ENVIRONMENTAL STRUCTURE AND FUNCTION: CLIMATE SYSTEM

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Contents

Summary

The Global Climate System and factors of climate variability are described. The main processes in the Global Climate System are considered. Climate over the Globe as it is seen today on observational data is presented. Climate changes in the last century and the most significant patterns of climatic trends are presented. Climate modeling and possibilities of the models to reproduce the Contemporary Climate and current climate changes are analysed. And at last an answer to question: what do climate models tell us about our future is offered.

1. Introduction

Our "blue planet" that we call "home of people" is a very special and unique place. It is the only planet in our solar system and possibly in the galaxy where life is known definitely to exist. All life concentrates within a thin blanket of air, water, and soil. This spherical shell of life is known as the biosphere. The biosphere can be in three environs: the atmosphere (air), the hydrosphere (water), and the lithosphere (land surface: rock and soil). It is the unique attributes of the Earth's atmosphere that allow it to be a habitable place for humans, animals, and plants.

The **atmosphere** is a mixture of gases and particles that surround our planet. When seen from space, the atmosphere appears as a thin seam of dark blue light on a curved horizon. The atmosphere serves several purposes: it provides us with the air we breathe; its gases retain the heat that warms the Earth; and its protective layer of ozone shields us from damaging rays emitted by the sun. The atmosphere also acts as a reservoir or storehouse for natural substances as well as emissions derived from human activities. Within the storehouse, physical and chemical actions and reactions take place. Physical processes and the characteristics of physical condition of atmosphere determine the weather and climate.

The terms "atmosphere", "weather" and "climate" frequently are used in daily life in a broad sense. For example, it is possible to speak about "friendly climate" or about "tense atmosphere". People sometimes use the terms “weather” and “climate” interchangeably, but they are not the same.

In science these terms have a narrower precise sense. **Weather** is defined as the physical state of the atmosphere at a specified point of the Globe and at a specified moment of time. Concerned variables include temperature and pressure, wind velocity, humidity, precipitation, sunshine and cloudiness, phenomena such as fog, frost, hail storms, and other characteristics. **Climate** in the narrow, but widely used sense is the synthesis of day-to-day weather variations. It is represented by the whole variety of weather conditions for a specified area and a specified interval of time. The statistical description in terms of the mean, variability and extreme of relevant quantities or phenomena frequency over a period of time is used to characterize climate. (All these statistical values are called as "climatic variables".) The standard period for assessing of the current or Contemporary Climate is three decades, as defined by WMO.

The properties that characterize the climate are thermal (temperatures of the surface air, water, land, and ice), kinetic (wind and ocean currents, together with associated vertical motions and the motions of air masses, aqueous humidity, cloudiness and cloud water content, groundwater, lake lands, and water content of snow on land and sea ice), and static (pressure and density of the atmosphere and ocean, composition of the dry air, salinity of the oceans, and the geometric boundaries and physical constants of the system). These properties are interconnected by the various physical processes such as precipitation, evaporation, infrared radiation, convection, advection, and turbulence.

Modeling the Global Climate and Future Projections. One of the most effective ways of estimating our future climate is to use powerful computer simulations of past and present climates.

Scientists have been able to make some projections about how greenhouse gas concentrations may change over the next hundred years, based on a range of scenarios. The most extreme scenario is based on an assumption that high economic growth will continue, and that humans will continue to use coal, oil, and gas globally for their energy needs. This scenario suggests that concentrations of carbon dioxide could reach more than three times pre-industrial levels by 2100. Even the most hopeful scenario based on low growth in global population and intensive conversion to renewable energies suggests that carbon dioxide concentrations would be about 75 percent higher than pre-industrial levels by 2100, and would continue to rise thereafter. Stabilizing global emissions at 1990 levels now would have the same effect, because of the long life of these gases in the atmosphere.

The international research community have employed the most advanced climate models to determine what these projected increases in greenhouse gas concentration could mean. Their research suggests that average global surface temperature may increase on average by almost a half degree each decade during the next century. To provide an idea of what that means, global warming over the next century may be as great as the change in temperature between the peak of the last ice age, some 25,000 years ago, and today.

Stabilizing greenhouse gases is only a part of the solution, though. Scientific projections also indicate that, even if the concentrations of greenhouse gases were stabilized by 2100, air temperature could continue to increase. As well, sea levels, which are expected to rise anywhere from 15 to 95 cm by 2100, could continue to rise at a similar rate in future centuries. This would be the case even after concentrations of greenhouse gases had been stabilized, and even after global mean temperatures had stabilized. This is because of the long time it takes oceans to heat up before they fully respond to increased air temperatures.

Potential Impacts of Climate Change. In general, all available models agree that warming will be greater in Arctic regions than in equatorial regions, and that continents will warm more than oceans. Beyond this, however, scientists are not able to predict the exact consequences of continued increases in greenhouse gas concentrations or its impact on specific regions.

Around the world, climate change is projected to:

- threaten the world's boreal forests with an increased fire risk because of the drying climate;
- cause water needs to outstrip supply;
- cause severe water loss due to changes in evaporation and precipitation patterns;
- cause flood damage to low-lying countries and island states, including loss of coastal land to rising sea levels;
- encourage the movement of tropical diseases such as malaria northward, where populations have little or no immunity; and
- affect international trade patterns.

The remainder of this paper introduces the problem of **Environmental Structure and Climatic System** in more detail.

What role does the greenhouse effect play in climate?
How does the water cycle affect the climate?
What role do oceans play in influencing climate?
How do the volcanoes affect the climate variability?

We describe components of the Global Climate System and factors of climate variability (see *Climate and the global climate system*, in EOLSS On-Line) and we answer the questions: Can we change the climate? Why are greenhouse gas amounts increasing?

We represent a general picture of the climate over the Globe as it is seen today on observational data (see *Climate now*). We discuss scales and major forms of climate variability including short-term climate oscillations, such as ENSO, QBO, Blocking etc. (see *Weather systems and weather forecasting*). As well, we consider how climate has changed in the last century and present the most significant patterns of climatic trends in surface temperature and precipitation, upper air temperature, atmospheric circulation etc. (see *Observed climate change in the twentieth century*, in EOLSS On-Line).

Then, we describe the basic aspects of climate modeling and possibilities of the models to reproduce the Contemporary Climate and current climate changes (see *Global climate models*) and, also, what do climate models tell us about our future (see *Climate* *projections and future climate*, in EOLSS On-Line).

We conclude with a reflection: Where do we go from here? And we describe the most important international actions and programs dealing with a problem of the Climate and Climate Change (see *International activity concerning climate*).

2. Processes in the Global Climate System.

In a simplistic sense, the Earth’s climate system is like a giant heat engine. Incoming short wave energy from the sun is the fuel that drives the system. This energy heats the Earth’s atmosphere, surface and oceans, and provides the thermal energy that produces the hydrological cycle of evaporation, condensation, precipitation and water flow. It also is the indirect source of the kinetic energy inherent in the atmospheric motion, ocean currents and storms. However, like an internal combustion engine, the climate system also needs a mechanism for dispensing heat back to space in order to avoid overheating. That mechanism is provided by the radiation of long-wave “heat energy” from the earth’s surface and atmosphere back to space. As long as the incoming solar energy and the net outgoing heat radiation are in balance, the Earth’s climate system neither heats up nor cools down. It is in “equilibrium”, and its average surface temperature will remain relatively constant.

The above energy flow within the planet’s climate system involves a large number of individual physical and chemical processes, many of which interact in complex ways. These processes not only take place within the atmosphere, but also involve each of the other components of the climate system, such as the oceans, the cryosphere (snow and ice) and the geo-biosphere (terrestrial ecosystems, soils, fresh water). Some of these processes have been studied for many decades and are well understood. However, others still defy adequate description. Some take place at the microphysical level, and on time scales of seconds, while others can be hemispheric in scale and take place over years, decades or even longer time scales. Yet all may be important in understanding how the climate system behaves and, perhaps more significantly, how it responds to any imbalances in the net energy flow into and out of the system that may occur.

To better understand these processes and how they interact, scientists use a combination of empirical information collected under controlled experiments or through observation of the natural climate system and theoretical models that attempt to describe these processes in terms of mathematics and physics. Progress in understanding thus becomes an iterative process of modeling theories developed on the basis of observations, then testing and refining these models against further observations. Such models range from very simple algorithms that describe relationships between two climate system variables to very complex biogeochemical and coupled climate models that attempt to portray a realistic simulation of how the entire real climate system works in space and time. All are important in advancing the scientific understanding of the climate system. This process of identifying and modeling such processes are described in more detail in the following sections.

2.1. Atmospheric Processes

2.1.1. Atmospheric Radiative Fluxes

The magnitude of the solar short wave energy that enters the climate system at the top of the atmosphere has been extensively measured by both surface and satellite systems. This energy, at the outer edge of the atmosphere facing the sun, varies slightly around a mean value of 1370 W m^{-2}. However, since the sun shines only on one side of the Earth at any given time, the average energy input entering the atmosphere decreases by a factor of four, to 342 W m^{-2}.

As the solar energy passes through the stratosphere, ozone molecules absorb most of the UV component of the sun's radiation. While this does not significantly reduce the total energy entering the lower atmosphere, the UV absorption has an important role in heating the atmosphere at this level and thus influencing the vertical temperature profile and circulation of the atmosphere. Periodic fluxes of volcanic aerosols into the stratosphere as the result of explosive volcanic eruptions, or intrusions of tops of thunderstorms can also interfere with the incoming energy flow, reflecting some of it back to space and scattering a fraction within the stratosphere (see Figure 1).

Most of the sun's energy, however, finds its way into the troposphere, where it interacts with clouds, aerosols and the Earth's surface. Observations suggest that clouds and aerosols help to absorb about 20% of the incoming energy within the troposphere and reflect another 22% back to space. Another 8 to 9% is reflected directly back to space by the earth's surface itself. Thus only about 50% of the energy entering the atmosphere is absorbed by land and ocean surfaces.

The distribution of this incoming energy varies considerably with space and time. Since the nature of the Earth's orbit around the sun results in more direct and consistent exposure of low latitude zones to the sun's energy than at high latitudes, the magnitude of solar radiation received at the equator exceeds the global average by almost 20%, while polar regions receive about 30 to 35% less than the average. Furthermore, since clouds and aerosols reflect much of the sunlight back to space, regions of the world with clear skies absorb considerably more of the incoming energy than cloudy or polluted areas. Likewise, land and ocean surfaces covered with snow and ice also reflect much more of the solar energy reaching the surface than do dark surfaces like water or dark soils. These modifying factors also vary with time, resulting in more absorption of solar energy in some seasons than others.

Some of the solar energy absorbed at the Earth's surface is used to evaporate water, and hence is converted to latent heat. The rest is either transformed into kinetic energy that drives the circulation and convection processes within the atmosphere and oceans or into sensible heat that warms the surface where it is absorbed. Like all objects, the atmosphere and surface re-radiates heat, with the intensity and wave length of this heat energy varying with the temperature of the object. At the temperatures prevalent at the Earth's surface and within its atmosphere, this radiation occurs primarily within the infrared region of the energy spectrum. The wavelengths of this infrared energy are one to two orders of magnitude longer than that of incoming solar energy, and hence it is referred to as long-wave radiation.

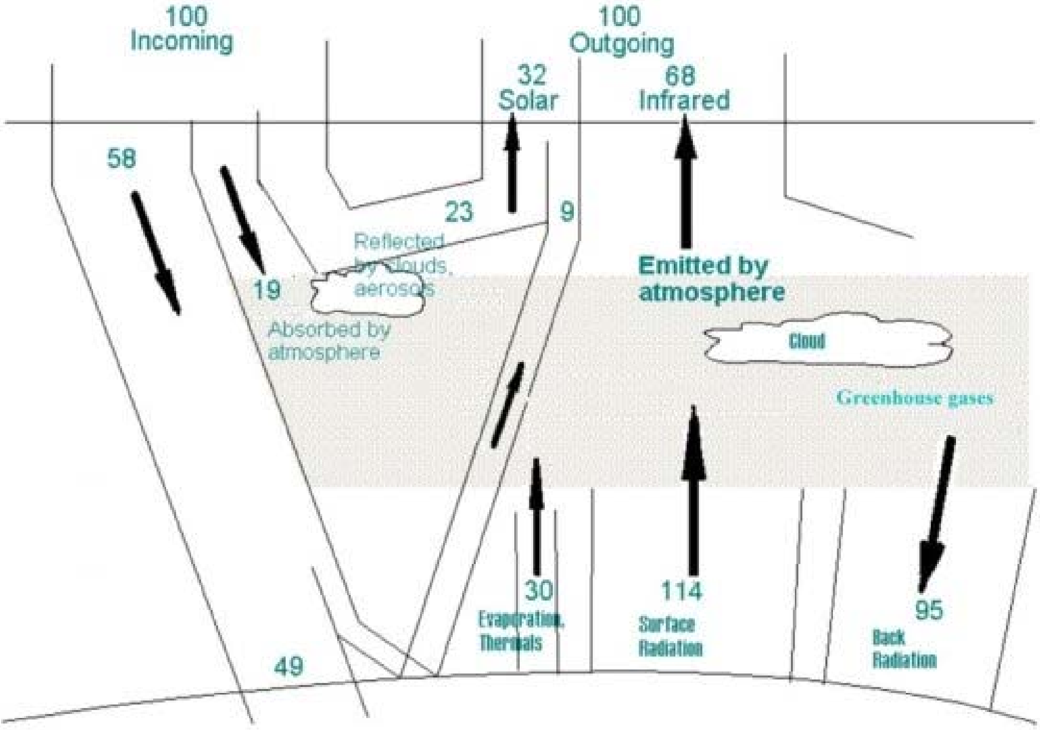

Figure 1. Estimates of the distribution and flow of incoming solar and outgoing long wave radiation within the atmosphere. Numbers are based on the fraction of each 100 units of incoming solar energy affected by various radiative processes, and hence are equivalent to percentages.

The atmospheric processes that control the transmission of the emitted long-wave radiation upwards through the atmosphere are significantly different from those for incoming short-wave energy. One of the most important processes is that of absorption and re-radiation of this energy by trace gases within the atmosphere. Since this process of absorption and re-radiation is somewhat analogous to that of glass in a greenhouse, they are generally referred to as greenhouse gases. Most greenhouse gases are inactive within the short-wave energy band of solar radiation (the major exceptions are ozone and, to a lesser extent, water vapor) but have active absorption bands within the infrared region. When these gas molecules absorb infrared radiation emitted towards space from surface objects or the atmosphere at lower levels, they become excited and re-radiate energy in all direction, some back towards the surface and some upwards where greenhouse gases at higher altitudes can absorb their radiation. Hence, like a blanket on a bed, these gases effectively trap heat energy near the surface of the Earth. Clouds and aerosols also contribute to this process. The net result is a natural greenhouse effect that is so effective in insulating the Earth’s surface from heat loss that it keeps surface temperatures on average some 33°C warmer than if it were completely absent. The present average temperature on Earth is about 15°C. That would mean the average temperature on Earth would be minus 18°C. By retaining heat within the lower atmosphere, the greenhouse effect makes it possible for life to survive.

The most important of these greenhouse gases is water vapor, which is released into the atmosphere through evaporation processes at the surface or through respiration of vegetation. The atmosphere’s holding capacity for water vapor is limited. When this limit, or saturation point, is exceeded, the water vapor is partially removed again through condensation into cloud droplets or as dewdrops on solid surface. These processes are all very dependent on temperature and available surface water sources, and hence vary substantially with space and time. Air masses over dry desert landscapes or in very cold polar environments, for example, have very low water vapor content, while the torrid air masses over tropical wetlands have very high concentrations.

Other important greenhouse gases include carbon dioxide, methane and nitrous oxide, which are long-lived gases and hence are well mixed throughout the atmosphere. Gases short-lived gases within the atmosphere, such as ozone, can also function as greenhouse gases. However, their concentrations can vary significantly from region to region and season to season, and hence their role, as greenhouse gases are generally less well understood.

In addition to the role of greenhouse gases, the atmosphere also transports heat from one region to another through advection. One mechanism for such transport is the movement of heated air both vertically and horizontally towards colder regions of the atmosphere. For example, as air near the surface is heated by incoming sun lighted or by contact with warmer land or ocean surfaces, it expands and becomes lighter than the cooler air above it. This gives the air buoyancy and causes it to percolate upwards, taking heat energy with it. Another process is that of evaporation and condensation. As water evaporates, either directly at the Earth’s surface or through plant transpiration, it absorbs heat. Thermal convection processes of warm air masses carry much of this water vapor vertically upwards. As this air ascends, it cools. If it is moist enough, the ascending air eventually passes the temperature threshold at which the air becomes water saturated. At this point, some of the water condenses to form droplets and clouds, meanwhile releasing the latent heat within the water vapor at this higher elevation within the atmosphere.

When the earth’s climate system is in equilibrium, the net amount of infrared heat energy that finally escapes from the top of the atmosphere to space is approximately equal to the net average short wave energy from the sun (incoming - reflected) entering the atmosphere. There are factors external to the climate system, however that can either alter the net amount of incoming solar energy absorbed within the climate system or change the net loss of infrared energy to space, thus perturbing the balance of incoming and outgoing energy at the top of the atmosphere. Such imbalances will cause a change in the basic flows of energy through the climate system and alter the climate itself until various processes return the climate to a new equilibrium. If the perturbation is a brief anomaly, such as that due to aerosol emissions from volcanic eruptions, the new equilibrium will be close to the initial conditions. If, however, the perturbation is sustained or long-term, a new equilibrium significantly different from initial conditions can result. Examples of such perturbing factors include changes in the intensity of incoming sunlight reaching the top of the atmosphere and changes in concentrations of greenhouse gases or aerosols, both due to geophysical processes and human emissions.

The basic principles that govern the radiative fluxes within the atmosphere have been studied extensively and are reasonably well understood. However, the interactions, or 'feedbacks', between these processes, and how they respond with time and space to perturbations caused by external forcing or other changes internal to the climate system are much more difficult to understand. Some of these feedback processes are still very controversial. Furthermore, because of the inhomogeneity of many of these processes, they are both difficult to observe and to 'parameterize', or describe in physical and mathematical terms, on scales suitable for climate models. Several of the key atmospheric feedback processes are examined in greater detail in the following sections.

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Biographical Sketch

Georgii V. Gruza was born in 19 August 1931 in Tashkent, UzSSR (now Uzbekistan). In 1949 he entered and in 1954 he graduated from the Tashkent State University, Physics & Mathematics Faculty. Post graduate studies he passed from 1954 to 1957. Next Education steps: 1961 - PhD, TSU & Uzbek Academy of Science, 1968 - Doctor of Science, Geophysics, 1976 - Full Professor of Meteorology. His working positions were: 1957-1959 - Scientist-member of the Soviet Antarctic Expedition (Mirny), 1959-1970 - Head of Numerical Weather Forecast Dept., Central Asian Research Hydrometeorological Institute (Tashkent) 1970-1975 - Head of Data Processing and Methods Developing Dept., at the Research Institute of Hydrometeorological Information - World Data Center (RIHI-WDC), Obninsk, Kaluga Region), 1975-1982 - Deputy Director (Science Branch) of RIHI-WDC, 1983 up to present - Head of Climate Monitoring and Probabilistic Forecasting Dept. in the Institute of Global Climate and Ecology, Moscow. Areas of his research activities: investigations of the global atmospheric circulation, development of statistical methods for medium and long-range weather forecasting, analysis, detection and forecast of climate change and computer processing of large hydrometeorological data sets. He was the author and co-authors of numerous scientific papers and reports, which he presented at international and national scientific meetings during his scientific career. During several periods he served as an expert, rapporteur or a member of various international boards and meetings, for example, he was a member of WMO Working Group on Climate Change Detection and chair of RA-V1 (Europe) Working Group on Climate-Related Matters, also he was one of lead authors of the Second and the Third IPCC Assessment Reports. Among his awards: - Diploma of senior researcher in geophysics (1966), Multanovskiy Award (highest for forecast investigation in the Hydrometeorological Service of Russia) (1976), title of Honoured Meteorologist of Russian Federation (1999).