

CURRENT AND FUTURE SURFACE OZONE LEVELS OVER EUROPE

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ABSTRACT

Climate change is one of the most important problems facing us today, and atmospheric chemistry controls the abundances and distributions of many of the radiatively important gases. Chemically active long-lived greenhouse gases have contributed about half of the radiative forcing of climate since the pre-industrial. Climate change itself affects atmospheric chemistry, for instance directly through changes in temperature and water vapour which affect the rates of chemical production and destruction processes. There are indirect effects too. The largest source of reactive hydrocarbons to the atmosphere comes from vegetation, but plants are expected to emit more hydrocarbons in a warmer climate. These increases may offset the decreases in anthropogenic emissions due to emission controls. A further impact is through increases in NO_x from lightning. While lightning is not a significant source of NO_x over industrial regions, it forms ozone over remote regions of the globe, thus contributing to the background concentrations of ozone. Due to the non-linear nature of the ozone regulations, small increases in the ozone background can cause large violations of the air quality standards. We have simulated the evolution of ground-level ozone over Europe under climate-change scenarios using a global chemistry transport model. We will present here the results of these experiments and the implications for our ability to meet air quality standards in the future

INTRODUCTION

In the United Kingdom, air quality targets for 2005 [1] have been set for a variety of pollutants, such as benzene, nitrogen dioxide, particulates and ozone. These compounds have an impact on human health. They are all primary pollutants except ozone, as they are emitted directly from sources such as vehicle exhausts. Ozone, however, is a secondary pollutant, because it is made from photochemical reactions in the atmosphere involving the primary pollutants. Control of ozone levels is more difficult owing to the complex and variable reactions involved in its production and destruction. The same levels of primary pollutants may produce quite different levels of ozone depending on the meteorological conditions. On top of this, climate change is another process which has to be considered when making decisions on pollutant reduction policies. The chemical reactions involved in the formation and destruction of ozone are temperature dependent, and if the future climate is warmer, these reactions will proceed more quickly and destroy ozone. The target set for U.K. ozone levels, to be achieved by the end of 2005, is a daily maximum of 50 ppbv, which must not be

exceeded more than 10 times per year [1]. In this paper, we present results from several different scenarios to assess the effect of climate change and other influences on surface ozone levels over Europe. We concentrate on summer values, as this is the time of year when the highest surface ozone values are observed. We also briefly discuss whether the air quality target for ozone can be met now and in the future.

COUPLED MODEL INTEGRATIONS

The Met Office Lagrangian tropospheric chemistry model STOCHEM is coupled to the Hadley Centre climate model. STOCHEM and its performance have been discussed in detail elsewhere [2]. In these simulations, anthropogenic emissions were in accordance with the SRES A2 scenario[3]. For each simulation, the model was run for at least 2 years, and results were taken from the last year of the run. In all cases below, descriptions of changes in ozone levels refers to the summer surface levels over Europe, which in this work are the mean of the June, July and August values predicted by the STOCHEM model.

EFFECT OF CLIMATE CHANGE ON SURFACE OZONE LEVELS

It is generally expected that a future climate will be warmer than the present one. The rate of the chemical reactions that form ozone are temperature dependent, and will proceed more rapidly in a warmer environment. However, there will also be more water vapour in a warmer atmosphere, which will result in greater destruction of ozone. Photolysis of ozone produces an oxygen atom which can either reform ozone via reaction with oxygen molecules or produce the OH radical via reaction with water vapour: $O(^1D) + H_2O \rightarrow 2 OH$ [2]. The latter reaction therefore represents a sink for ozone.

We have performed two simulations with the STOCHEM model to assess the effect of climate change (principally temperature and humidity changes) on surface ozone levels over Europe for the present day and the 2090s. In each case the model was run for 110 years continuously. The control run had constant greenhouse gas concentrations, and hence a fixed climate. In the climate change run greenhouse gas concentrations were allowed to increase according to the SRES A2 scenario [3], which results in the climate slowly warming over the course of the simulation. In both simulations, the anthropogenic emissions of reactive gases such as nitrogen oxides, carbon monoxide and hydrocarbons increased according to the SRES A2 scenario [3], but the vegetation distribution and natural hydrocarbon emissions were fixed and did not vary between each year of the simulation. Further details of these two model integrations are given elsewhere [2,4].

Figure 1(a) shows the change in summer mean surface ozone levels over Europe owing to increased emissions of pollutants. The ozone levels over northern Europe have increased by 5 – 20 ppbv, and are 30 – 40 ppbv higher over eastern and southern Europe. Figure 1(b) shows the same difference but allowing the climate to change as well. It can be seen that pattern of ozone increases in this run are quite different. Over northern Europe, the ozone levels have increased by a smaller amount, 5 – 15 ppbv, whereas over all of southern Europe the ozone changes are 30 – 40 ppbv, higher than in the control run. The effect of climate change in

these simulations is complex. The reduction in ozone values over northern Europe is caused by an increase in the ozone destruction rate via the reaction of excited state oxygen atoms with water vapour, as described above. However, southern Europe has become warmer and drier, and so the ozone destruction rate is correspondingly smaller. Production of ozone is expected to increase in a warmer climate and this may exceed the increase in destruction.

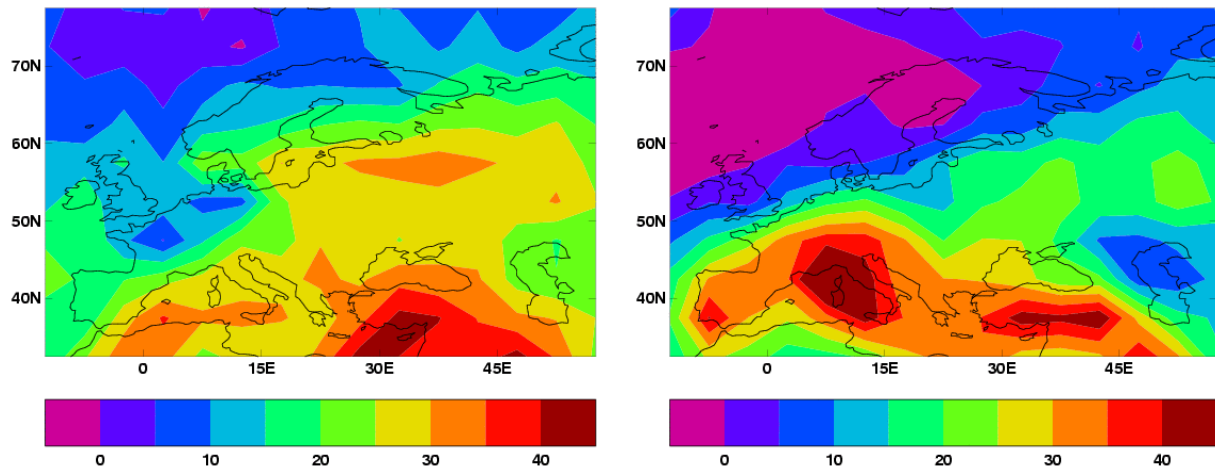


Figure 1. Change in summertime surface ozone levels in ppbv over Europe. (a) Left panel, showing the change in ozone between the 2090s and the 1990s with a fixed 1990s climate. (b) Right panel, the same change for the climate change study. See text for details.

EFFECT OF CHANGES IN NATURAL HYDROCARBON EMISSIONS AS A RESPONSE TO CLIMATE ON SURFACE OZONE LEVELS

In a future climate, with higher temperatures and increased levels of carbon dioxide, a shift in vegetation patterns is likely. Emissions of reactive gases from vegetation such as isoprene will also respond to climate. In this set of simulations, isoprene emissions were modelled using the well-established algorithms developed by Guenther et al. [5]. Details of the model simulations are given elsewhere [6].

To examine the effect of changed vegetation and hence natural hydrocarbon emissions on surface ozone levels, we have run two experiments which were identical except for the vegetation maps used. In the first case the vegetation map used was for the 1990s, and in the second we used the changed vegetation map from Cox et al. [7]. Over Europe, the density of vegetation is found to have increased in the future climate, owing to larger carbon dioxide concentrations and the warmer climate.

Figure 2 shows the difference in the summer surface ozone concentrations between the two simulations of the 2090s. A positive value indicates that the predicted surface ozone values are greater when the vegetation distribution is unchanged from the 1990s. The largest differences are seen over the North Sea, the Bay of Biscay and parts of Russia, and range from +8 to -8 ppbv. However, the changes in surface ozone over most of Europe are smaller, at +4 to -4 ppbv. These changes in surface ozone levels are also smaller than those resulting

from climate change, which lie within the range 8 – 14 ppbv, as discussed in the previous section. Hence changes in natural hydrocarbon emissions have a significant impact on predicted future surface ozone levels over Europe.

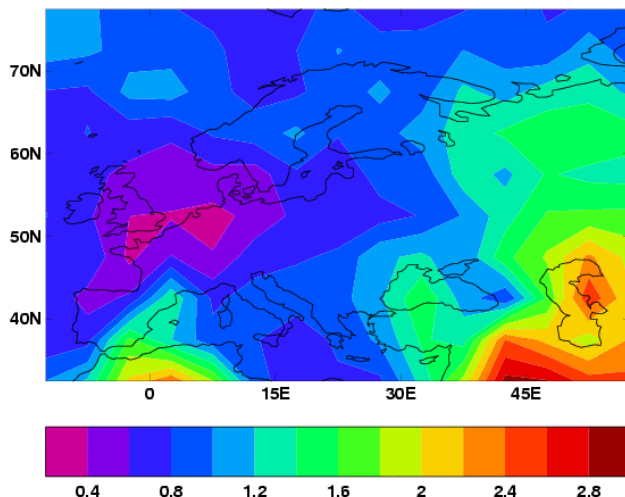


Figure 2. Difference in summertime surface ozone values in ppbv for 2095 when a change in vegetation species and distribution as a response to climate, and hence isoprene emissions, is considered. A positive value indicates an increase in surface ozone when vegetation changes are ignored. See text for details.

EFFECT OF ANTHROPOGENIC EMISSION CHANGES ON SURFACE OZONE LEVELS

Nitrogen oxides, referred to as NO_x , and carbon monoxide are major primary pollutants. Substantial reductions in emissions of these two pollutants are required in the DETR air quality strategy [1]. We have used the STOCHEM model to assess the effect of a 50 % reduction in global anthropogenic NO_x emissions on current summer ozone levels. The change in ozone values resulting from this reduction are shown in figure 3. A negative value indicates that the ozone levels have fallen as a result of reducing the NO_x emissions. The biggest changes are seen over Spain, and the eastern Mediterranean and beyond, where the ozone levels have fallen by 6 – 10 ppbv. Interestingly, the ozone values over the North Sea and Scandinavia have risen by 4 – 6 ppbv. This increase seems to be due to reduced titration of ozone by NO. Reductions in emissions of hydrocarbons and carbon monoxide as well as NO_x may be needed to achieve the required reductions in surface ozone levels.

EFFECT OF NO_x PRODUCTION FROM LIGHTNING

Lightning produces significant amounts of nitrogen oxides in the atmosphere, and contributes 8 – 16 % of the global total NO_x production [8]. Significant amounts are produced near the tropopause and the surface, which can have an important effect on ozone levels. The STOCHEM model was integrated using the climate and emissions for the 2090s, with and

without production of NO_x by lightning. The changes in summer ozone levels are shown in figure 4. Negative values indicate that the ozone levels have fallen when the lightning NO_x emissions are neglected. Ozone levels have fallen over all of Europe, but the largest changes are only 2.0 – 2.5 ppbv over eastern and parts of southern Europe. Over northern and western Europe, the changes are only 1 ppbv or less. Production of NO_x by lightning does not have a significant impact on surface ozone levels over Europe.

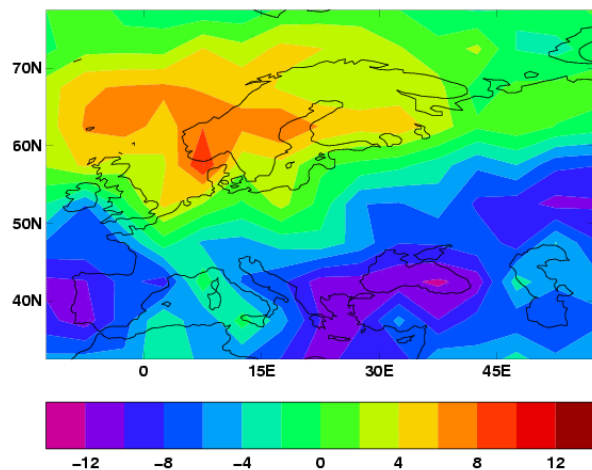


Figure 3. Change in present day summertime ozone levels when anthropogenic emissions of NO_x are reduced by 50 %. Units are ppbv.

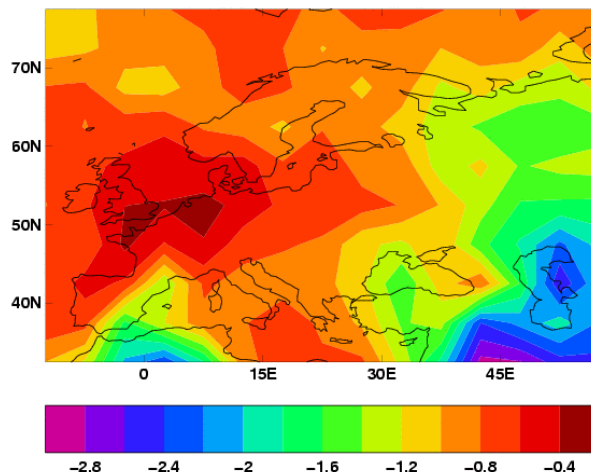


Figure 4. Change in 2090s summertime ozone levels when production of NO_x by lightning is neglected. Units are ppbv.

CONCLUSIONS

We have shown that climate change, emissions and other atmospheric processes exert an important influence on the summertime surface levels of ozone over Europe. Climate change, resulting in higher temperatures and higher amounts of water vapour, acts to reduce the modelled levels of ozone by 8 – 14 ppbv. Reducing the anthropogenic emissions of NO_x by 50 % reduced ozone levels over most of Europe by 4 – 10 ppbv, but the ozone levels increased slightly in a few locations. Vegetation changes and in turn isoprene emissions as a response to climate change had a small effect on ozone levels over Europe, where the ozone levels only changed by 4 ppbv. The interaction between climate, emissions and chemistry is highly complex. Significant reductions in emissions of ozone precursors do not necessarily yield large decreases in surface ozone levels.

The current predictions of present day surface summertime ozone levels using STOCHEM lie within the range 40 – 50 ppbv. Most of the predictions of 2090s surface levels are well above this range, up to 90 ppbv in a few locations. Although climate change and possibly vegetation changes act to reduce the ozone levels to some extent, considerable effort will be needed if the air quality targets [1] are to be met.

Air pollution and surface ozone levels are not just a local problem but a global one. For example, Derwent et al. [9] studied intercontinental transport of pollution at many sites in

Europe. They found that, for an average surface ozone concentration of 40 ppbv, about 13 ppbv or 33 % had been transported from America and Asia. Any reduction in surface ozone levels from European strategies could be offset by rising background ozone levels caused by increased precursor emissions from America and Asia. International cooperation and implementation of pollution-reducing strategies is therefore required.

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