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Impact of global climate change on regional air quality: Introduction to the thematic issue

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Abstract

Despite the major international efforts devoted to the understanding and to the future estimate of global climate change and its impact on regional scale processes, the evolution of the atmospheric composition in a changing climate is far to be understood. In particular, the future evolution of the concentration of near-surface pollutants determining air quality at a scale affecting human health and ecosystems is a subject of intense scientific research. This thematic issue reviews the current scientific knowledge of the consequences of global climate change on regional air quality and its related impact on the biosphere and on human mortality. This article provides a presentation of the key issues, summarizes the current knowledge, and introduces the thematic issue. ***To cite this article: R. Vautard, D. Hauglustaine, C. R. Geoscience 339 (2007).***

Résumé

Impact du changement climatique global sur la qualité de l'air à l'échelle régionale : introduction au fascicule thématique. Malgré les efforts internationaux de recherche pour mieux comprendre et prédire le changement climatique futur et ses impacts sur les processus régionaux, l'évolution de la composition chimique de l'atmosphère dans un climat perturbé est loin d'avoir livré ses secrets. En particulier, l'évolution future de la concentration à la surface des principaux polluants déterminant la qualité de l'air et affectant la santé humaine ainsi que les écosystèmes est un sujet d'intense recherche scientifique. Ce fascicule thématique propose une revue des connaissances actuelles des conséquences du changement climatique global sur la qualité de l'air à l'échelle régionale ainsi que de son impact sur la biosphère et en termes de santé publique. Cet article contient une présentation des questions clé, donne un résumé des connaissances et introduit ce fascicule thématique. ***Pour citer cet article : R. Vautard, D. Hauglustaine, C. R. Geoscience 339 (2007).***

Keywords: Climate change; Air quality

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1. Introduction

A major challenge humanity will have to face over the next decades is to manage the consequences of its development and increasing population. Access to resources like water, food, and energy is unevenly distributed and global climate change will worsen this situation. Climate change will undoubtedly strike areas in developing countries and elsewhere the most vulnerable regarding access to vital resources, food production, and economical development. The frequency of extreme meteorological events such as heat waves, floods, or hurricanes is predicted to increase in the future [12], and these phenomena are likely to affect strongly our society.

Future climate change, in the strict sense, is however not the only environmental challenge our society will have to face. Changes in atmospheric composition will also largely affect human health, food production, and hence the economy. Near the surface, changes in atmospheric composition affect the air we breathe, and induce air-quality issues. Several pollutants such as ozone and aerosols are known to generate health problems. The symptoms may be acute inside or in the surroundings of large cities, due to the high concentration of pollutants close to their source. These increased levels of atmospheric pollutants also damage ecosystems like forests and limit crop yields. Since most of the worldwide population is foreseen to live in these megacities within the next decades, enhanced health problems due to poor air quality are expected, despite the efforts in developing new technologies for cleaner combustion processes. Due to their relatively long-lived residence time in the atmosphere and transport by the atmospheric circulation, these changes in air quality are not confined in urban areas, but they also extend to neighbouring or remote regions.

Both climate and air-quality changes can simultaneously affect health, especially during weather extremes like heat waves. A premonitory picture of such problems was provided by the summer 2003 heat wave in western Europe, with an estimated toll of 35,000 extra deaths [35]. It is therefore important to assess the impact of climate change on air quality. Conversely, it is also of high relevance to climate change to understand the physics and chemistry of air quality near pollutant sources. Indeed, the fate of these pollutants largely determines the concentration of key radiatively active species like ozone (the third important greenhouse gas of human origin), or the hydroxyl radical (OH), which controls the oxidizing capacity of the atmosphere and is the main sink of methane (the second important greenhouse gas of anthropogenic origin).

The fourth IPCC report [12] provides a major assessment of the current and expected climate change. In that report, a chapter has been devoted to the coupling between climate change and the biogeochemical cycles [2]. However, only a moderate emphasis has been put on the consequences of climate change on air quality, which is a fairly recent field of scientific investigation. The goal of this thematic issue is to review briefly the current state of knowledge of the impact of global climate change on atmospheric composition for pollutants having a direct impact on human health and ecosystems. In this paper, we provide a brief overview of this thematic special issue, present the motivation for research in this field, and we give a summary of the current state of knowledge.

2. Changes in the global atmospheric composition

In the troposphere, air parcels rapidly travel and mix. At mid latitudes, the typical time scale for an air parcel to travel around the Earth is of a few weeks. The time taken for the air parcel to visit the two hemispheres is longer, about one year or more. These time scales are however much shorter than the time scale associated with climate change, say a few decades. At these time scales, pollutants such as ozone and its precursors and particulate matter have the time to mix around the Earth. This atmospheric transport maintains a background concentration level that can be measured in areas remote to source regions. Closer to the sources, the distribution of pollutants is less homogeneous and is influenced by the geographical distribution of the emissions, their time variations, and the local or regional climate. There, air quality results from the interaction of baseline atmospheric composition, influenced by global pollutant emissions and global climate, with regional pollutants, influenced by nearby sources and regional climate. The tools used to understand the two 'components' of air quality are often different (global models vs. regional, limited-area models), the research communities are even different, but converging efforts are presently made to build a coherent vision of future air quality across the different geographical scales [14,29,15].

Two main drivers for the changes in global chemical atmospheric composition are generally distinguished and studied separately: changes in precursor *global emissions* and changes in *climate* (e.g., temperature, humidity, general circulation and mixing, clouds). Despite the fact that there is now a significant body of literature on this subject, the prediction of these drivers and their relative contributions to future changes in atmospheric composition still have very large uncertainties [12].

Climate change alone has the potential to significantly modify the global atmospheric composition through a number of processes whose net effect is still not clear [11,13,22,24–26,28,37,38]. The increase in temperature and water vapour tends to reduce the ozone burden [13], especially in tropical and equatorial areas. However, drought increase in subtropical and southern/central mid latitudes should increase photochemistry, and therefore ozone concentrations. Increase in tropospheric ozone concentration also results from the increase in the frequency of intrusions of stratospheric air linked to mid-latitude frontal systems [3,37]. Direct dynamical and chemical effects of climate change affect also the concentration of primary pollutants through modifications in atmospheric stability [11,16,17,20].

In addition to these processes involving changes in dynamics and atmospheric temperature, climate changes can also affect atmospheric composition through perturbations of natural emissions of precursors. This is particularly the case for lightning NO_x [1,11], biogenic emissions of volatile organic compounds [1,11,16,21] and emissions of nitrogen oxides by microbiological activity in soils [36]. Changes in methane emissions from flooded areas are also likely to occur under a different climate, but the magnitude of this effect is still poorly quantified. All these emissions increase should have a positive effect on ozone formation, but this feature will depend on the background NO_x levels. Dry deposition is also a major sink for species like ozone, and it can also be significantly perturbed in an evolving climate due to changes in turbulence in the lowest atmospheric layers and also due to changes in ecosystems.

The way vegetation adapts to global climate change and increased CO_2 levels is however very complex and highly nonlinear, and depends on the availability of water, but also on the concentration of ozone [23]. Hydric stress, as well as cellular damages due to high ozone concentrations, inhibits deposition and therefore has a positive feedback on ozone concentrations. The article of Felzer et al. [5] in this thematic issue is devoted to a review of the effects of ozone on vegetation and crop yield. Areas where drought is predicted to increase should witness more forest or vegetation fires and become more sensitive to aeolian erosion, both phenomena giving rise to an increase in natural aerosol emissions.

Finally, climate change also modifies anthropogenic emissions, but this effect has not been deeply investigated. Evaporative emissions of solvents increase with temperature and fugitive dust emissions increase with drought. The demand for energy production should have a seasonal pattern: in the mid-latitudes, warmer winters should induce a decrease in heating, but warmer summers should provoke an increase in energy demand for air conditioning.

The impact of climate processes (taken independently from anthropogenic emission changes) on future atmospheric chemical composition has been investigated in several modelling studies. Despite the large variety of results found in these studies, some common conclusions can be drawn for the global tropospheric composition that should be witnessed in the second part of the 21st century:

- surface ozone should increase (typical range 5–15 ppb) at mid-latitudes, where the impact of increased radiation, temperature and more stagnant conditions over the continents dominate over the increase of water vapour and the associated ozone destruction;
- ozone should decrease in a similar range in tropical/equatorial areas due to increase in water vapour and ozone photochemical destruction;
- nitrogen oxides emissions should increase by up to a factor of two due to increased lightning intensity;
- biogenic volatile organic compounds emissions should increase in the future due to the CO_2 fertilisation effect on vegetation and temperature changes.

Global atmospheric composition will also primarily change due to perturbations of anthropogenic emissions of pollutants, independently of climate change. A global increase of all primary emissions is predicted for the end of the century, especially due to the massive economic development and population increase in several developing countries. Acceleration in carbon dioxide emissions have even been recently found [19], as a first verification of this prediction. There is, however, a range of uncertainties in envisaged emission scenarios [12]. Consequently to global emission increase, global air quality is predicted to worsen and the pollutant base lines should increase, for ozone, primary pollutants and aerosols.

3. Changes in regional air quality

Predicting the future changes in regional air quality, near pollutant sources, is a major challenge for human health and ecosystems. In tropical or equatorial areas, convection and subsequent wet deposition makes pollutant concentration at the surface relatively low. However, during a few calendar months, stable atmospheric conditions can lead to severe photochemical or dust episodes. The main air quality problems in these regions arise from the increasing population density in megacities, in areas where large pollutant sources exist. This feature is independent of climate conditions, which can hardly 'save' the air quality in these cases. There is a rising concern about air quality in megacities, and recently an effort has been devoted to the analysis of the mixture of substances present in the air in a few large cities in order to determine their concentrations. Mexico has been considered a prototype for such a study, and a large measurement campaign has been carried out in 2006 (MILAGRO). The city of Beijing is also among the largest megacities where focus should be put. In this thematic issue, the article of Gros and Sciare [7] presents preliminary results of a measurement campaign that took place in Beijing and compares the concentrations with those measured in Paris. Such studies are crucial because these cities can be considered, to a certain extent, representative of many other megacities in developing countries (São Paulo, Lagos, Cairo, etc.).

Future megacities are not only exclusively located in developing countries. During the last two decades, large efforts in understanding air-quality physics and chemistry have been put on North-American cities like Los Angeles, New York or other polluted cities like Houston. In Europe, operational air-quality agencies monitor surface air quality for regulated compounds, and recent measurement campaigns have exhaustively described the atmospheric composition in major cities or polluted regions (PIPAPO for Milan [18]; BERLIOZ for Berlin [10]; ESQUIF for Paris [31], ESCOMPTE for Marseille [4]). In these regions, emissions of pollutants significantly decreased over the last decades, and will certainly continue to decrease in the future, so that air quality will undergo different trends.

In this thematic issue, the emphasis is put on Europe, and several articles describe the fate of air quality due to these emission changes, but also to regional climate changes. As far as emissions are concerned, European air quality will face contrasting forcings: the increase of global emissions, leading to larger baseline concentrations at the European boundaries, and the decrease of regional emissions. As indicated by the comparison of observations and model simulations, lower ozone concentration centiles increase, while upper centiles decrease [32]. This should also occur for other pollutants like primary pollutants. In this issue, Szopa and Hauglustaine [30] also find that this should continue in the future, using various emission scenarios for 2030. However, the prediction of emissions beyond 2030, and even for 2030, is highly uncertain, because it depends on the technological choices countries will make, as discussed in their article.

As shown in several studies, Europe should witness important regional climate changes (see, e.g., [8]), which should have consequences on air quality. The climate of northern Europe should become wetter, which is favourable to air-quality improvement, but that of southern Europe should become drier, which is unfavourable. The variability of weather should become larger, with an increasing frequency of extreme events. Among these extremes, heat waves are of particular importance for air quality. In recent years, Europe has witnessed a series of such heat waves (August 2003 in central/western Europe, July 2006 in central/eastern Europe; April 2007 in western Europe). The summer of 2003 has often been proposed as a prototype of the European climate of the end of the 21st century [27]. It is thus important to understand the peculiarity of weather and air quality during this particular summer. In the thematic issue, the article of Vautard et al. [33] provides a review of summer 2003 weather and air quality, their impacts on human health and discusses to what extent it is possible to infer future air quality from simulations of European air quality during this summer.

The impacts of European and global climate change on European air quality are also examined in a quantitative way in two articles of this thematic issue. Giorgi and Meleux [9] give a thorough review of this question, and show air-quality simulations for the end of the century for the whole continent at moderate resolution (1/2 degree). Forkel and Knoche [6] present results at a finer scale for a smaller European region: southern Germany and central Europe. Both find increasing ozone concentrations due to a more anticyclonic weather, inducing higher biogenic emissions, and a more stagnant and photochemically active weather. However, these studies considered only changes in regional climate. So far, no modelling study considered simultaneously the three major causes of changes in regional air quality for Europe: (*i*) climate change, (*ii*) regional emission changes, and (*iii*) global emission changes influencing boundary conditions. The weight of each process is still to be determined for a prediction of future air quality. Based on the articles presented in this thematic issue, a tentative synthetic conclusion may be drawn for ozone in Europe:

- highest centiles, corresponding to peak values in episodes should decrease in the future decades thanks to regional emission reductions;

- the frequency and the length of ozone episodes should increase due to climate change and its consequences on heat waves;
- the increase of global emissions and subsequent baseline ozone should make the average and lower ozone centiles increase, which may have an impact on human and ecosystem exposure.

Aspects of future regional air quality concerning aerosol particulate matter have had very little focus in research studies. This is not surprising, since the complexity of aerosol nature, chemistry and sources is larger. Before projections for the future can be built, more accurate source apportionment should be made for present air quality. The assessment of the evolution of important pollutants such as persistent organics, heavy metals is still to be done. Thus, it is clear that there is a large space for research studies in understanding the future of regional air quality in a wide sense.

4. Organization of the thematic issue

This thematic issue of the *Comptes rendus Geoscience* provides an overview of the state of the art about the impact of global climate change on air quality and its related effects on human health and the continental biosphere, with illustrative examples and research studies. After this introduction, the linkage between global and regional emissions of pollutants and their relative contribution to future air quality in Europe is presented by Szopa and Hauglustaine [30]. It is followed by the review of the impact of climate change on European air quality by Giorgi and Meleux [9]. At a smaller scale, climate change impacts on air quality in central Europe are presented in the Forkel and Knoche article [6]. The analysis of weather conditions and air quality during summer 2003 in Europe and in the Paris region is then presented by Vautard et al. [33]. There, deductions from the 2003 experience are tentatively drawn. In order to understand what could become air quality at finer urban scale in future megacities, the experimental measurements of Gros and Sciare [7] in Beijing are presented and compared to concentrations obtained in Paris. The thematic issued is then followed by two articles concerning the impact of present and future air quality on human health by West et al. [34] and on crop yield and forests by Felzer et al. [5].

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