# 1

# Introduction

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## 1.1 Introduction

Climate change is *the* issue of our time. It is global, international, and pervasive. Of all the impacts of climate change, those on human health are perhaps the most significant. Indeed, the prestigious medical journal *The Lancet* recently stated that ‘Climate change is the biggest global health threat of the 21st century’ (Costello *et al*., 2009).

The impacts of climate change on human health are many and varied. Beyond what are thought of as the direct impacts on human health, such as the direct effects of temperature extremes and severe weather, are a multitude of indirect impacts of climate change on human health, or what Butler (2014) has recently described as secondary (and tertiary) effects. The UN Intergovernmental Panel on Climate Change (IPCC) has most recently described these indirect or secondary impacts on human health as ‘ecosystem-mediated impacts’ (Smith *et al*., 2014). The impacts of climate change on allergic diseases fall clearly within this realm.

Allergic diseases, such as asthma and allergic rhinitis, are of global importance for a number of reasons. It is estimated that 235 million people currently suffer from asthma, this being the most common non-communicable disease among children (World Health Organization, 2015). The prevalence of allergic diseases has increased dramatically over recent decades and continues to increase (Pearce *et al*., 2007). And allergic disease markedly affects the quality of life of both individuals with this disease and their families and negatively impacts the socioeconomic welfare of society (Pawankar *et al*., 2011).

Our environment contains allergens from many sources. These include pollen from trees, weeds and grasses, mould spores, house dust mites, cockroaches, and others. Climate plays a major role in the lives of allergenic organisms, as well as their production of allergens and our eventual exposure to such allergens. Climate influences the distribution and abundance of all allergenic organisms. Similarly, the variations in temperature, precipitation, humidity, and other factors that characterise the seasons control the activities of allergenic organisms, including their production of allergens. The so-called pollen season is perhaps the best known example of this. Climate extremes are also important, with the rampant growth of mould indoors following flooding of buildings, such as that in New Orleans following Hurricane Katrina, and the phenomenon of 'thunderstorm asthma' being just two examples of this. It is therefore to be expected that climate change would result in changes to allergenic organisms, exposure to their allergens, and allergic diseases.

The impacts of climate change on allergens and allergic diseases have progressively received increasing attention over the last 25 years or so, both as a topic and as an issue. In particular, the impacts of climate change on aeroallergens and allergic respiratory diseases were highlighted as one of only seven key health effects that supported the US Environmental Protection Agency's (EPA) finding that current and future concentrations of greenhouse gases endangered public health, in 'Endangerment and Cause or Contribute Findings for Greenhouse Gases under the Clean Air Act' (US EPA, 2009, 2016). Such impacts were the focus of one of just eight chapters on climate change health effects in the recent *Health Effects of Climate Change in the UK 2012* report (Kennedy and Smith, 2012). Perhaps most recently, the topic has again received prominent attention, being the focus of a chapter in the book titled *Climate Change and Global Health* (Beggs, 2014).

There has been much outstanding research on this topic – most prominent among this were the study by Ziska *et al*. (2011) published in the *Proceedings of the National Academy of Sciences of the United States of America* demonstrating lengthening of the ragweed pollen season in North America in recent decades due to warming over this period, and a very recent study by Hamaoui-Laguel *et al*. (2015) published in *Nature Climate Change* showing that airborne ragweed pollen concentrations in Europe will be approximately four times higher by 2050 than they currently are as a result of future climate and land use changes. The acceleration of research in this area has been astounding, with, for example, one recent analysis showing that since 1998, one-third of the literature on this topic has been published in just a span of two-and-a-half years, from 2013 to mid-2015 (Beggs, 2015).

The topic is now at a turning point. What is needed is a comprehensive and authoritative assessment of the whole of this topic to clearly document where we stand in terms of our understanding of this topic and to highlight gaps in our knowledge and research priorities for the future. This book, the first one to be entirely devoted to the impacts of climate change on allergens and allergic diseases, aims to fill this need. The following section provides a brief description of climate change itself – the changes in the composition of the Earth's atmosphere, its temperature, precipitation, and so on. The final section introduces the other nine chapters of this book.

## 1.2 Climate Change

Our climate is changing. Climate change due to human activities, the focus of this book, has been witnessed for at least the last 100 years and is projected to continue for centuries to come. Climate change involves the whole climate system, including not only our atmosphere but also our hydrosphere, cryosphere, land surface, and biosphere. With other authoritative and in-depth assessments of climate system changes readily available (i.e., IPCC, 2013a), the purpose of this section is to provide a brief description of 'the physical science basis' of climate change, focussing on the aspects of climate change most relevant to allergens and allergic diseases.

The atmospheric concentrations of several greenhouse gases have increased since the start of the Industrial Era (1750). Atmospheric carbon dioxide ($CO_2$) concentrations have increased by 41% since this time, primarily from fossil fuel emissions and secondarily from net land use changes (IPCC, 2013b). The most recent global annual mean atmospheric $CO_2$ concentration, for 2013, was 395.22 parts per million (ppm) (National Oceanic and Atmospheric Administration (NOAA), 2015a), an increase of over 100 ppm from the pre-Industrial Era value of approximately 280 ppm. As the records from the Mauna Loa Observatory illustrate (Figure 1.1), the increase in atmospheric $CO_2$ concentration since 1750 has not been linear, with much of the increase occurring in just the last 60 years or so and the increase during this last 60 years getting steeper and steeper toward the present time.

This increase in the atmospheric concentration of greenhouse gases such as $CO_2$ has led to an uptake of energy by the climate system (IPCC, 2013b), and this has resulted in observed warming of the climate system. Between 1880 and 2012, the Earth's average surface temperature warmed by 0.85°C (with a 90% confidence interval (CI) of 0.65°C–1.06°C) (IPCC, 2013b). Most of this warming (0.72°C (CI 0.49°C–0.89°C)) occurred after 1951 (Hartmann *et al.*, 2013). Warming of the Earth's surface has also varied over space, with, for example, the land surfaces tending to warm more than the oceans. This means that some parts of the Earth's surface have warmed considerably more than the average of 0.85°C, as much as double or more in some places.

Changes in precipitation have also been observed. For example, since 1901, precipitation has increased over the mid-latitude land areas of the Northern Hemisphere (Hartmann *et al.*, 2013). Other components of the Earth's hydrological cycle have also changed. The moisture content of the air around us, and in our

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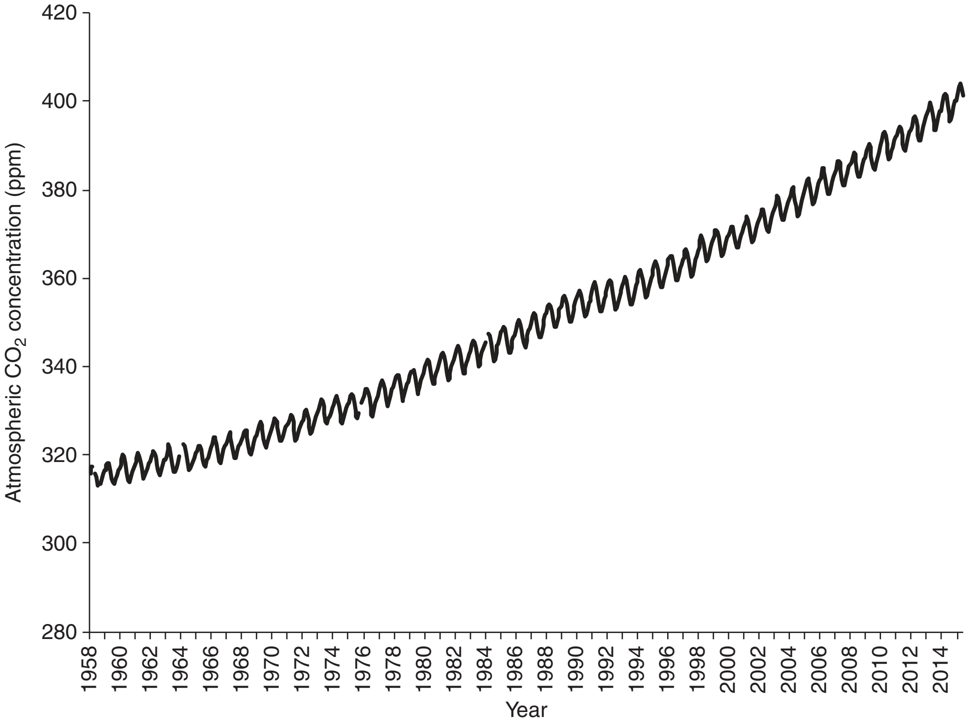


Figure 1.1. Monthly mean atmospheric carbon dioxide concentration at Mauna Loa Observatory from March 1958 to July 2015. Note that the last year of data is preliminary. A few months are missing in the records and these account for the gaps in the graph.
*Source:* NOAA (2015b).

environment generally, has increased since the 1970s. Finally, it is likely that the Earth's general atmospheric circulation has changed, and in particular such features as storm tracks and jet streams have moved poleward since the 1970s, involving a widening of the tropical belt and a contraction of the northern polar vortex (Hartmann *et al.*, 2013).

The past half century or so has also been assessed to have experienced changes in a range of extreme weather and climate events. In terms of temperature extremes, over most land areas, such changes include warmer and/or fewer cold days and nights, warmer and/or more frequent hot days and nights, and increased frequency and/or duration of warm spells/heat waves (IPCC, 2013b). In terms of precipitation extremes, on the one hand, there has been an increase in the frequency, intensity, and/or amount of heavy precipitation, and on the other hand there have been increases in intensity and/or duration of drought (IPCC, 2013b). And finally, intense tropical cyclone (hurricane) activity has increased. More fundamentally though, Trenberth (2012) concludes that 'all weather events are affected by climate change because the environment in which they occur is warmer and moister than it used to be'. He supports this conclusion with an eloquent commentary on the climate system, climate change, and recent climate extremes.

As significant and important these observed changes in the climate system are, they are only half the picture. To complete the picture, we must also look into the future. This requires information about future emissions or concentrations of greenhouse gases, aerosols, and other climate drivers, and the scientific community has developed sets of potential scenarios (of human activities and corresponding emissions, etc.), the latest being labelled Representative Concentration Pathways (RCPs).

Sophisticated climate models that have evolved over decades of development provide us with a range of possible climate futures based on the RCPs. Such possible future climates are referred to as climate change projections. According to the IPCC, 'A projection is a potential future evolution of a quantity or set of quantities, often computed with the aid of a model. Unlike predictions, projections are conditional on assumptions concerning, for example, future socioeconomic and technological developments that may or may not be realized' (Agard *et al*., 2014; IPCC, 2013c).

There are four RCPs (labelled RCP2.6, RCP4.5, RCP6.0, and RCP8.5), according to which atmospheric $CO_2$ concentrations will reach 421, 538, 670, and 936 ppm by 2100, respectively (IPCC, 2013b). The first pathway (RCP2.6) is thought of as a 'mitigation scenario' (a topic to be expanded upon in Chapter 10 of this book). The second and third pathways are thought of as 'stabilisation scenarios', and the fourth pathway is one with very high greenhouse gas emissions.

By the end of this century (2081–2100), global mean surface temperatures are projected to increase relative to those for the period 1986–2005. The Earth's surface temperature is projected to increase anywhere from 0.3°C to 4.8°C, wherein the extent of warming depends on the pathway: 0.3°C to 1.7°C (RCP2.6), 1.1°C to 2.6°C (RCP4.5), 1.4°C to 3.1°C (RCP6.0), and 2.6°C to 4.8°C (RCP8.5) (IPCC, 2013b). Regardless of the pathway followed, this further warming will not be uniform across the surface of the Earth. The mean warming over land will be larger than over the ocean, and the Arctic region will warm more rapidly than the global mean (IPCC, 2013b).

Globally, on average, precipitation is projected to increase by the end of this century (Collins *et al*., 2013). However, there will be substantial spatial variation in precipitation changes, with some regions experiencing increases, some decreases, and some no change at all. The IPCC has concluded: 'that the contrast of annual mean precipitation between dry and wet regions and that the contrast between wet and dry seasons will increase over most of the globe as temperatures increase' (Collins *et al*., 2013). Atmospheric moisture will generally increase into the future.

Complex changes in atmospheric circulation are projected. These include an increase in the area encompassed by monsoon systems and a lengthening of the monsoon season in many regions. Monsoon winds, however, will likely weaken (IPCC, 2013b). Similarly, the Hadley and Walker Circulations in the tropics are likely to slow down (Collins *et al*., 2013).

Climate extremes will also continue to change into the future. Hot temperature extremes, including heat waves, will be more frequent, and cold temperature extremes will be less frequent, over most land areas. Extreme precipitation events will become more intense and more frequent over most of the mid-latitude land masses and over wet tropical regions (IPCC, 2013b).

## 1.3 The Chapters that Follow

The chapters that follow discuss the impacts of climate change on allergens and allergic diseases under eight sub-topics, with the final chapter acting to provide a synthesis of these eight sub-topics and a conclusion to the book as a whole. As is made clear in this introductory chapter, each of the following chapters will consider both observed (past and current) and projected (future) impacts, where possible. Similarly, the spatial scope of the book is global and international. However, the nature of this topic requires that the full range of scales be considered, from the micro and molecular to the macro.

Chapter 2 focusses on the impacts of climate change on aeroallergen (pollen and fungal spore) production and atmospheric concentration. It considers the research that has investigated long-term aerobiological records as well as a range of experimental studies. Chapter 3 examines changes in the types of allergen in our environment by examining the impacts of climate change on the spatial distributions of allergenic species. It explores the evidence for range shifts of allergen-producing plant species as well as a number of stinging insects including wasps, hornets, ants, and bees. Our exposure to environmental aeroallergens also depends on the dispersion and transport of them within the atmosphere and deposition of them from the atmosphere, and it is in Chapter 4 that the impacts of climate change on these processes are considered. With so little existing research in this area, Chapter 4 presents not only an assessment of previous research but also the results of new research by the authors. While this research focusses on Europe, the methods it uses and to some extent the results it obtains provide insights that will inform future research endeavours on this aspect of the topic in other regions of the world.

Chapters 5 and 6 assess the impacts of climate change on two other important aspects of environmental allergens – their potency and timing. Chapter 5 focusses on changes in allergenicity not only of pollen but also, to a lesser extent, of mould spores, contact allergens, and food allergens. Chapter 6 then examines changes in allergen seasonality, including changes in season start dates, end dates, and durations. Again, this chapter focusses primarily on pollen, on which most of the relevant research has focused, but also to a lesser extent on fungal spores.

While much of this book focusses on outdoor environmental allergens, allergens also occur in our indoor environment. It is therefore important that the impacts of climate change on such allergens also be explicitly examined, and this is the focus of Chapter 7. The chapter considers house dust mite, cockroach, mouse, and fungal allergens. In addition to an assessment of existing literature, the chapter presents new research by the authors on the vulnerability of parts of the United States to flooding and therefore mould growth, through an analysis of the extent of homes with basements.

In the final chapter of the book to focus on the impacts of climate change on allergens per se, Chapter 8 tackles the topic of interactions among climate change, air pollutants, and aeroallergens. Following an overview of the impacts of climate change on air pollution, including ozone and particulate matter, the chapter examines the interactions between air pollutants and pollen both within the human body and in the atmosphere.

It is in Chapter 9 that the focus of the book turns explicitly to the impacts of climate change on allergic diseases, wherein a spectrum of allergic diseases is considered. Asthma and allergic rhinitis occupy much of the coverage, but other important allergic diseases include allergic conjunctivitis, atopic dermatitis, insect sting allergy, and food allergy, all of which are discussed.

Chapter 10 provides a synthesis of the discussions in the preceding chapters – a complete picture of the impacts of climate change on allergens and allergic diseases. This final chapter also provides an overview of the basic responses to the impacts of climate change, specifically mitigation and adaptation, as well as adaptation responses specific to impacts on allergens and allergic diseases. The chapter, and the book, finishes with some words of encouragement and a call to action.

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