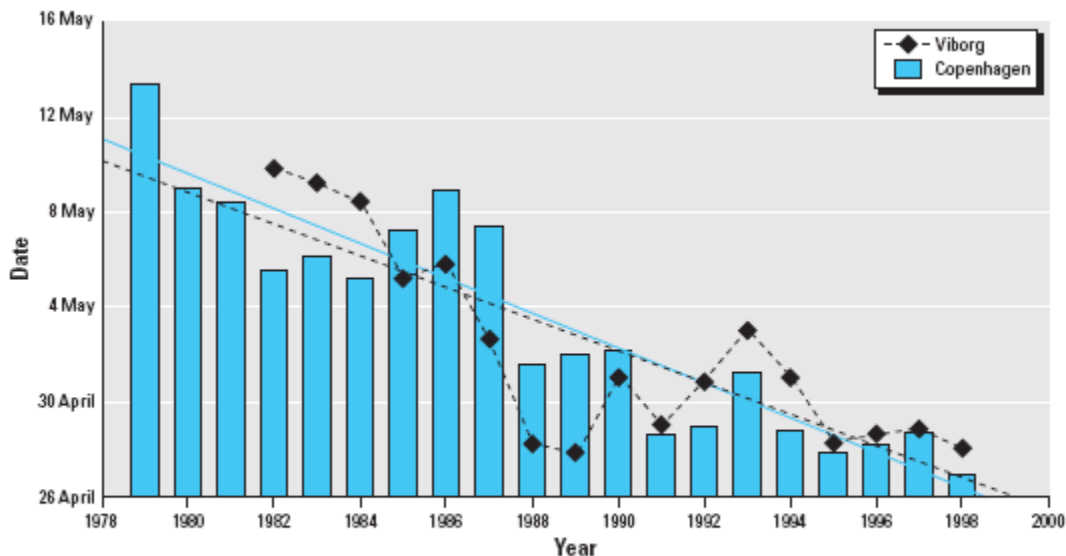


Figure 1. Peak date of airborne birch (*Betula*) pollen concentrations in Denmark, 1978-1999. (Gilmour et al., 2006).

## Pollen production

Many studies have shown that rising temperatures and ambient CO<sub>2</sub> concentrations induce allergenic plants to release more pollen (Beggs, 2004). One particular study observed ragweed plants grown at CO<sub>2</sub> concentrations of 280 ppm, 370 ppm, and 600 ppm, which reflect pre-industrial, current, and projected levels for the mid-late 21<sup>st</sup> century. Results showed that ragweed plants produced 131% and 320% more pollen in current and projected conditions, than did plants grown at pre-industrial levels (Ziska and Caulfield, 1998 and Knowlton et al., 2007).

Field studies have also supported these laboratory findings, providing further evidence that global warming will exacerbate pollen production. A study performed at an urban site in Japan between 1983 and 1998 revealed a positive correlation between total pollen count and temperature (Beggs, 2004). Another U.S.-based field study compared ragweed plants in urban and rural areas, finding that the plants in cities – where the temperatures were warmer and CO<sub>2</sub> levels were about 30-31% higher – grew “faster, flowered earlier, and produced significant more aboveground biomass and pollen” than their rural counterparts. Similar findings have been

obtained with other allergenic plants, showing that birch, oak, and pine also produce pollen earlier, for longer, and in greater amounts in the presence of higher CO<sub>2</sub> levels and at higher temperatures (Knowlton et al., 2007).

According to the IPCC, global warming will likely increase the severity of extreme weather events (i.e. floods, droughts, heat waves, thunderstorms), which all can impact the amount of aeroallergens in the air. According to recent studies, it has been posited that thunderstorms can cause osmotic shock in pollen grains, resulting in their rupture and release of large amounts of respirable allergens into the air. These allergenic particles are small enough to penetrate the lower airways and induce bronchoconstriction (D'Amato, 2008). After a thunderstorm in Birmingham, 26 subjects in 36 hours were hospitalized for asthma, compared to 2-3 subjects around the same time the previous year (Packe and Ayres, 1985). The largest episode occurred in London, June 24-25, 1994, when 100 patients went to the ER after a thunderstorm, many of whom had never experienced asthma before (Murray et al., 1994). All of these subjects were outdoors upon the arrival of the storm. Pollutants (i.e. PM or ozone) were found to be at average concentration levels, however, grass pollen was significantly higher. In addition, subjects with pollen allergies who remained indoors did not exhibit the same symptoms or reaction as those outdoors. However, subjects with allergic rhinitis who had *not* experienced asthma previous to the storm, suffered severe asthma attacks (D'Amato et al., 2002). As such, the increase in thunderstorms due to climate change, pose a serious risk to subjects with allergies who are not under appropriate asthma treatment.

In addition to allergenic plants, mycotoxin-producing fungi may exacerbate allergies due to rising CO<sub>2</sub> levels, warmer temperatures, and extreme weather. Field studies show that some fungi have enhanced growth and sporulation due to increased CO<sub>2</sub> levels (D'Amato, 2002). According to the EPA, climate change will alter precipitation regimes, leading to drought in some regions and flooding in others. Drought can weaken seed kernels of plants, which increases the chance of a fungal contamination. On the other hand, the high moisture levels associated with heavier downpours and flooding can also foster fungal growth and “exposure to fungal spores is unequivocally associated with exacerbations of allergy and asthma” (Bunyanavich, 2003 and Gilmour et al., 2006).

### *Who is at risk?*

Climate change is widely accepted as a global issue, but its impact on public health will be disproportionate across regions and demographics. While asthma rates have risen globally, the sharpest increases in prevalence and severity have occurred in children (Knowlton et al., 2007). Between 1980 and 1994, there was a 160% increase in pediatric cases of asthma in children under 4 years and a 74% increase in ages above 4 years (Pandya, 2002).

“Some researchers have voiced concerns about children’s health being threatened by global warming and have proposed that the observed rise in asthma cases could be an early impact of climate change.”

- Knowlton et al., 2007

Urban areas will be, and likely already are, facing the greatest threats to respiratory health associated with global warming such as rising temperatures, declining air quality and increasing pollen levels and duration. First of all, temperatures are generally higher in urban regions than

rural areas with similar meteorological and climatic factors. One reason for this “urban heat-island effect” is that pavement materials capture and re-radiate heat at a slower rate than vegetation (Pandya, 2002). The IPCC determined that an increase in regional air stagnation due to climate change and the urban heat island effect could cause major cities to suffer the greatest increases in ozone pollution (Denman et al., 2007). Furthermore, industrial and vehicular emissions from urban areas create “CO<sub>2</sub> domes” in which ragweed has been shown to thrive and, consequently, threaten local respiratory health (Knowlton et al., 2007).

The NRDC mapped areas in the U.S. where ragweed and unhealthy ozone pollution overlap (Knowlton et al., 2007). Their findings show that 110 million Americans reside in areas with both high ozone and high ragweed levels – one of the most vulnerable regions being the Los Angeles basin. The implications on respiratory health may be reflected in the fact that 13 of the top 15 asthma capitals 2007 are in counties where both of these problems occur.

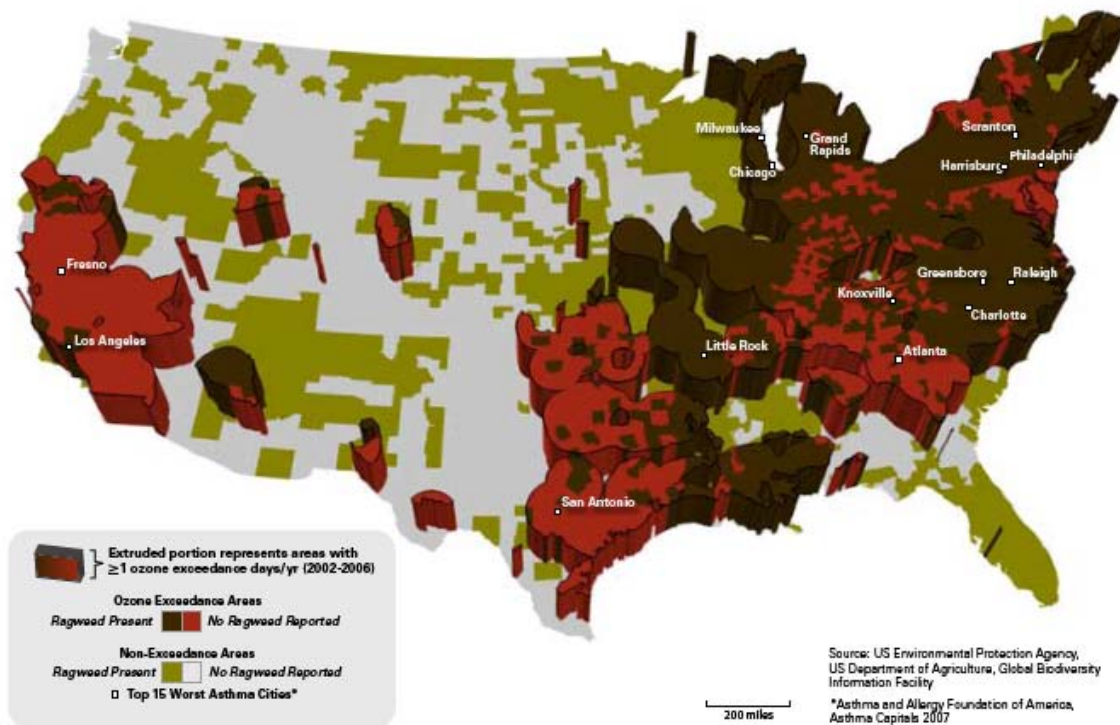


Figure 2. Map of regions where ragweed and high ozone levels overlap. The red areas indicate 8-hour Ozone Exceedance-Positive Areas. The light green areas are ragweed-positive. The dark green areas show where both problems are present (Source: US Environmental Protection Agency cited in Knowlton, 2007)

## Conclusion

While the impact of global warming on asthma requires further research, studies do indicate that several climate-induced changes can significantly exacerbate the environmental triggers for asthma and, consequently, are likely responsible for the observed increases in the prevalence and severity of this respiratory disease. Residents of urban areas, children with developing lungs, the elderly, and asthmatics will likely suffer the most from rising ozone and pollen levels.

## Recommendations

### *Research*

While the effect of temperature and CO<sub>2</sub> levels on main allergenic plants (*Ambrosia*, *Betula*, *Cryptomeria*, *Juniperus*, *Quercus*, *Carya*, etc) has been investigated, other plant species affected by climate change should be identified and examined. In these future investigations, local warming (i.e. “urban heat island effect”) should be clearly characterized in order to separate its effects from global climate change. In addition to plants, indoor toxins should also be studied where climate models will differ than those for outdoor allergens (Beggs et al., 2004).

Due to the complexity of respiratory disease and mechanisms, many studies need to examine the combination of multiple environmental triggers of allergies and asthma and their relationship with genetic susceptibility, dietary factors, daily activity patterns and ecological variables such as water and nutrient availability (Gilmour et al., 2006).

### *Policy*

Up to an average of 16 days per year, ozone levels exceed the 8-hour ozone standards set by the EPA to protect public health. The regions with the highest average ozone levels occur in Southern California (Figure 3). Over 150 million people currently live in areas in harmful ozone conditions and that number will likely increase due to global warming (Knowlton et al., 2007).

In order to help “create better air quality conditions today and a cooler, healthier environment for the future,” governments must take action (Knowlton et al., 2007). Policy makers must develop aggressive policies to mediate global warming, invest in public health care systems, support education and public awareness of the threats from climate change, and fund interdisciplinary research to develop strategies to cope with climate change (“Committee on Environmental Health”, 2008). Regarding ozone and pollen pollution specifically, the NRDC lists the following recommendations (Knowlton et al., 2007):

- The U.S. EPA should require states to reduce pollution and lower the allowable standard for ozone in order to protect public health.
- The U.S. EPA should establish ozone monitoring stations in different areas of the country to study local conditions that lead to smog formation.
- Government agencies should create pollen collection sites and networks to share the findings with health practitioners and researchers.

- The U.S. Department of Agriculture, National Institutes of Health , and National Science Foundation should establish a standardized system for reporting and tracking or allergenic plant species.
- The Center for Disease Control should create a national initiative to assist state and county health agencies prepare for global warming.

Furthermore, as fossil fuel burning is the main culprit of global warming, policies should promote development of and access to renewable energy sources.

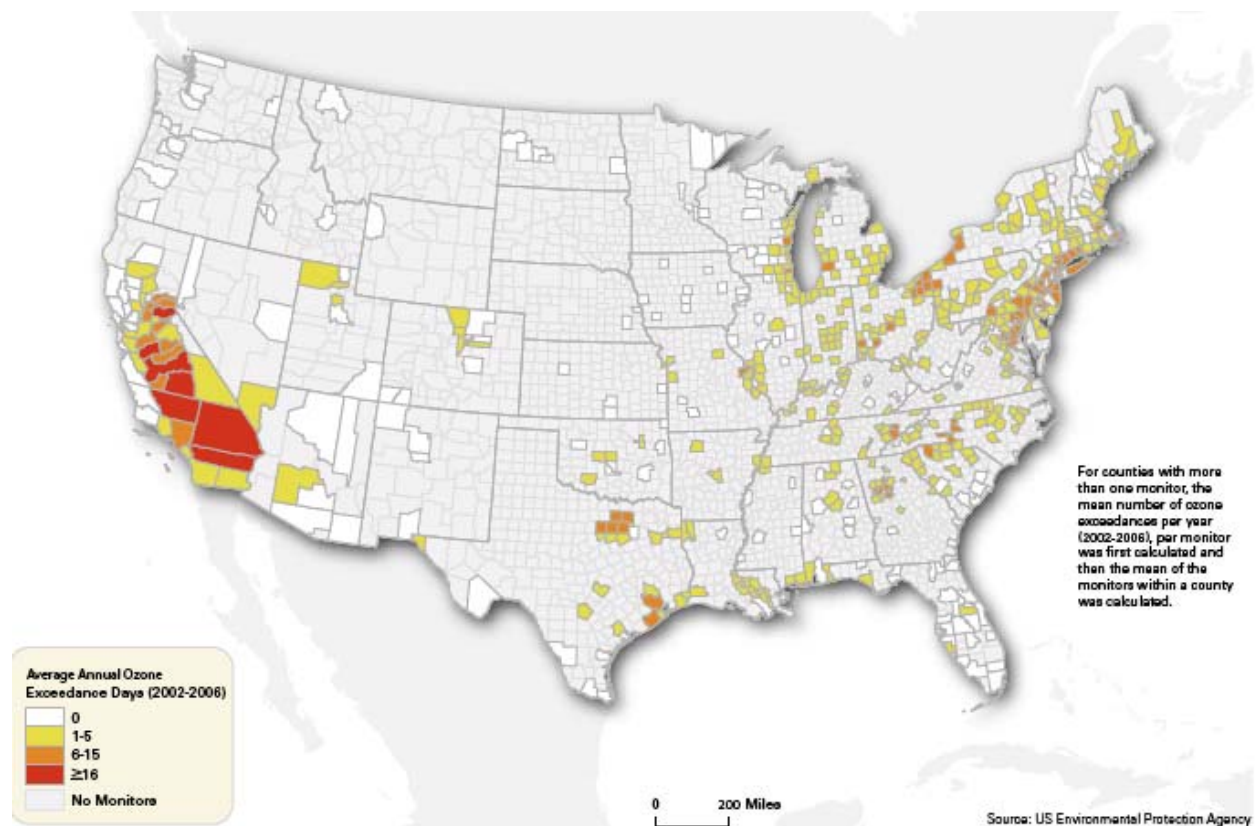


Figure 3. Map of the U.S. showing the average annual ozone exceedance days between 2002 and 2006 (Source: US Environmental Protection Agency cited in Knowlton, 2007)

### *Physician Care*

Physicians must understand the health risks of climate change, as well as help educate their patients and get involved in the community. The Committee on Environmental Health provide the following recommendations to physicians:

- Encourage patients to take alternate transportation.
- Advocate for policies that address climate change.
- Educate elected officials on the impact of climate change on public health.

- Spread the word by writing letters to the editor, attend public meetings, and provide expert testimony.
- Develop networks of support and change by working with local schools, child care centers, and other community organizations.
- Work with local and state health departments to promote public health and strengthen infrastructure of our system.
- Promote health concepts related to climate change as part of physician training.

The EPA's website provides information on how to counsel patients regarding ozone, asthma, and respiratory symptoms at [www.epa.gov/03healthtraining/](http://www.epa.gov/03healthtraining/).

### *Individual Health*

You can help reduce the negative health impacts of pollen and ozone pollution by following the tips on the right given by the NRDC.

- Listen to the radio, watch TV, or visit online news outlets for daily pollen reports and air quality conditions ([www.airnow.gov](http://www.airnow.gov))
- Bathe or shower after being outdoors in order to remove pollen from skin and hair.
- Wash bedding frequently to remove pollen from pillows and sheets
- Vacuum regularly, preferably with a high-efficiency particulate (HEPA) filter
- Minimize family's exposure to other known allergens (e.g. mold from damp surfaces) to avoid the cumulative effect of multiple asthma triggers.
- Avoid heavy exercise outdoors during days with high ozone levels. Keep windows closed.
- Try to exercise in the mornings when ozone levels are low.

In addition, help fight global warming by reducing pollution from private traffic in cities and taking alternate means of transportation (walk, bike, train, etc). Transportation is the second largest source of greenhouse gas emissions in the U.S. (EPA, 2008).

### **References**

American Lung Association. Asthma & Children Fact Sheet. December 2007. Available at: <http://www.lungusa.org/> Accessed: Oct 10, 2008.

Bayram H, RJ Sapsford, MM Abdelaziz, OA Khair. Effect of ozone and nitrogen dioxide on the release of proinflammatory mediators from bronchial epithelial cells on nonatopic nonasthmatic subjects and atopic asthmatic patients in vitro. *Journal of Allergy and Clinical Immunology* 107:287-294 (2001).

Beggs PJ and HJ Bambrick. Is the global rise of asthma an early impact of anthropogenic climate change? *Environmental Health Perspective* 113:915-919 (2005).

Beggs PJ. Impacts of climate change on aeroallergens: past and future. *Clinical and Experimental Allergy* 34: 1507-1513.

Bunyavanich S, CP Landrigan, AJ McMichael, PR Epstein. The impact of climate change on child health. *Ambulatory Pediatrics*. 3:44-52 (2003).

Committee on the Environment and Natural Resources, National Science and Technology Council. Scientific Assessment of the effects of climate change on the United States. May 2008.

D'Amato G, G Liccardi, M D'Amato, and M Cazzola. Outdoor air pollution, climatic changes, and allergic bronchial asthma. *European Respiratory Journal* 20: 763-776 (2002).

D'Amato G., G Liccardi, M D'Amato, and S Holgate. Environmental risk factors and allergic bronchial asthma. *Clinical and Experimental Allergy* 35:1113-1124 (2005).

D'Amato G and L. Cecchi. Effects of climate change on environmental factors in respiratory allergic diseases. *Clinical and Experimental Allergy* 38: 1264-1274 (2008)

Denman, K.L., G. Brasseur, A. Chidthaisong, P. Ciais, P.M. Cox, R.E. Dickinson, D. Hauglustaine, C. Heinze, E. Holland, D. Jacob, U. Lohmann, S. Ramachandran, P.L. da Silva Dias, S.C. Wofsy, and X. Zhang, 2007: Couplings between changes in the climate system and biogeochemistry. In: *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor, and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, pp. 499-588.

Devlin RB, WF McDonnell, R Mann. Exposure of humans to ambient levels of ozone for 6.6 hours causes cellular and biochemical changes in the lung. *American Journal of Respiratory Cell and Molecular Biology* 4:72-1 (1991).

Environmental Protection Agency (EPA). Climate change – health and environmental effects. Available at <http://www.epa.gov/climatechange/effects/health.html>. Accessed July 28, 2008.

Gilmour MI, MS Jaakkola, SJ London, AE Nel, and CA Rogers. How Exposure to Environmental Tobacco Smoke, Outdoor Air Pollutants, and Increased Pollen Burdens Influences the Incidence of Asthma. *Environmental Health Perspectives*. 114:627-633 (2006).

Intergovernmental Panel on Climate Change (IPCC). Climate change 2007: A Synthesis Report. Available at: [http://www.ipcc.ch/pdf/assessment-report/ar4/syr/ar4\\_syr.pdf](http://www.ipcc.ch/pdf/assessment-report/ar4/syr/ar4_syr.pdf) . Accessed Sept 25, 2008.

Knowlton et al. K, M Rotkin-Ellman, and G Solomon. How global warming could increase ragweed allergies, air pollution, and asthma. Natural Resources Defense Council. Oct 2007.

Molfino NA, Wright SC, Katz I et al. Effect of low concentrations of ozone on inhaled allergen responses in asthmatic subjects. *Lancet* 338:199-302 (1991).

Murray V, K Venables, T Laing-Morton, M Partridge, D Wiliams. Epidemic of asthma possibly related to thunderstorms. *European Respiratory Journal* 8:500s (1995).

Packe GE and Ayres JG. Asthma outbreak during a thunderstorm. *Lancet* 199-204 (1985).

Pandya RJ, G Solomon, A Kinner, and JR Balme. Diesel exhaust and asthma: hypotheses and molecular mechanisms of action. *Environmental Health Perspectives* 110:103-112 (2002).

Price CG. Global lightning activity and climate change. Thesis (PH.D.) Columbia University. Source: Dissertation Abstracts International, Volume: 54-07, Section: B, page: 3671 (1993).

Shannon MW, D Best, HJ Binns, JA Forman, CL Johnson, CJ Karr, JJ Kim, LJ Mazur, and JR Roberts. Global climate change and children's health. *Pediatrics*.120:1149-1152 (2007).

Ziska LH and EA Caulfield. Rising CO<sub>2</sub> and pollen production of common ragweed (*Ambrosia anemissifolia*) a known allergy-inducing species: implications for public health. *Australian Journal of Plant Physiology* 27: 893-898 (2000).