Basics of Global Warming

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1. Climate, Climate System and Global Warming

WMO shows:

- Weather describes short term natural events - such as fog, rain, snow, blizzards, wind and thunder storms, tropical cyclones, etc. - in a specific place and time.
- Climate, sometimes understood as the average weather, is defined as the measurement of the mean and variability of relevant quantities of certain variables (such as temperature, precipitation or wind) over a period of time, ranging from months to thousands or millions of years. Climate in a wider sense is the state, including a statistical description, of the climate system.
- The climate system consists of five major components: the atmosphere, the hydrosphere, the cryosphere, land surface, and the biosphere (Fig.1). The climate system is continually changing due to the interactions between the components as well as external factors such as volcanic eruptions or solar variations and human-induced factors such as changes to the atmosphere and changes in land use.

Figure 2 shows past changes in global mean surface temperature. In particular, it can be seen that there has been a significant increase since around 1980. Figure 3 shows atmospheric CO_2 concentrations observed in the past. Since the atmosphere is well-mixed, it is affected locally by human activities and forests, but on average over a relatively large area, it is almost uniform over the entire globe. It can be seen that this has increased little by little since industrialization. Figure 4 shows the results of past surface temperature changes calculated using a climate model, distinguishing between natural and anthropogenic factors. We can see that anthropogenic factors have contributed to the increase in global mean surface temperature.

Triggered by anthropogenic (human-induced) factors such as CO_2 emissions, the surface temperature is gradually rising. The climate system is a complex system, and various changes are occurring in the climate system, NOT limited to the increase in surface temperature. This is the "Global Warming".

2. Greenhouse Effect and Greenhouse Gases

The earth receives about 400 W/m^2 of solar radiation on average on the whole earth, and about 30% of it is reflected or scattered. The Earth emits 240 W/m^2 of terrestrial radiation, which roughly balances the amount absorbed. Assuming a uniform temperature of the earth, the temperature corresponding to this radiant energy is about 255K. This is much lower than the actual surface temperature. Assuming that the Earth's atmosphere does not absorb solar and terrestrial radiation, the average surface temperature is also about 255K.

The Earth's atmosphere is approximately 99% composed of approximately 78% N2, approximately 20% O2, and approximately 1% Ar. These homonuclear diatomic and monatomic molecules absorb little solar and terrestrial radiation. On the other hand, molecules of the earth's atmosphere, such as CO2 and H2O, which have more complex structures, absorb electromagnetic waves of specific wavelengths specific to each molecule, and simultaneously undergo a transition to a higher energy level. Solar radiation and terrestrial radiation are in different wavelength bands, and these gas molecules absorb more light with terrestrial wavelengths.

Assuming a system of a single parallel-plate atmosphere that is transparent to solar radiation and completely absorbing terrestrial radiation, calculations yield a surface temperature of 288 K for the Earth. This is pretty close to the real world average surface temperature.

In this way, the difference in absorption characteristics of solar radiation and terrestrial radiation by the earth's atmosphere affects the temperature of the earth, and this effect is called the greenhouse effect. The gas molecules that cause the difference in absorption characteristics are called greenhouse gases. In addition to H2O and CO2, O3 and NH3 etc. are known as greenhouse gases.

As the greenhouse effect increases and the greenhouse effect intensifies, the surface temperature of the earth becomes higher. This is clearly shown in the vertical one-dimensional radiative and radiative-convective equilibrium models. Therefore, the increase in greenhouse gases is considered to be the trigger and essence of global warming.

3. Projection of global warming and elucidation of its mechanism using climate models

In order to predict the future of the climate system, which is a complex system, numerical simulations have been performed using the coupled atmosphere-ocean model, which has been developed and used for research since around 1970. Since the IPCC (Intergovernmental Panel on Climate Change) was launched (1988), it has become active little by little, and the future projections of the climate system are now being made using climate models developed by many institutions/groups. Originally, it was based on an ideal experimental setup with simple models, such as atmospheric models coupled with simple ocean models (e.g., slab ocean models), given the greenhouse gases concentrations. Since then, the models have been improved by introducing ocean models, various processes of aerosols, and material cycle processes such as carbon, etc. In addition, numerical calculations are now being performed in a variety of experimental designs, enabling a variety of investigations that contribute to mitigation measures. One example of this is the utilization of factor analysis shown in Figure 4.

The climate models have been developed and improved by reflecting not only meteorology but also various knowledge related to atmospheric, oceanic, and land surface processes. Although the climate models still have many shortcomings and uncertainties, its ability to reproduce past climates has improved through observational verification.

Using the climate models, we can not only predict the future, but also obtain various scientific knowledge related to global warming. In the following sections, we will introduce some of the knowledge about global warming obtained from the physical processes incorporated into the climate models and the behavior of the climate models.

4. Various processes in the climate system and their effects on global warming

As already mentioned, the climate system has many components. Its state changes due to external forcing and variability within the climate system (variation within each component, interaction between components). The change in surface temperature due to the strengthening of the greenhouse effect can also be considered as the response of the atmosphere and ground surface to the input of CO2 etc. from the outside.

Changes in the climate system are not limited to changes in surface temperature. Various subsequent physical processes change the state of the climate system. Below are some of the main physical processes. Some physical processes have feedback effects. Also, the response time (time to reach equilibrium) varies.

[1] Planck response: When the amount of greenhouse gases in the atmosphere increases, the atmosphere and ground surface heat up in a short period of time, and then terrestrial radiation increases and almost reaches an equilibrium state

(Planck response, negative feedback). [2] Ice-Albedo feedback: Due to the increase in surface temperature, the area of sea ice and snow cover will decrease. This lowers the surface albedo (reflectance of solar radiation), causing further warming and ice melting (positive feedback). This also decreases the global reflectance of solar radiation, increasing the net shortwave incidence. This leads to an increase in the surface temperature of the earth. In addition, the melting of ice sheets causes sea level rise. [3] Water vapor feedback: As the atmosphere warms, the amount of saturated water vapor in the atmosphere increases by about 7%/K. Assuming that the relative humidity does not change, the amount of water vapor, which is a greenhouse gas, increases and the greenhouse effect is strengthened (positive feedback). The increase in water vapor content in the atmosphere causes an increase in precipitation intensity, or extreme precipitation. This also intensifies the precipitation pattern observed under the current climate to increase water vapor transport and enhance water vapor convergence (wet-get-wetter/dry-get-drier). [4] Cloud feedback: Clouds have a high reflectance, which reduces the amount of solar radiation that enters them, thus reducing global warming. On the other hand, it also works to increase warming due to the greenhouse effect, which absorbs terrestrial radiation. There are still many uncertainties about the effect of clouds on global warming, but it is believed that low-level clouds play the former role, and high-level clouds play the latter role. [5] Lapse rate feedback: There is a difference between the amount of warming in the lower atmosphere and that in the upper atmosphere due to global warming. It is thought that the amount of warming is greater in the upper atmosphere at low latitudes and in the lower atmosphere at high latitudes. Under the condition that the terrestrial radiation emitted into space is equal, when the amount of warming in the upper atmosphere is large (small), the amount of warming near the surface of the earth is small (large). This is called lapse rate feedback. In addition, since the amount of warming in the upper atmosphere is greater in low-latitude regions, it is thought that the atmosphere is becoming more stable with global warming, and that convection occurs less frequently. [6] Absorption by the sea: CO2 and heat enter the upper ocean from the lower atmosphere, which further warms the deep ocean and increases carbonation (ocean acidification and its impact on marine ecosystems). This time scale is thousands of years. Also, even if CO2 emissions decrease in the future, it will be emitted from the ocean instead, which will delay the decrease in atmospheric CO2 concentration over a long period of time. Ocean warming causes sea level rise through the expansion of seawater. The warming is also feared to have serious impacts on marine ecosystems.

5. Important concepts related to global warming

Radiative forcing and climate sensitivity are known as important concepts.

Radiative forcing is the amount of change in the radiation balance at the top of the troposphere caused by a factor when the climate system changes. Higher radiative forcing means that the factor has a greater impact on global warming. Future projections using climate models require future scenarios for greenhouse gas concentrations, emissions, etc., and the total radiative forcing is taken into account in creating future scenarios.

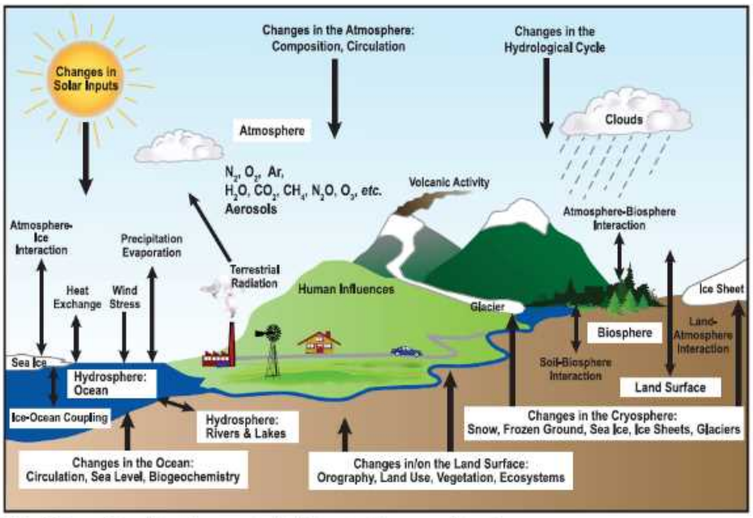
Climate sensitivity is a quantity that quantitatively indicates how much the climate system is affected by a certain external factor. Global warming usually uses changes in global average surface temperature as the impact on the climate system. In particular, it is generally evaluated in the form of changes in surface temperature (effects on the climate system) against changes in radiative forcing (external factors) when the atmospheric CO2 concentration is doubled.

6. Summary and Comments

The basics of global warming were lectured. Global warming is caused by intensifications of the greenhouse effect due to increases in anthropogenic greenhouse gases. The climate system is extremely complex, and there are many physical and other processes that cause various changes.

As per the IPCC report, if society continues to rely on fossil fuels as before, radiative forcing will reach 8.5W/m2 at the end of this century, and it is estimated that the temperature will rise by about 4K compared to pre-industrial times. Since this has a great impact on human life, international cooperation is required to reduce CO2 emissions under policies such as moving away from fossil fuels.

Figures:



FAQ 1.2, Figure 1. *Schematic view of the components of the climate system, their processes and interactions.*

Figure 1: Schematic diagram of the climate system. (AR5)

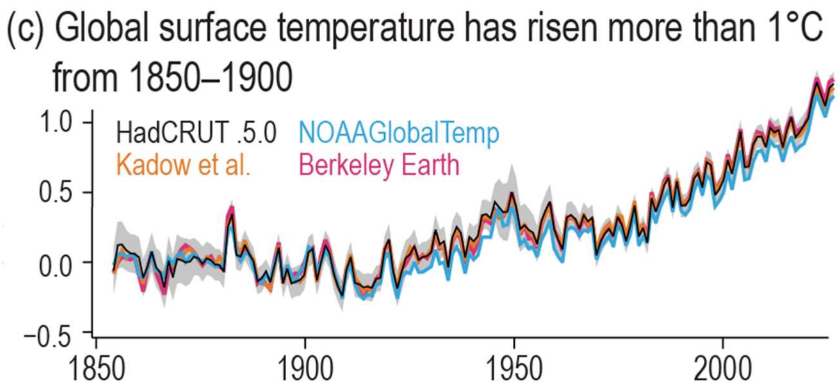


Figure 2: past changes in global mean surface temperature. (AR6)

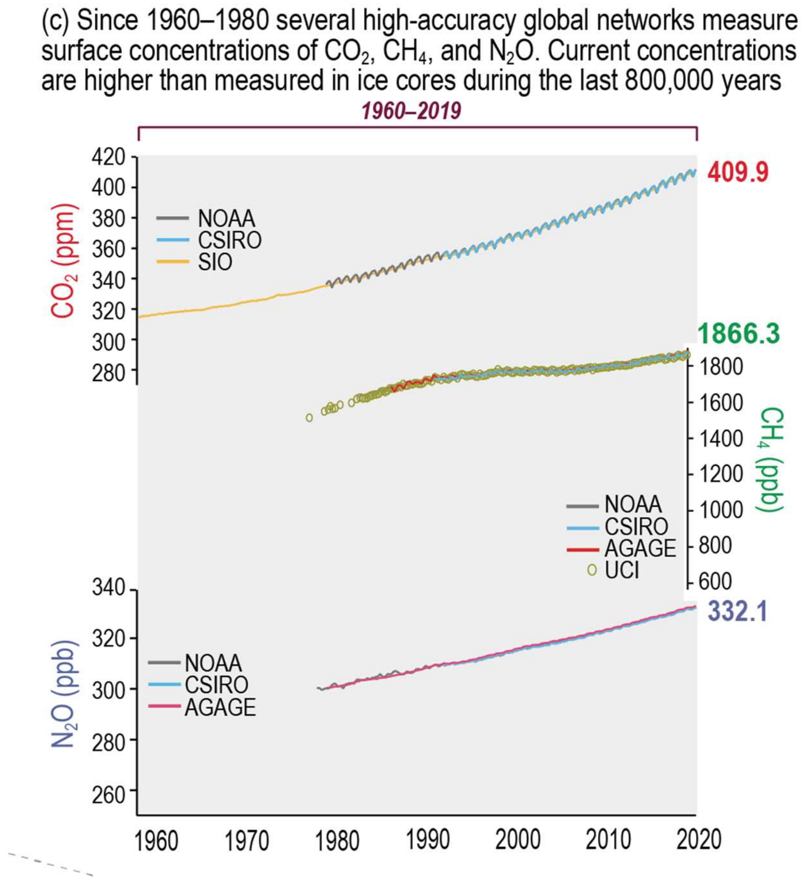


Figure 3: Atmospheric CO_2 concentrations observed in the past. (AR6)

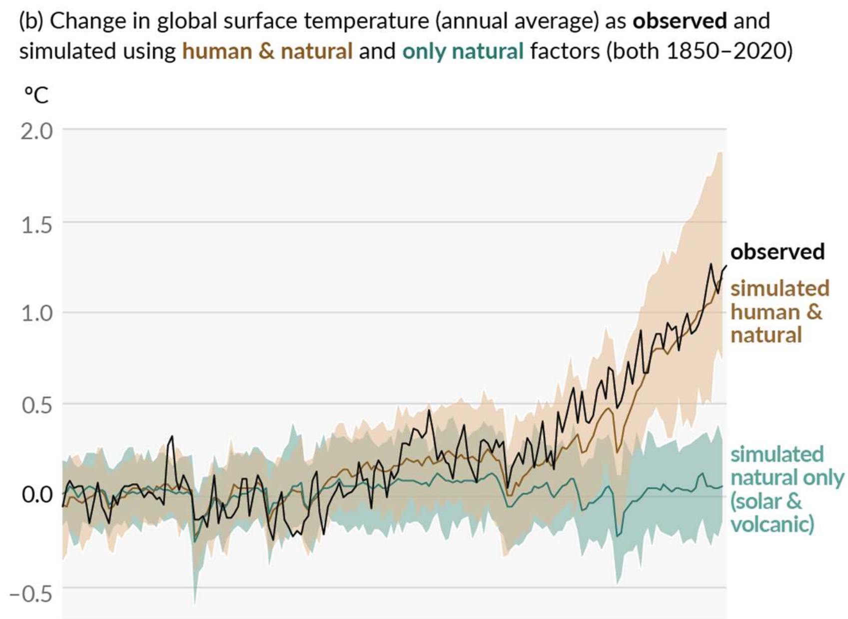


Figure 4: Change in global surface temperature as observed and simulated using human & natural and only natural factors. (AR6)