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Green House Gases interactions in Atmospheric Thermodynamics for Climate Change

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Abstract

Global climate change is a very complex subject. Carbon dioxide (CO_2), chlorofluorocarbons (CFCs), methane (CH_4), nitrous oxide (N_2O), and tropospheric ozone (O_3) are common green house gases. Atmospheric thermodynamic diagrams are used as tools in the forecasting of storm development. Atmospheric thermodynamics forms a basis for cloud microphysics and convection parameterizations in numerical weather models, and is used in many climate considerations, including convective-equilibrium climate models. Greenhouse gases trap some of the escaping heat closer to the Earth's surface, making it harder for it to shed that heat, so the earth warms up in order to radiate the heat more effectively.

Keywords: Climate; GHG; thermodynamics; model; atmosphere.

1. Introduction

A primary goal of climate science is to understand how the statistical properties of the climate system change as a result of variations in the value of external or internal parameters. An approach has been recently proved to have formal analogies with the usual Kubo 20 response theory for quasi-equilibrium systems [1] and to be amenable to numerical investigation [2]. The emphasis lies on the analysis of the irreversibility of the 10 climate system, and, especially, of its entropy production. This largely results from the intellectual stimulation coming from the maximum entropy production principle (MEPP), which proposes that an out-of-equilibrium nonlinear system adjusts in such a way to maximize the production of entropy. Even if the general validity of MEPP is unclear [3-4], its heuristic adoption in 15 climate science has been quite fruitful [5-6], and has stimulated a detailed re-examination of the importance of entropy production in the climate system [7]. Moreover, this has resulted into a drive for adopting of a new generation of diagnostic tools based on the 2nd law of thermodynamics for auditing climate models [8-10] and for outlining a set of parameterisations to be used in conceptual and intermediate complexity models, or for the reconstruction of the past climate conditions [5-6, 11-12].

Recently a link has been found between the Carnot efficiency, the entropy production and the degree of irreversibility of the climate system [13]. This has made possible a new fruitful exploration of the onset and decay of snowball conditions [14] as parametrically controlled by variations in the solar constant. Investigation is performed using the simplified and portable climate model Planet Simulator (PLASIM) [8-10]. Assuming local thermodynamic equilibrium which applies well everywhere except in the upper atmosphere, which has a negligible mass and, neglecting the impact of mixing processes [15]. Slab ocean climate models are well suited for providing an accurate steady state climate response [16]. The global atmospheric energy balance is greatly improved with respect to previous versions of the model by re-feeding the kinetic energy losses due to surface friction and horizontal and vertical momentum diffusion [17]. The three temperature indicators feature, as expected, positive sensitivities: the surface temperature sensitivity is well within the range of what is simulated by the climate models included in IPCC [18], whereas the two bulk thermodynamic temperatures have smaller sensitivities.

2. Atmospheric Thermodynamics

Atmospheric thermodynamics is the study of heat to work transformations (and the reverse) in the earth's atmospheric system in relation to weather or climate. In addition to the globally averaged surface temperature, the intensity of the Lorenz energy cycle, the Carnot efficiency, the material entropy production and the degree of irreversibility of the system are linear with the logarithm of the CO2 concentration. The generalized sensitivities proposed here demonstrate that the climate system becomes less efficient, more irreversible, and features higher entropy production as it becomes warmer. Changes in intensity of the latent heat fluxes tend to be the dominating ingredients, thus showing, at a fundamental level, how important it is to address correctly the impact of climate change on the hydrological cycle. Due to the monotonic (and, in particular, linear) dependence of the diagnosed variables with respect to the logarithm of the CO2 concentration, it is possible to reparameterise efficiently all the variables with respect to just this one. Using a recent theoretical approach, we study how the impact of global warming of the thermodynamics of the climate system by performing experiments with a simplified yet Earth-like climate model. In addition to the globally averaged surface temperature, the intensity of the Lorenz energy cycle, the Carnot efficiency, the material entropy production and the degree of irreversibility of the system are linear with the logarithm of the CO2 concentration. These generalized sensitivities suggest that the climate becomes less efficient, more irreversible, and features higher entropy production as it becomes warmer. Following the fundamental laws of classical thermodynamics, atmospheric thermodynamics studies such phenomena as properties of moist air, formation of clouds, atmospheric convection, boundary layer meteorology, and vertical stabilities in the atmosphere.

Atmospheric thermodynamics focuses on water and its transformations. Areas of study include the law of energy conservation, the ideal gas law, specific heat capacities, adiabatic processes (in which entropy is conserved), and moist adiabatic processes. Most of tropospheric gases are treated as ideal gases and water vapor is considered as one of the most important trace components of air. The major role of atmospheric thermodynamics is expressed in terms of adiabatic and diabatic forces acting on air parcels included in primitive equations of air motion either as grid resolved or subgrid parameterizations. These equations form a basis for the numerical weather and climate predictions. The sun warms the Earth. The Earth and its atmosphere radiate heat away into space. They radiate most of the heat that is received from the sun, so the average temperature of the Earth stays more or less constant.The greenhouse gases make the Earth warmer - like a blanket conserving body heat. The second law of thermodynamics (heat generally cannot flow spontaneously from a material at lower temperature to a material at higher temperature) has been stated in many ways.

3. Global Climate Change: Human Influences Chemistry

Components of environment viz. biosphere (living things), hydrosphere (water), lithosphere (rock/soil), and atmosphere (air) work together to create and maintain climate. However, the biosphere, humans in particular, has had an increasingly greater impact on climate in recent decades. One way in which humans have affected the climate is by increasing emissions of greenhouse gases. This heats the earth's atmosphere and ultimately contributes to increasingly warmer climates, a process known as global warming. Carbon dioxide (CO_2) is a byproduct of the combustion--or burning--of fossil fuels such as coal and oil. Since the Industrial Revolution, humans have burned increasingly greater amounts of fossil fuels for energy. This energy has been used to heat homes, operate automobiles, and power industry.

As the practice of burning fossil fuels grows, so does the amount of carbon dioxide emitted to the atmosphere. During the process of combustion, O_2 reacts with glucose ($C_6H_{12}O_6$, a form of sugar) to produce water and CO_2. As the organic matter burns, chemical energy in the form of heat and light is released. The following chemical equation describes the chemical process of combustion: $6\ O_2 + C_6H_{12}O_6$ --------> $6\ H_2O + 6\ CO_2$ + energy. Chlorofluorocarbons (CFCs) are anthropogenic compounds; that is to say they are created by humans. There is no known natural source of these greenhouse gases which contain chlorine, fluorine, and carbon. Methane (CH_4) production—methanogenesis can occur in a number of ways. The one that may have the largest impact on the climate occurs in freshwater wetlands, such as rice paddies. As the area of land used for rice paddies grows to feed the growing human population, so does the amount of methane it produces. During the microbial metabolic process of methanogenesis, acetate (CH_3COOH) is split into CO_2 andCH_4: CH_3COOH -------->

$CO_2 + CH_4$. Nitrous oxide (N_2O) is a byproduct of nitrification and denitrification the natural processes by which NH_4^+ and NO_3^-, respectively, are biotically transformed (*i.e.* changed by microbes).

Studies have shown that the use of nitrogen fertilizer on agricultural fields stimulates these processes and thus increases the production of N_2O. Tropospheric ozone (O_3), a constituent of smog that irritates the eyes and lungs of many city inhabitants, is a greenhouse gas that can be produced from another greenhouse gas--methane (see above section on the production of methane). This process involves many steps, the net reaction of which is described by the chemical equation: $CH_4 + 4O_2$ --------> $HCHO + H_2O + 2O_3$. Another source of tropospheric ozone is atmospheric nitrate (NO_2). First, the nitrate is broken down into nitric oxide (NO) and a single atom of oxygen (O): NO_2 + sunlight --------> NO + O; then, the atom of O combines with a molecule of O_2 to produce O_3: O + O_2 --------> O_3. The net reaction, which is in equilibrium (*i.e.* it goes back and forth), is: $NO_2 + O_2$ <--------> $NO + O_3$.

4. Atmospheric Chemistry Modeling

The composition of the atmosphere is changing faster than at almost any time in the Earth's history, and human activities are the main cause. The research areas focuses on modeling atmospheric chemistry and climate from the surface to the top of the stratosphere, using sophisticated chemistry-climate models include anthropogenic ozone depletion, the ozone hole, and associated questions, such as the return date of stratospheric ozone to historical levels; global tropospheric air pollution, the oxidizing capacity of the troposphere, and tropospheric ozone chemistry; and global and regional climate change and its links with atmospheric chemistry. Consequences include climate change, stratospheric ozone depletion, and regionally poor air quality. International treaties and national policies have been introduced to combat ozone depletion and to improve air quality; these have often been successful. In particular, the Montreal Protocol of 1987 is credited with preventing further dangerous damage to the stratospheric ozone layer.

However, climate change remains the great unsolved problem of our time, and it is linked to all other aspects of atmospheric chemistry. For example, stratospheric ozone changes are also exerting a strong influence on climate in the Southern Hemisphere, and ozone recovery will interfere with global warming caused by increasing concentrations of most greenhouse gases. Likewise, tropospheric air quality and the capacity of the troposphere to cleanse itself of pollutants are also impacted by both climate change and ozone recovery. Conversely, tropospheric chemistry can affect climate, e.g. through a feedback mechanism involving the removal of methane. Much of this research is centred on ozone, which is both a UV absorber and a potent greenhouse gas, and is chemically linked to many other greenhouse gases.

5. Atmospheric Chemistry & Climate

The atmospheric concentration of pre-industrial tropospheric ozone is not accurately known, so that the resulting radiative forcing cannot be accurately determined, and must be estimated from models. Interactions between climate and atmospheric oxidants, including ozone, provide important coupling mechanisms in the Earth system. The concentration of tropospheric ozone has increased substantially since the pre-industrial era, especially in polluted areas of the world, and has contributed to radiative warming. Emissions of chemical ozone precursors (carbon monoxide, CH_4, non-methane hydrocarbons, nitrogen oxides) have increased as a result of larger use of fossil fuel, more frequent biomass burning and more intense agricultural practices. The decrease in concentration of stratospheric ozone in the 1980s and 1990s due to manufactured halocarbons (which produced a slight cooling) has slowed down since the late 1990s.

Model projections suggest a slow steady increase over the next century, but continued recovery could be affected by future climate change. Recent changes in the growth rate of atmospheric CH_4 and in its apparent lifetime are not well understood, but indications are that there have been changes in source strengths. Nitrous oxide continues to increase in the atmosphere, primarily as a result of agricultural activities. Photochemical production of the hydroxyl radical (OH), which efficiently destroys many atmospheric compounds, occurs in the presence of ozone and water vapour, and should be enhanced in an atmosphere with increased water vapour, as projected under future global warming. Other chemistry-related processes affected by climate change include the frequency of lightning flashes in thunderstorms (which produce nitrogen oxides), scavenging mechanisms that remove soluble species from the atmosphere, the intensity and frequency of convective transport events, the natural emissions of chemical compounds (e.g., biogenic hydrocarbons by the vegetation, nitrous and nitric oxide by soils) and the surface deposition on molecules on the vegetation and soils.

6. Aerosol Particles & Climate

Even though some particle types may have a warming effect, most aerosol particles, such as sulphate (SO_4) aerosol particles, tend to cool the Earth surface by scattering some of the incoming solar radiation back to space. In addition, by acting as cloud condensation nuclei, aerosol particles affect radiative properties of clouds and their lifetimes, which contribute to additional surface cooling. In many areas of the Earth, large amounts of SO_4 particles are produced as a result of human activities (e.g., coal burning). With an elevated atmospheric aerosol load, principally in the Northern Hemisphere (NH), it is likely that the temperature increase during the last century has been smaller than the increase that would have resulted from radiative forcing by greenhouse gases alone. Other indirect effects of aerosols on climate include the evaporation of cloud particles through absorption of solar radiation by soot, which in this case provides a positive warming effect. Aerosols (i.e., dust) also deliver nitrogen (N), phosphorus and iron to the Earth's surface; these nutrients could increase uptake of CO_2 by marine and terrestrial ecosystems.

7. Conclusion

Greenhouse gases absorb infrared (long-wave, heat) radiation. This is the form of the sun's energy reflected off the earth's surface. Greenhouse gases then radiate heat energy back toward the earth. Changes in atmospheric chemical composition that could result from climate changes are even less well quantified. Changes in the circulation and specifically the more frequent occurrence of stagnant air events in urban or industrial areas could enhance the intensity of air pollution events. Atmospheric aerosol particles modify earth's radiation budget by absorbing and scattering incoming solar radiation. There is need for further research to understand green house gases interactions in atmospheric thermodynamics for climate change.

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