The Effects of Industrial and Agricultural Practices on Atmospheric Chemistry During the Anthropocene with Emphasis on the Tropics[1]

Paul J. Crutzen*
Max-Planck-Institute for Chemistry, Mainz, Germany

INTRODUCTION

The gases that are most significant for atmospheric chemistry and for Earth's climate are not its main components - nitrogen (N_2), oxygen (O_2), and argon (Ar), which together with variable amounts of water vapor make up more than 99.9% of the mass of the Earth's atmosphere - but many gases that are found only in very low concentrations. Carbon dioxide (CO_2), which currently has a concentration of approximately 370 per million air molecules, is of crucial importance in that, together with water vapour and sunlight, it builds the organic molecules of living matter. As a so-called greenhouse gas, carbon dioxide is also significant for the Earth's climate. However, despite these important aspects, it plays no role in atmospheric chemistry.

The chemically active gases have much lower abundances in the atmosphere than CO_2. Among these, ozone (O_3) and water vapour are the most important drivers of the photochemistry of the atmosphere. Without ozone, the chemistry and chemical composition of the atmosphere would be totally different. Looking at the vertical distribution of ozone, an example of which is shown in Figure 1, we see that there is little ozone up to about 10 km altitude. In the stratosphere, above about 10 km, ozone concentrations rise quickly with altitude. Looking at the vertical distribution of temperatures, we also see that in the stratosphere they no longer decrease with altitude. Because of this temperature distribution, vertical mixing in the stratosphere is much suppressed.

Until about 20 years ago it was thought that the troposphere contained only ozone which had been transported down from the stratosphere and its enormous importance for the chemistry of the troposphere, as we will describe in this paper, was not recognized. Tropospheric ozone makes up only about 10% of the total ozone in the atmosphere, with an average mixing ratio of about 40 nmol mol $^{-1}$ (nanomole per mole).

Figure 2. shows the altitude to which solar radiation penetrates into the atmosphere. Radiation with wavelengths shorter than 200 nm is to a large degree removed above 50 km. This happens primarily through absorption by N_2 and O_2. But absorption of solar radiation by these main atmospheric gases does not occur beyond about 240 nm. Fortunately, ozone strongly absorbs ultraviolet radiation in the wavelength range 200-310 nm. Were it not for atmospheric ozone, this radiation would penetrate uninterrupted to the Earth's surface. For the Earth's current biosphere, this would have catastrophic

---
[1]Keynote speech and dialogue at the Faculty of Science, Chiang Mai University, Chiang Mai 50200, Thailand on 4 December, 2003.

*Professor Dr. Paul J. Crutzen is a Nobel Laureate for Chemistry in 1995.

consequences. It is worthwhile noting here that only during the last 20-25% of Earth's age its atmosphere may have contained about the current level of oxygen and ozone. The Earth was thus without the protective oxygen and ozone shields for most of its history. This must have forced primitive life to develop only in dark hideaways. The average mixing ratio of ozone in the atmosphere amounts to only about 0.3 per million air molecules. It is, nevertheless, sufficient to absorb the most part of the dangerous UV radiation. Beyond 300 nm the absorption ability of ozone becomes so weak that the UV radiation can penetrate to the Earth's surface. It is the radiation up to 340 nm, also called UVB radiation (B stands for biologically active), that still exerts a stress on the biosphere. We are all familiar with the fact that when we stay too long unprotected in the sun, we may get sunburnt. Plants can also be affected by this radiation.

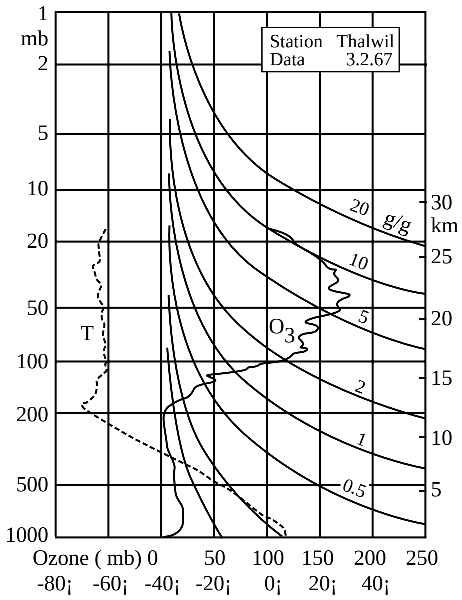

Figure 1. Measured ozone and temperature profiles over Thalwil, Switzerland, 1967.

On the other hand, we know from research conducted during the past 25 years (Levy, 1971) that this same radiation is also very important for keeping our atmospheric environment clean. The reason is the following: up to wavelengths of about 340 nm UV radiation is capable of splitting an ozone molecule into an oxygen molecule and an excited oxygen atom (O^*). The latter has enough energy to react with atmospheric water vapor to produce hydroxyl radicals, with the chemical formula OH (note: this is a neutral molecule and not the base ion OH-).

R1	$O_3 + hv$	$\rightarrow O^* + O_2$
R2	$O^* + H_2O$	$\rightarrow 2OH$

The OH radical, "the detergent of the atmosphere", reacts with almost all gases, of both natural and anthropogenic origin, thus removing them for the atmosphere.