Oecologia Montana 2012,
21, 11 - 14

Influence of the greenhouse gases on the Earth's ozone layer evolution in the 21st century

Conference "Mountains and Climate", Bishkek, December 10-11, 2012

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Abstract. A numerical 2-D zonally averaged interactive dynamical radiative-photochemical model of the ozonosphere including aerosol physics is used to examine the future long-term changes of the Earth's ozone layer caused by anthropogenic pollution of the atmosphere by the greenhouse gases CO_2, CH_4, N_2O, by ozone-depleting chlorine and bromine compounds, and by H_2O emitted from engines of supersonic aircrafts. The model takes into account also an increasing of the ocean surface temperature caused by greenhouse effect and accompanying increase of water vapour influx into the atmosphere from the ocean. The model calculations showed that by the middle of 21st century the total ozone changes caused by the greenhouse gases are predicted to be comparable in absolute value with those due to chlorine and bromine species. Abundance of the greenhouse gases in the atmosphere will be the main anthropogenic factor controlling the state of the ozone layer in the second half of the 21st century. Anthropogenic increasing of water vapour abundance in the atmosphere due to heating of the ocean surface caused by greenhouse effect and due to emission from supersonic aircrafts is shown to give a sensible contribution to the calculated ozone changes.

Key words: Ozonosphere, greenhouse gases, polutants, numerical two-dimension zonally averaged model

Introduction

It is well known that anthropogenic emissions of greenhouse gases into the atmosphere produce a warming of the troposphere due to greenhouse effect and a cooling of the stratosphere. The expected stratospheric cooling essentially influences the recovery of the ozone layer after reduction of anthropogenic discharges of chlorine and bromine species into the atmosphere. Model calculations by Danilin *et al.* (1998) showed that stratospheric cooling enhances polar ozone depletion via increased polar stratospheric cloud formation and retard the expected recovery of the ozone layer. On the other hand, Dyominov and Zadorozhny (2001, 2005a) showed that anthropogenic growth of CO_2 led to a decrease of the global ozone depletion caused by chlorine and bromine compounds at the end of the last century. This effect, which is triggered by a weakness of the efficiencies of catalytic cycles of the ozone destruction in the cooled stratosphere, is predicted to accelerate the ozone layer recovery (Rosenfield *et al.* 2002, Dyominov and Zadorozhny 2005b, Rosenfield and Schoeberl 2005, Portmann and Solomon 2007). One more mechanism of how greenhouse gases impact the ozone layer is an enhanced evaporation H_2O from the oceans into the atmosphere because of increasing temperatures of the ocean surface due to the greenhouse effect.

The subject of this paper is a detailed study of mechanisms of the influence of anthropogenic growth of the greenhouse gases CO_2, CH_4, and N_2O on expected long-term changes of the Earth's ozone layer in the 21st century as well as a study of ozone layer dynamics resulting from an enhanced water vapour content in the atmosphere due to global heating of the ocean surface and H_2O discharges from aircrafts engines.

Model description

The numerical two-dimension zonally averaged model of the ozonosphere by Novosibirsk State University (Dyominov and Zadorozhny 2001, 2005a, 2008) has been used for calculations. The model allows to self-consistently calculate diabatic circulation, temperature, and gaseous composition of the troposphere and stratosphere at latitudes from the South to North Poles, as well as distribution of sulphate aerosol particles and polar stratospheric clouds (PSCs) of type I and type II. The model calculates the distribution of 64 minor gas constituents, which interact in 203 gas phase photochemical reactions and in 14 heterogeneous reactions on surfaces of PSCs and sulphate aerosols. Calculation of atmospheric heating and cooling rates takes into account heat fluxes due to convection, eddy heat exchange, and radiative transfer in ultraviolet, visible and infrared spectral ranges.

The model takes into account an anthropogenic pollution of the atmosphere by the greenhouse gases CO_2, CH_4, and N_2O, by ozone-depleting chlorine and bromine species, by sulphur dioxide and by H_2O emitted from supersonic planes. The feature of this model is an account taken for an enhanced evaporation from oceans because of higher temperatures of the ocean surface due to the greenhouse effect. The model time-dependent runs were made

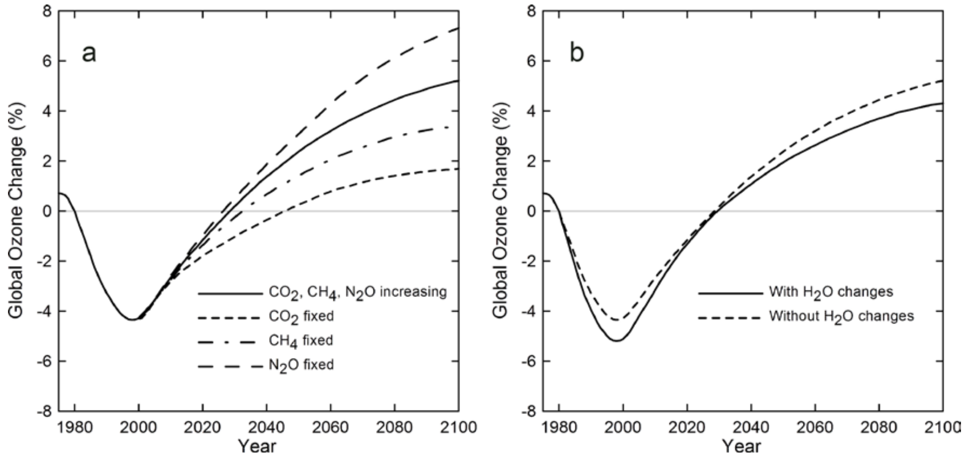

Fig. 1. Local (a) temperature and (b) ozone changes caused by anthropogenic discharges into the atmosphere of CO_2, CH_4, N_2O (IS92a scenario) and chlorine and bromine species calculated for December 2050 at 45°N.

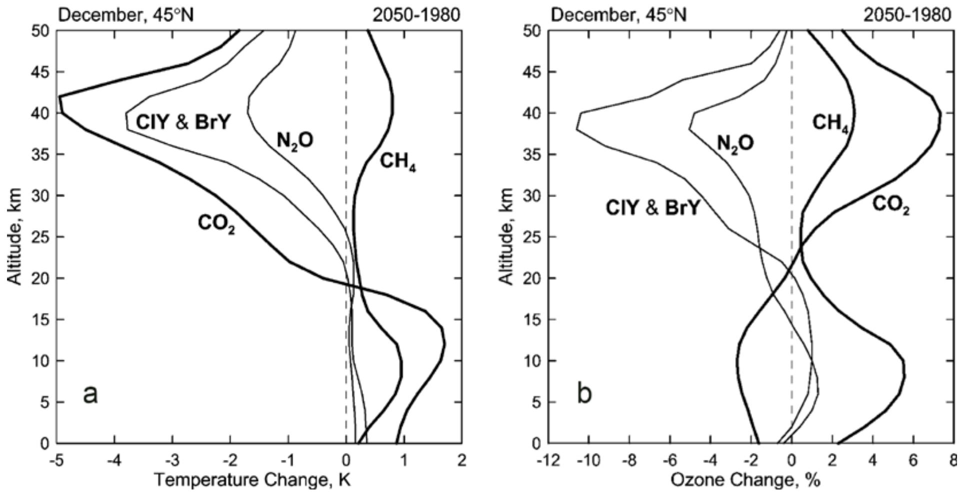

Fig. 2. (a) Changes in annual average global total ozone caused by anthropogenic pollution of the atmosphere by greenhouse gases CO_2, CH_4, N_2O (A_2 scenario) and chlorine and bromine species calculated for anthropogenic growth of all greenhouse gases (solid curve), and for CO_2 (dash curve), CH_4 (dot and dash curve) and N_2O (long dash curve) fixed at 2000 values, as well as (b) for H_2O increasing (solid curve) due to greenhouse effect and aviation and without H_2O changes (dash curve).

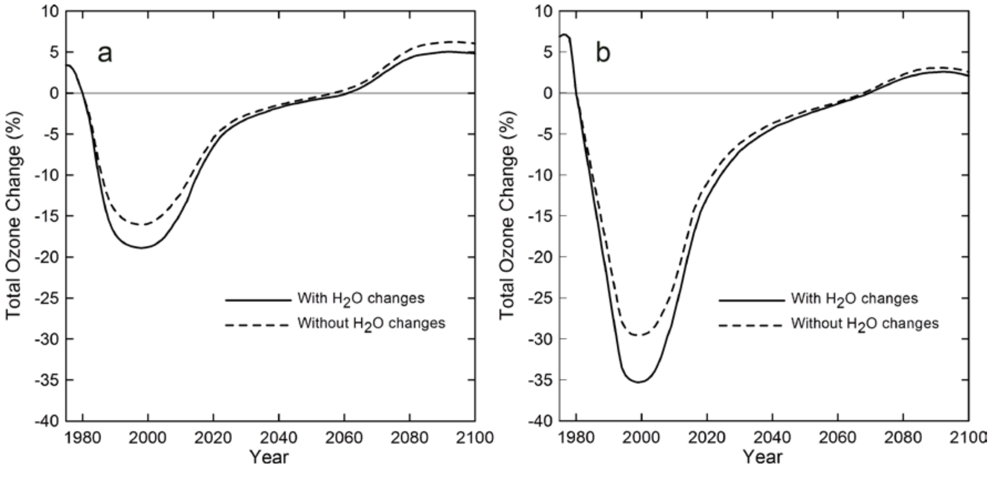

Fig. 3. Changes in global total ozone in the latitude ranges (a) from 60°N to 90°N in March and (b) from 60°S to 90°S in October caused by anthropogenic pollution of the atmosphere (A_2 scenario) calculated for H_2O increasing due to greenhouse effect and aviation (solid curves) and without H_2O changes (dash curve).

for the period from 1975 to 2100 using scenarios A_2 and IS92a depicting maximum (A_2) and average (IS92a) expected increases of CO_2, CH_4 and N_2O concentrations (IPCC 2001). Scenarios of anthropogenic pollution of the atmosphere by chlorine and bromine species are taken from WMO (2007). Data on fuel consumed by fleet of 1000 supersonic planes is taken from Kawa *et al.* (1999).

Results and Discussion

Fig. 1a shows atmospheric temperature changes caused by anthropogenic discharges of CO_2, CH_4, N_2O, and chlorine and bromine species calculated according to scenario IS92a for December 2050 at 45°N. The greenhouse effect essentially increases temperature in the troposphere. In contrast to troposphere situation, a greenhouse gas increase causes a cooling of the stratosphere. The largest contribution to a cooling of the stratosphere is given by carbon dioxide. All pollutants but CH_4 lead to a cooling of the stratosphere and a heating of the troposphere. Ozone changes produced by direct photochemical impact of the pollutants on the stratospheric composition are also considered in the temperature calculations. Chlorine and bromine species, as well as N_2O, decrease ozone concentration, which leads to additional cooling of the stratosphere. However, CH_4 growth leads to ozone increasing in the stratosphere due to chains of photochemical reactions of methane oxidation. This photochemical impact of CH_4 on the atmosphere warms the stratosphere.

The impact of each of the anthropogenic species on the ozone has its own distinctive features. The calculated according to scenario IS92a local ozone changes (Fig. 1b) are the result of direct photochemical impact on the ozone and temperature feedbacks. The cooling of the stratosphere weakens the efficiencies of all catalytic cycles of the ozone destruction due to the temperature dependencies of chemical reaction constants, which, in its turn, increases the ozone concentration. This explains why anthropogenic growth of CO_2 abundance in the atmosphere leads to an increase of stratospheric ozone concentration. Temperature feedbacks reduce essentially the efficiencies of photochemical impact of CH_4, N_2O and chlorine and bromine species on stratospheric ozone. Ozone changes in the troposphere, which are mainly due to smog mechanism of O_3 creation with the participation of methane and carbon dioxide, give no noticeable contribution into total ozone variations.

Fig. 2a shows how an anthropogenic CO_2, CH_4, N_2O increases change global total ozone in the Earth atmosphere in accordance with maximum scenario A_2. We can see that changes of annual average global total ozone in 2100 in comparison with 1980 are equal to approximately 5,21% for anthropogenic growth all greenhouse gases, and to 1,69%, 3,38% and 7,31% for values of CO_2, CH_2 and N_2O fixed at 2000 level accordingly.

Fig. 1b and 2a show that by the middle of 21st century the ozone changes due to the greenhouse gases are predicted to be comparable in absolute value with those due to chlorine and bromine species. Abundance of the greenhouse gases in the atmosphere will be the main anthropogenic factor controlling the state of the ozone layer in the second half of the century.

The calculations show that with the account taken for enhanced evaporation from oceans because of higher temperatures of the ocean surface due to the greenhouse effect and H_2O discharges from engines of supersonic aircrafts, the predicted concentration of water vapour in the stratosphere noticeably increases. This increase noticeably influences the annual average global total ozone (Fig. 2b). In the A_2 scenario and without this source of water vapour in the atmosphere the annual average global total ozone will approach its unperturbed level of 1980 by about 2027 (Fig. 2b). When compared with the year of 1980, the 2100 year-averaged global total ozone will increase by approximately 5.21%. The atmospheric water vapour surplus decreases an atmospheric ozone concentration, and the unperturbed level of 1980 ozone concentration will be attained 2 years later. The 2100-to-1980 global total ozone increase will be approximately 4,3% (Fig. 2b).

The behaviour of total ozone concentration in polar latitudes of both Northern and Southern hemispheres is shown in Fig. 3. In polar latitudes, a water vapour increase in the lower stratosphere due to the greenhouse effect and aviation noticeably strengthens the impact of anthropogenic pollution of the atmosphere by the greenhouse gases on ozone through modification of polar stratospheric clouds. As a result, with the A_2 scenario a water vapour increase also delays the attaining of unperturbed level of total ozone concentration in polar latitudes. In the Northern hemisphere the delay is about 5 years, in the Southern hemisphere the delay is about 2 years.

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