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The Earth's Climate System as a Resource

The climate as we know it is a natural resource that is becoming depleted due to the rising demand for energy. The most emission-intensive sectors are those providing for our comfort and welfare. We discuss these issues with **Prof. Mirosław Miętus** from the Institute of Meteorology and Water Management.

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Why are we so afraid of emissions from fossil fuels?

MIROSŁAW MIĘTUS: Fossil fuels are, of course, fuels that we extract from the interior of the Earth. From the perspective of the climate, such fuels are harmful. Why? We only need to look at the Earth's energy balance. The model that explains the related processes dates back over 100 years and is very simple. From the perspective of energy transfer, the Earth, treated simply as a sphere, is situated within the stream of solar radiation. For the climate system to be in equilibrium, the amount of energy that reaches the Earth from the Sun must be equal to the amount of energy that leaves the system.

How does this happen?

The Earth takes in shortwave solar radiation in an amount defined by what is referred to as the "solar constant" (the amount of solar energy per unit of time per unit of area measured on a surface perpendicular to the rays at the Earth's mean distance from the Sun – editor's note). Some of this energy is reflected back out to space, with the exact amount depending on the planet's albedo (the ratio of reflected radiation to incident radiation). This means that the climate system in fact takes in an amount of energy proportional to 1 minus the albedo, multiplied by the solar radiation flux. The planet absorbs shortwave radiation, which causes it to warm up, and then emits thermal energy back out of the system. For the climate system to remain in equilibrium, the amount of energy emitted must be equal to the energy that reaches the system from the Sun. This second type of radiation is longwave radiation (also called thermal radiation, it corresponds to the radiation of a body whose temperature is about 300 K), and its energy flux is determined by the Stefan–Boltzmann law. This law states that longwave radiation is proportional to the fourth power of the surface temperature. So we have the value of the energy flux of the shortwave radiation reaching the Earth on one side, and that of longwave radiation on the other. If we assume that Earth's atmosphere is completely "transparent" to the radiation that passes through it, which means that the radiation is not absorbed in any way by the atmosphere, and that the albedo is about 0.3, as has been confirmed by numerous studies, we will obtain an effective temperature of the Earth of about 255 K, which is about –18°C.

And so, if the atmosphere were "transparent" to longwave radiation, the temperature in the lower layer of the atmosphere would be –18°C, and this would be the average temperature near the Earth's surface. However, the atmosphere is not completely "transparent" to radiation and absorbs it partially, so the energy flux of the longwave radiation leaving the climate system is smaller. If we assume that the radiation capacity has this specific value (0.6), we can demonstrate that the effective temperature at the Earth's surface in the lower layer of the atmosphere is about 288 K, which

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means 33 K (and 33°C) more than the temperature that we would have if the atmosphere were "transparent" to longwave radiation.

What role does the atmosphere play in this process?

By interacting with the Earth's longwave outgoing radiation, the atmosphere absorbs some of this radiation, trapping it in the layer of gases. If there were no atmosphere, this phenomenon would not occur – longwave radiation would immediately leave the climate system, and the Earth would be much cooler. But because we have this layer of gases, the temperature near the surface is 33°C higher. We call this phenomenon the natural greenhouse effect. This happens because the Earth's atmosphere has numerous bands absorbing the Earth's thermal radiation. The atmosphere is composed of natural greenhouse gases, or gases that are present in the atmosphere as a result of natural processes and cause the Earth's surface temperature to be higher. These gases are carbon dioxide (CO_2), nitrous oxide (N_2O), and methane (CH_4). This makes life on Earth as we know it possible. We should stress that we are still talking about the average temperature. Even without the presence of gases, the temperature would vary spatially. The average temperature for the whole of the globe is 14–15°C, but the temperature near the equator is more than 10 degrees higher, and the temperature at the poles is tens of degrees lower.

How has the atmosphere and the climate system changed as a result of the emergence of human civilization?

The atmosphere and the climate began to undergo gradual transformations in tandem with the advancement of civilization. The human impact on the Earth's climate system was initially negligible due to the small population size and a low level of the complexity of social life. With the arrival of the industrial era, however, when the burning of fossil fuels, coal, and wood, intensified, this impact started to grow. This led to the emission of gases, mainly CO_2, which plays a dominant role in the natural greenhouse process. From the early 19th century to the end of the 20th century, CO_2 emissions rose more than twentyfold, and the concentration of this gas in the atmosphere increased from 270 ppm to 415 ppm (parts per million). The concentration of other greenhouse gases has also increased. For example, N_2O is also a product of the burning of fossil fuels, mainly petroleum and its derivatives in engines. In turn, CH_4 emissions result primarily from agricultural activities. Today's agriculture differs greatly from the agriculture 200–250 years ago. If I were to name just one reason for this situation, it would be the massive rise in the number of people – from less than 1 billion to over 7.5 billion. The intensity of food production increased, and so did CH_4 emissions. These mainly come from the growing surface area of rice cultivation in the world (rice is the staple food for much of

Horse-drawn carriage, 1940

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the world's population) and meat production (we are eating more and more meat).

These last 200 years seem crucially important from the perspective of climate change. What else has changed over this period?

Some of the changes have occurred in the aspects of everyday life that may not be the first things that come to our minds, for example human mobility. Since the beginning of the 19th century, the distance traveled per person per day has increased by more than 1000 percent! Two hundred years ago, a person traveled up to 100 m a day because there was simply no need to travel any further. For example, if people went to work, their workplace was near their home. Today, we travel an average of 40 km per day! Growth in human activity has driven up the demand for energy, and fossil fuels are still its main source.

Road transport, which makes this increased mobility possible on a daily basis, is also a powerful source of anthropogenic greenhouse gases. Burning one liter of gasoline emits almost 2.6 kg of CO_2 into the atmosphere, which means that traveling a distance of 100 km by car translates into the emission of approximately 25.5 kg of CO_2 into the atmosphere (assuming that a car uses an average of 10 L/km). In the case of oil, the emission of CO_2 is approx. 2.8 kg per liter of fuel burned, and this process is coupled with the emission of carcinogenic benzo[a]pyrene.

How do we know that greenhouse gas concentrations are now higher than ever?

From the perspective of the past 800,000 years, we know that the concentration of greenhouse gases is now higher than ever. We also know that this concentration has grown at the fastest rate over the past 2000 years. There were periods in the Earth's natural history when the concentration of greenhouse gases was nearly comparable to today's levels, but we cannot demonstrate that the rate of this growth was as fast as it is today. This is important, because even if this value was once similar to today's levels, its possible effects, including the climate change at that time, did not affect humans because they did not exist at the time. After all, we look at climate from the perspective of its impact on us. We see it as a natural resource that supports the development potential of our civilization. The ongoing change may cause it to lose these qualities in many regions of the world, which will lead to mass migrations. This will result in a growing population density in the regions where humans will be able to function, which will negatively affect the quality of life, causing problems with the supply of food, access to water, and so on.

The Intergovernmental Panel on Climate Change (IPCC) publishes graphics showing changes in radiative forcing (which means changes in the radiative balance resulting from the anomalies that occur in the climate system) related to the increased concentration of gases that make up the Earth's atmosphere. As a consequence of this increase, a discrepancy arises between the amount of energy reaching and leaving the Earth's climate system. Recent IPCC data from seven years ago show that radiative forcing resulting from the concentration of CO_2 is 1.7 W/m². This value is estimated at 1 W/m² for CH_4 and at 0.17 W/m² for N_2O. When we add these values together, it turns out that the radiative forcing caused by the three main greenhouse gases is 2.87 W/m². Then there are the gases collectively referred to as chlorofluorocarbons (CFCs) and hydrofluorocarbons (HFCs), which appeared as a result of human activity, but they mix well, so their radiative forcing is 0.18 W/m². However, there are also gases that cause the climate system to cool.

Do different greenhouse gases warm the Earth to different degrees?

Each greenhouse gas has a different warming potential. The warming potential of a gas is its capacity to warm the atmosphere compared to that of CO_2. This means that if the atmosphere takes in the same amount of methane and CO_2, the warming of the atmosphere caused by methane will be 28 times greater over a period 100 years. In turn, CO_2 has globally the greatest impact on climate change because it is by far the most abundant.

In addition, greenhouse gases have different "lifetimes" in the atmosphere. CO_2 produced today has a lifetime of up to 100 years, while CH_4 survives only around 12 years. The aforementioned chlorocarbons have an even greater warming potential. In addition, they stay in the atmosphere for tens of thousands of years! They include gases called chlorofluorocarbons, which we once identified as being responsible for the degradation of the Earth's ozone layer and the warming of the atmosphere. One of the most dangerous gases in this group is sulfur hexafluoride, which has the chemical formula SF_6 (a lifetime of about 3,000 years and a global warming potential of approximately 23,000 for a 100-year timescale).

Some gases have short lifetimes in the atmosphere. Examples include carbon monoxide, various nitrogen oxides, aerosols, and ozone. These gases can both warm and cool the climate. Gases that evidently cool the climate include nitrogen oxides (up to −0.15 W/m²). Since sulfur aerosols cool the climate, it was proposed that they should be used in the fight against global warming. Such ideas came from volcanology, because volcanic eruptions are able to cool the climate for a short period of time. The year 1816 went down as the "Year Without a Summer" because the ash related to the eruption of Mount Tabora in Indonesia blocked access to sunlight for months, causing many weather anomalies even in Europe.

Could the way different greenhouse gases affect the atmosphere change?

Yes, it could change in a significant way if the relationship between their concentrations changes. For example, this may happen if the huge deposits of CH_4 currently trapped in permafrost or deep in the sea are released as a result of global warming. The ocean floor is characterized by relatively stable physical conditions, so the methane trapped there is found in solid form and should remain there for the time being. But the methane trapped in permafrost is a ticking time bomb, because thawing will release this gas into the atmosphere and it could speed up the warming process in a very significant way. We should bear in mind that CH_4 has a much greater warming potential, and the thawing of permafrost would release huge amounts of this gas into the atmosphere. This methane is natural, but its release into the atmosphere will be caused by human activity.

The effects of modern climate change are multifaceted and are difficult to predict accurately. What are our chances of survival?

Forecasts suggest that the changes resulting from the ongoing climate warming will be rapid and extensive, and they will become real in just a few decades. Also, we should remember that what we know about greenhouse gases and climate change is changing as well. From the perspective of the IPCC's activity (slightly over 30 years), our knowledge of greenhouse gases in the climate system has evolved. Thirty years ago, we stressed that we had a good understanding of the role of the three natural greenhouse gases I mentioned earlier, but we also said that we knew little about other gases and more in-depth studies were needed in this field. Today's assessment of the level of our scientific knowledge of the role of these gases in the climate system is very different. We know a lot about most of the natural gases, but our knowledge of short-lived gases remains moderate.

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The continuance of life on Earth in some form is not in jeopardy, because there are organisms that can survive even in extremely high temperatures, but humans may prove unable to withstand them. The question is, will the current potential of the climate system, which is conducive to the development of civilization, be exhausted slowly and will we manage to slow down these changes to a level that is acceptable and safe for us? Or will the climate change be so rapid and significant that it puts our existence in jeopardy?

Interview by **Justyna Orłowska, PhD**