GLOBAL WARMING IMPACT ON ATMOSPHERIC POLLUTION

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Abstract. *Global warming refers to the gradual increase in global surface temperature, observed or projected, due to the radiation forcing caused by the anthropogenic emissions of greenhouse gases. The impact on air pollution at regional and local scale, is quantified by the modifications induced by the global warming on pollutant emissions, dispersion properties of the planetary boundary layer, physical parameters of the atmosphere determining the deposition processes of pollutants and intensity of their chemical reactions. Dominant impact of the global warming on a large number of pollutant species is determined by the surface temperature increase and the variation of water vapour quantity, anticipated by the climate models for the emission scenarios considered by the Intergovernmental Panel on Climate Change of United Nations Organization. Recent studies indicate that sulphur dioxide, ozone, nitrogen oxides, volatile organic compounds as well as the atmospheric radon will undergo significant concentration variations due to the global warming.*

Keywords: global warming, climate change impact, atmospheric pollution, climate model, dispersion model

1. Introduction

Global warming describes the process of gradual increase of surface temperature (2 m above the ground) at the planetary level, observed or forecast, due to the radiation forcing caused by the antropogenic emissions of greenhouse gases. Radiative forcing is defined as the change in the net, downward minus upward, irradiance (Wm^{-2}) at the tropopause due to a change in an external driver of climate change, such as a change in the concentration of greenhouse gases or the output of the Sun. Greenhouse gases absorb infrared radiation, emitted by the Earth's surface, by atmosphere itself due to the same gases, and by clouds. The absorbed radiation is reemitted to all sides, including downward to the Earth's surface. Thus greenhouse gases trap heat within the surface-troposphere system, inducing a temperature increase in this one. This additional warming is known as greenhouse effect. Water vapour (H_2O), carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4) and ozone (O_3) are the primary greenhouse gases in the Earth's atmosphere.

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Antropogenic sources of greenhouse gases contribute to enhancing the natural greenhouse effect (beneficial, caused by natural sources), leading to an imbalance in the energy balance of the planet, that induces the global warming. The scientific reports worked out by Intergovernmental Panel on Climate Change of UNO [1], on the basis of accumulated knowledge at global level, have shown that global warming has a significant impact on physical and chemical processes in the climate system components, one of which is terrestrial atmosphere. The atmospheric pollution as a process of change in composition as against a reference composition considered ”clean” is determined by:

(i) existence of natural and antropogenic sources of pollutants (chemical or radioactive),

(ii) physical behaviour of the atmosphere and

(iii) chemical reactions taking place among the emitted pollutant (called primary ones) or between them and other substances in the atmosphere resulting the secondary pollutants.

In case of radioactive pollutants, the decay may generate other radioactive pollutants. The global warming impact on atmospheric pollution can be quantified by estimation of the modifications induced by climate change on pollutant sources, dynamics of the atmospheric processes and chemical reactions. Basically, the study of global warming impact on atmospheric pollution requires the existence of a climate model describing the dynamics of physical parameters of climate system, including the atmosphere, for different scenarios of greenhouse gas emissions, usually until the end of the 21st century and of a dispersion model that calculates the future pollution state of atmosphere using as input data those generated by the climate model [2,3]. Recent studies show noticeable effects of global warming on the variation of pollutant concentrations in the atmosphere [4]. Here is the first paragraph.

2. Simulation of the global warming and pollutant dispersion

2.1. Global warming

Global warming process can be described by means of the climate models. These are mathematical representations of the climate system based on the physical, chemical and biological properties of its components, their interactions and feedback processes. Coupled atmosphere-ocean general circulation models including boundary conditions quantifying the interactions with other components of the climate system (biosphere, cryosphere, lithosphere) are considered the most advanced climate models.

At present, the future dynamics of the climate parameters is estimated by means of the climate models making use of an greenhouse gas emission scenario resulting from the assumed development characteristics of society until the end of this century.

The most used emission scenario is A2 which assumes the society development at the regional level only, the continuous increase of world population and introduction of technology more slowly [1,2].The CO2 emissions corresponding to this scenario ranges from 7,97PgC/y, in 2000, to 29,09Pg/y (1Pg=10^{15} g), at the end of 21st century [2]. Global climate models have a spatial resolution between 200 km and 300 km [5], too large to study the dynamics of climate parameters at the local scale, e.g., a space scale of a town. In order to work out the local scale studies, the regional climate models are used with boundary conditions provided by the global models. Thus, the dynamics of the physical parameters of the atmosphere can be simulated in much finer space domains, such as, 25 km [8] or 10 km [6]. Examples of general circulation models used for the studies on the impact of global warming on atmospheric pollution may be referred ECHAM4 [7], HadCM3 [18, 19], HadRM3 [9], RegCM [10, 11]. ECHAM4 is a coupled atmosphere-ocean general circulation model worked out at Institute of Meteorology "Max Planck" in Germany, on the basis of the weather prediction model of the European Center for Medium-Range Weather Forecast (ECMWF). HadCM3 is a coupled atmosphere-ocean general circulation model made at Hadley Center for Climate Prediction and Research, in UK. HadRM3 and RegCM are regional climate models made, the first, at Hadley Center, and the second at International Center for Theoretical Physics in Trieste (Italy). For the studies on climate change impacts in northern emisphere, the ECHAM model has been used coupled with an ocean general circulation model (OPYC3), ECHAM4-OPYC3 [4].

2.2. Dispersion of the air pollutants

The simulation of pollutant dispersion in the atmosphere for estimating the impact of global warming on air quality at different spatial scales, is achieved by means of the numerical solving of either eulerian continuity equation, as in the case of CAMx model [12], or three-dimensional advection-diffusion equation, as in the case of DEHM model [4], with the source and sink terms describing the real sources of pollutants and removal by physical processes (wet and dry deposition) and chemical reactions. In order to estimate the pollutant concentration with a harmful effect on human health and environment, the models must consider a sufficient number of chemical reactions

The DEHM model covers the northern hemisphere with a spatial resolution of 150 km/150km and takes into account 63 different chemical compounds, among which are the SOx(SO_2, SO_4), NOx(NO_2, NO), O_3, CO, volatile organic compounds (VOC), $PM_{2,5}$, PM_{10}. The vertical structure of the grid points allows to consider 7 steps within the planetary boundary layer, 10 within the troposphere and 3 within the stratosphere. CAMx model has the possibility to use a variable spatial resolution by nesting the modeling area (with steps of 1-2 km) and considering the boundary conditions from the space domain with larger resolution. Using as input data the physical parameters of atmosphere (wind speed, air temperature at 2m, precipitation intensity, cloud cover) generated by the climate models for the scenarios of greenhouse gas emissions, the dispersion models calculate the atmospheric pollutant concentrations by supposing constant anthropogenic emission rates at the level of the period 1990-1999. This methodology allows for the estimation of the air pollution states for different future periods, e.g., the period 2090-2099.

3. Results and discussions

In what follows, results regarding (1) the dependence of pollutant concentrations on physical parameters of the atmosphere, obtained by measurements, (2) the influence of global warming on atmospheric variables determining the air pollution and (3) the effect of global warming on pollutant concentrations in the atmosphere.

3.1. Regarding point 1

Meteorological parameters have a significant influence on the air quality, what means on the pollutant concentration values as compared with the limit values and alert threshold [13, 14, 15]. Hereinafter, examples regarding the effects of wind speed, surface temperature and precipitations on pollutant concentrations are shown. Figure 1 presents the variation of NOx concentration as function of the wind speed, obtained from measurements made at an automatic station from the pollution monitoring network in London [3].

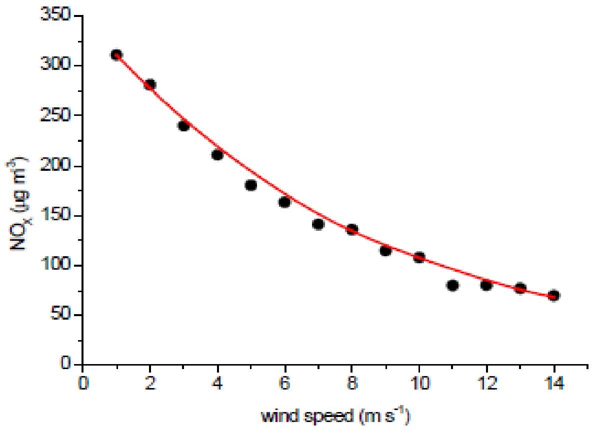

Figure 1.Nitrogen oxides concentration as a function of wind speed at an automatic monitoring station in London [3]

It notes, as was expected, a significant increase in concentration with decreasing wind speed because the atmosphere becomes more stable, which leads to reduction of turbulence and, consequently, to the diminution of pollutant diffusion. The examples in figures 2 and 3 show the influence of wind speed on particulate matter(PM) with size equal to or greater than 2.5 µm, $PM_{2,5}$ and $PM_{>2,5}$ and are derived from data measured in the pollution monitoring network in London [3].

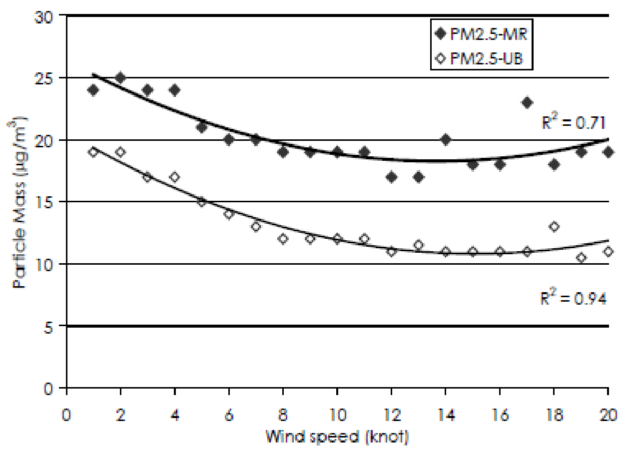

Figure 2. The $PM_{2,5}$ concentration as a function of wind speed at two monitoring stations (MR-Marylebone, UB-Bloomsbury, 1knot=0,514 m/s) in London [3]

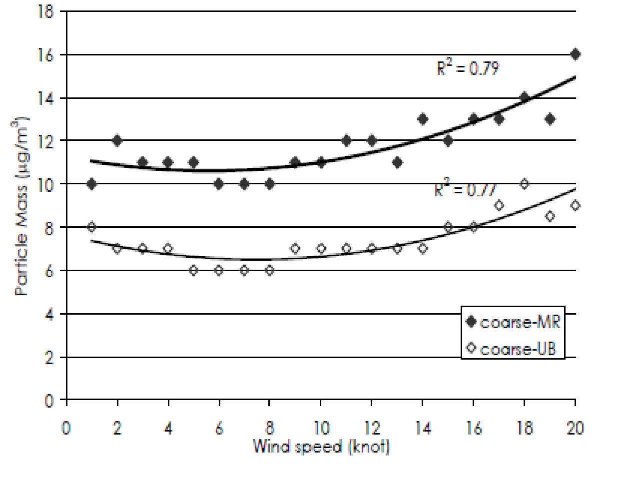

Figure 3.The PM>2,5 concentration as a function of wind speed at the same monitoring stations as in Figure 2 [3]

It is noted that in case of $PM_{2,5}$ the concentration decreases with increasing wind speed due to the enhancement of dispersion process, but in the case of PM>2,5 the concentration increases with increasing wind speed due to the resuspesion process of the particles deposited on soil. Figure 4 shows the close relationship between daily maximum temperature and daily maximum surface ozone concentration, in particular, a heightened sensitivity at higher temperatures [16].

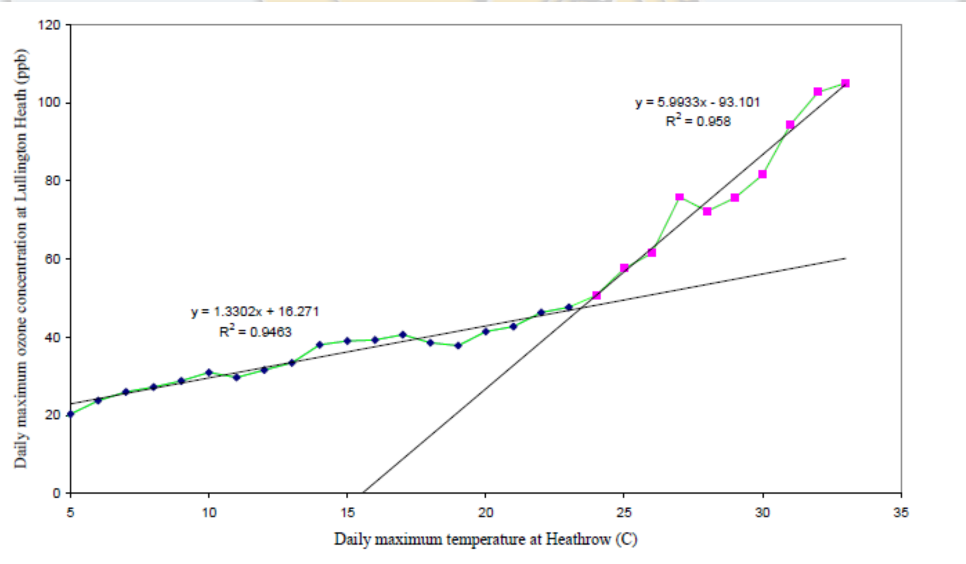

Figure 4. Relationship between daily maximum temperature and daily maximum ozone concentration (1ppb=2µg m^{-3} for O_3, at 20^0 C and 101,3kPa) [16].

It should be noted that the surface temperature is dependent on the intensity of solar radiation, planetary boundary layer height and atmospheric stability. In Figure 5, the averaged effect of rainfall on average PM_{10} and $PM_{2,5}$ concentration is presented [3].

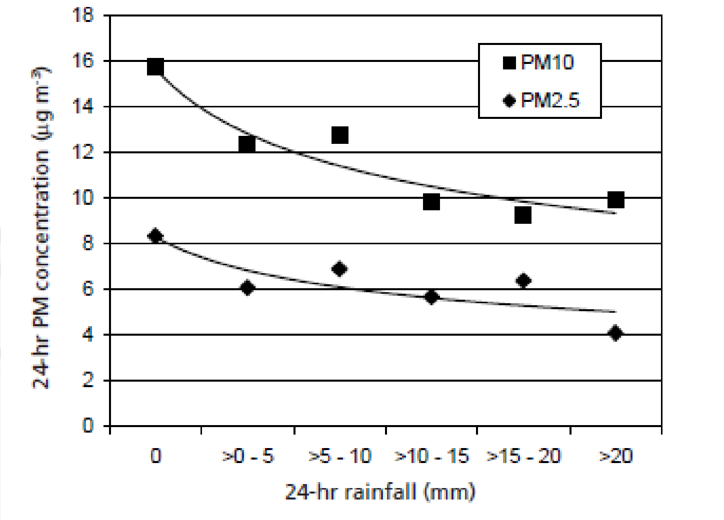

Figure 5. Averaged effect of rainfall on 24-hour PM_{10} and $PM_{2,5}$ concentration.

Decrease of the 24 hour average concentrations with increasing amount of rainfall can be explained by the wet deposition that refers to the natural processes by which the air pollutants are scavenged by atmospheric hydrometeors (cloud and fog drops, rain, snow) and are consequently delivered to the Earth's surface. These processes effectively cleanse the air of gases and small particulates.

3.2. Regarding point 2

Making use of the UKCIP02 emission scenarios, the variations induced by the global warming on atmospheric variables that determine the level of atmospheric pollution were simulated [3, 7]. Simulations were performed by using the HadRM3 regional climate model with spatial resolutions of 50 km and 25 km [3] and the boundary conditions provided by the HadCM3 global model.
Table 1 presents the results regarding possible variations of the main atmospheric variables affecting air pollution in case of the UKCIP02 scenarios [9].

Table1.Potential impact of global warming on atmospheric variables affecting the air pollution

Atmospheric variables	UKCIP02 scenarios	Impact on air quality
Surface temperature	- annual warming by the 2080s of between 1° and 5°C depending on region and scenario - winter, greater night-time than day-time warming -summer, greater day-time than night-time warming - greater warming in summer and autumn than in winter and spring	may favor intense ozone episodes
Precipitation	-generally wetter winters -significantly drier summers	possibly, more intense pollution during summer because the wet deposition decreases
Wind speed	-summer, lower wind speeds -winter, higher wind speeds	-summer, dispersion weakening, more intense pollution -winter, less intense pollution
Boundary layer depth	-summer – increased frequency of depths greater than 1500m -**w**inter – no obvious modifications	possibly, weaker pollution, more intense dilution and turbulent mixing
Cloud Cover	-reduction in summer and autumn and an increase in radiation -small increase in winter cloud cover	possibly, weaker local pollution, more intense turbulence. Longer duration of the Sun's light increases photochemical reactions and consequently, the pollution with O_3
Pressure (mean sea level)	-summer – high pressure more prevalent -winter – low pressure more prevalent	-summer, more intense pollution due to anticyclone conditions (stagnation) -winter, weaker pollution, turbulence being more intense

One of the major risks for air pollution caused by global warming is the increased frequency of occurrence of vegetation fires. Other anticipated effects of global warming on atmospheric pollution indicates a significant increase in ozone concentration at ground surface in Central and Southern Europe and a decrease in Northern Europe [20].Simulation of ozone levels in the city of New York for the years 2050 anticipates an increase of 4.5% of cases of deaths due to ozone levels [21].

3.3. Regarding point 3

Using the coupled atmosphere-ocean ECHAM4-OPYC3 model and dispersion model of chemical pollutants DEHM, in paper [4] is analyzed the global warming impact on concentrations of sulfur dioxide (SO2), sulphate (SO4), ozone (O3), nitrogen dioxide (NO2), hydroxyl radical (OH) and isoprene (C5H8), for the greenhouse gas emission scenario IPCC-A2.Calculations were performed for the period 2090-2099 assuming inventory of antropogenic emissions of pollutants in the years 1990-1999. The most pronounced variations of atmospheric variables predicted by the coupled model ECHAM4-OPYC3 are the increase of the global temperature in the northern hemisphere (Figure 6), more intense towards the north pole, the diminution of rainfall in Southern Europe and in the South West U.S.A and increase in Arctic regions.

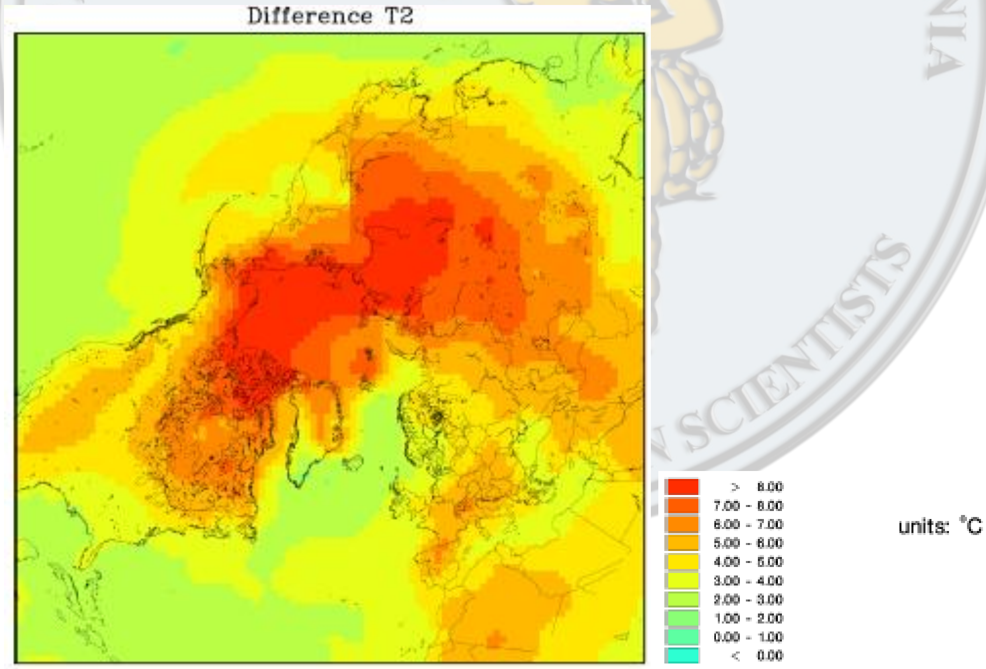

Figure 6.The increase of surface temperature in northern hemisphere in the years 2090 to that in the 1990s, under the A2 scenario conditions [4].

Whereas the sources of pollutants were kept constant at the level of the 1990s, simulations on concentrations of pollutants in the period 2090-2099 show only the changes caused by variations in atmospheric parameters caused by global warming.

<u>Sulfur dioxide</u>

Global warming causes increases in the concentration of SO_2 over 12% in industrial areas, most often coincide with the densely populated areas (figura7).For example, in this case is Central and South East Asia and the east coast of USA. In the Pacific and Atlantic oceans are lines of high concentrations of SO_2 (increases between 3 ÷ 9%) associated to the international shipping transport lines. Simulations also show a significant decrease (~ 12%) in Siberia, possibly due to increasing quantities of rainfall (Figure 8).

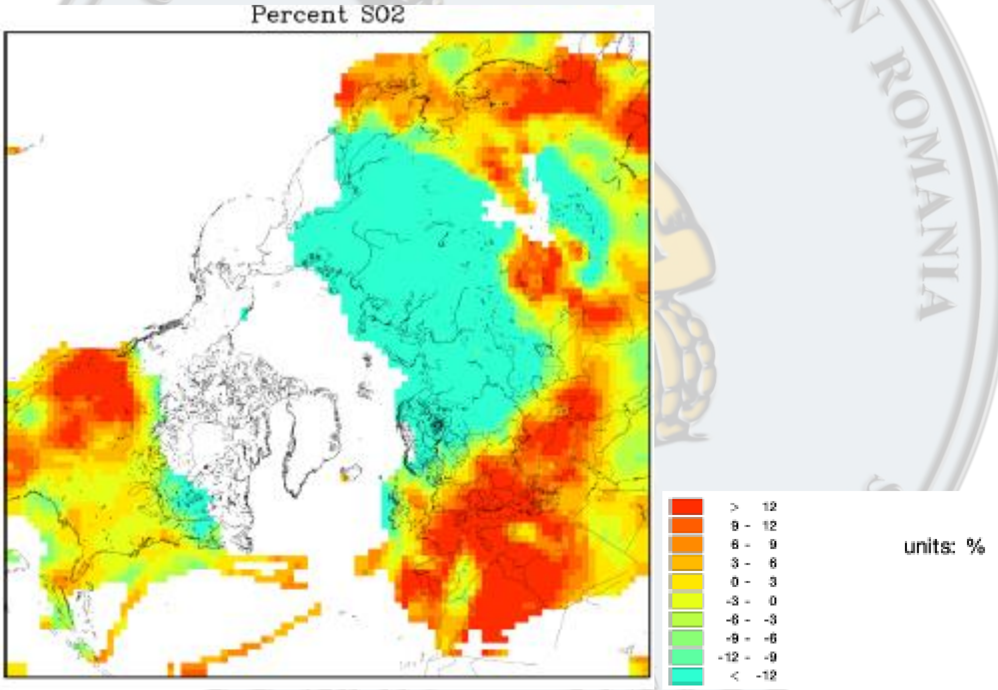

Figure 7. Impact of global warming on the concentration of SO_2 [4]

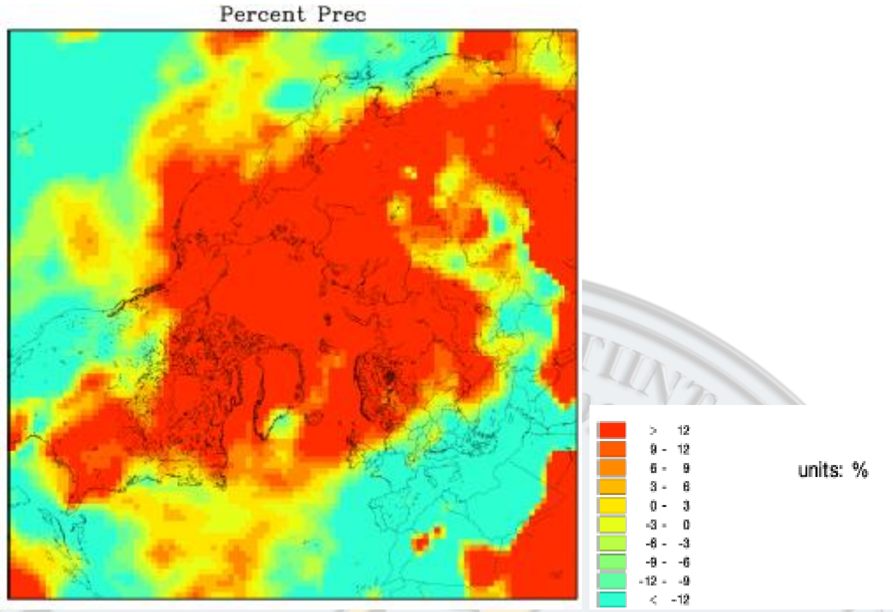

Figure 8. Changes in quantities of rainfall in the A2 scenario [4]

Ozone

In Figure 9 shows the impact of global warming on surface ozone concentrations in the northern hemisphere.

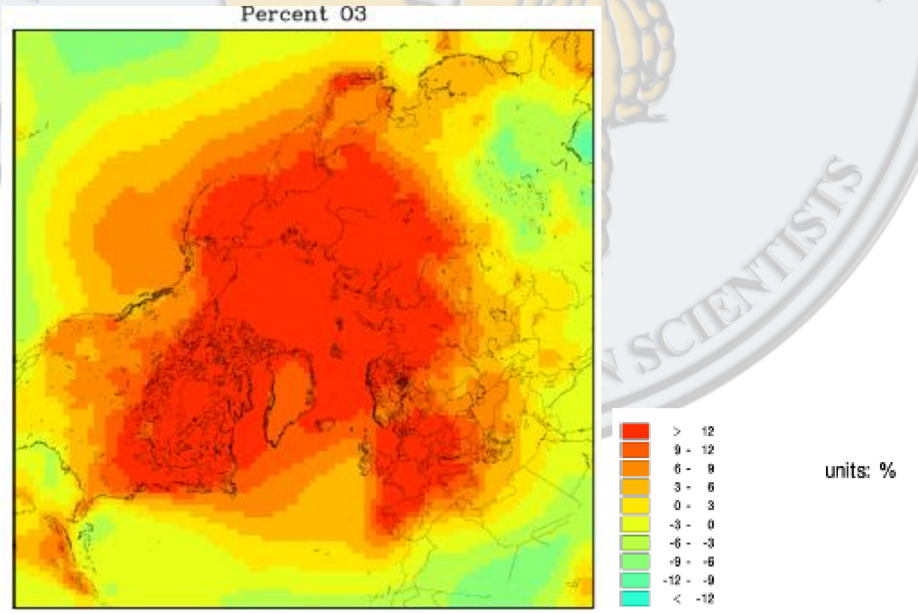

Figure 9. Impact of global warming on the ozone concentration [4]

From the spatial distribution of the difference of average concentrations in the atmosphere during the periods 2090-2099 and 1990-1999 may be anticipated a significant increase (> 12%) of ozone concentration with increasing latitude, beyond the 30^0 north.

In equatorial areas the differences between the two periods is clearly downward. In general, ozone concentrations over the oceans is growing weaker.

Area of maximum of the ozone concentration increase is correlated with the area of maximum of the temperature increase caused by the greenhouse effect.

Nitrogen dioxide

Emissions of NO and NO2 are mainly due to traffic and thermal power stations, leading to increased concentrations in populated areas. In general, the level of NO2 decreases where ozone levels increase, and vice versa. The mechanism underlying this dependency is explained by the reactions:

$$NO + O_3 \rightarrow NO_2 + O_2$$

$$NO_2 + h\nu \rightarrow NO + O$$

$$O + O_2 \rightarrow O_3$$

This mechanism explains the opposing trends of variation of the two elements in certain areas (near the mountains Himalayas), but does not explain the simultaneous increases of NO2 and O3 in other geographical areas (Caribbean area).

Isoprene

Isoprene is a volatile organic compound and an important precursor of ozone. In the DEHM model, isoprene sources are of biogenic nature, and hydroxyl OH radicals by chemical reaction, leads to the isoprene disappearance. Simulation of the global warming impact show that the isoprene will increase everywhere over land, areas with trees and bushes being the main sources. Expected increase of isoprene concentration will cause an increase of ozone concentration more than 12%.

Radon

Radon is an inert radioactive gas emitted by soil. Studies on trends of radon radioactivity are necessary to evaluate the radiological impact of the natural radiation background on the population. Emission rate is dependent on atmospheric pressure, wind speed, thermal gradient at the surface soil and vegetation. Modeling the influence of global warming on radon radioactivity in the atmosphere has highlighted an increase of 18 ÷ 20% in radon concentration in the lower atmosphere [22], which leads to an increased radiological impact on the population, with adverse consequences on the respiratory system.

Conclusions

Global warming causes notable variations of physical parameters of the atmosphere such as temperature at the surface, the amount of precipitation, wind speed, cloud cover, intensity of solar radiation at land surface.

These variations lead to changes in atmospheric dynamics, in particular, planetary boundary layer where take place the processes determining the level of atmospheric pollution.

Using the results of climate and dispersion models, in this paper is presented on the one hand the influence of global warming on the atmospheric variables that determine the level of pollution and on the other hand, the estimation of the variation in concentrations of air pollutants caused by global warming.

Increased temperature globally and increase in certain geographical areas and decrease in others, of the amount of rainfall, in the 21st century, are the dominant factors resulting from climate predictions under in the future growth of emissions of greenhouse gases foreseen by the IPCC-A2 and UKCIP02 scenarios.

Increasing temperature has resulted in increasing emissions of biogenic isoprene, which is an important precursor of ozone, leading to a significant increase in concentration of ozone in the low atmosphere.

Increasing quantities of rainfall causes intensification of wet deposition, which leads to decrease the degree of pollution of the atmosphere, especially in northern regions.

Modeling anticipates a significant increase of natural radioactivity in the atmosphere under the global warming conditions.

A study of the impact of the global warming on pollution levels in different parts of Romania would be extremely useful for analysis of possible measures for the protection of human health and environmental conservation.

Until now, a study on the impact of climate change on agricultural and forest ecosystems and water resources in Romania, funded by the U.S. government has been carried out by the Romanian and American specialists [2324].

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