NATURAL RESOURCE SYSTEM CHALLENGE: CLIMATE CHANGE, HUMAN SYSTEMS, AND POLICY

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Summary

The permanent and complex interaction of a great number of different systems on our planet has been realized in a prevailing balanced way throughout geological epochs. Any disturbance of the balance, even between some of these systems, at any moment, can cause serious hazards or catastrophes and threaten the existence of human civilization. Knowledge of the earth's systems, and especially of the life support systems (LSSs), can help to a great extent to avoid or to diminish the damages related to such events.

This article focuses on one type of LSS, namely the climate system. It begins with some basic information on the past, present and future global climate. The potential large-scale effects of global warming, the potential effects of global warming on human society, and the effects of potential sea-level rises are presented, further followed by a discussion of the economics of potential global climate change and the response strategies for stabilization of atmospheric composition. Finally, the policy framework and systems management of global climate change are discussed. In order to provide a more detailed picture, the main sections of the paper are divided into sub-sections.

The general approach followed in this article is to summarize the detailed contributions by different authors on corresponding subjects. (See "Knowledge in depth" for an outline of these contributions.) The author's own studies, views, and understanding are respectively included.

1. Introduction

The life on our planet is a permanent and complex interaction of a great number of different systems. The disturbance of the balance even between some of these systems at any moment can cause serious hazards and catastrophes, or even threaten the existence of human civilization. Knowledge of the earth's systems, in particular of the LSSs, can help to a great extent to avoid or to diminish the damages related to such events.

This article aims to present in an integrative way knowledge on the specific interaction between climate change and human systems, with regard to the development of policy to address such change. Its main sections are divided into relevant sub-sections. Thus, in the second main section, matters like climate changes in the course of human history, anthropogenic climate influences, modeling of global climate change, and the IPCC as the major international body on climate change issues, are discussed. In the third section, the potential large-scale effects of global warming are presented in detail with regard to some specific elements of the environment: rangelands and degraded lands, wetlands, mountain systems, marine ecosystems, water resources, and environmental pollution. The fourth section is devoted to some effects of global warming on human society and human systems, such as cultural diversity, migration, energy production and consumption, agriculture, and tourism. The fifth section focuses on the potential effects of sea-level rises, including ones related to coastal and residential zones, coral reef zones, and small island states. The cost implications of potential global climate change are discussed in the sixth section, and the implications for agriculture, forests, industry, fisheries, and some other economic sectors are considered separately. Response strategies to stabilize atmospheric composition are presented in the seventh section, where carbon dioxide emission reduction, energy policy, energy efficiency and the switch to renewable energy resources, methane and nitrous oxide emission reduction, and chlorofluorocarbons and their substitutes, are discussed. In the eighth section, emphasis is given to matters such as climate change assessments, decision-making to address climate change, policy options like engineering, mitigation, and adaptation measures, abatement measures and tradable permits, emission tax policies, equity and social considerations, cost–benefit analyses, and integrated assessments.

In general, the article summarizes the detailed articles on corresponding subjects, and makes reference to them. The author's own studies, views and understanding are also presented where relevant. Since the number of matters discussed is quite great and they are all rather complex, it is difficult to present them in detail, so only some of the most specific and important ones have been given detailed attention.

2. Global climate in the past, present, and future

The results from research on climate in the past epochs of the earth's history show that there are no historical analogues for the rate at which mankind is now transferring carbon from its terrestrial reservoir to the atmosphere (see also "History, status and prediction of global climate change"). This is true especially for the last 150 years. We need all our knowledge and a great deal more to understand fully the role we are playing in altering the climate system, as well as to find the best way to cope with the related problems. The basis for solutions of these problems lies in knowledge of the climate in the past, its current status, and recently available projections for its future state.

2.1. Climate changes and human history

The importance of past climate for climate prediction and development of relevant policy to address climate change determines the necessity for research on climate in the past periods of the earth's history. In brief, the most important conclusions from such research are as follows. (See also "Climate changes and their influence on the course of human history"*)*

- The composition of terrestrial atmosphere and global mean temperature can be reconstructed relatively well for the last 570 million years (the Phanerozoic period). During this period, the carbon dioxide content in the atmosphere was as much as 1,016 kg, or about five times morethan the amount known as the pre-industrial level, of 2 × 1,015 kg. In the early Carboniferous period, it reached the maximum amount of about ten times greater than the pre-industrial level. However, in the last 70 million years, the atmospheric carbon dioxide amount never exceeded the average value (1,016 kg); moreover, it was gradually decreasing until the Holocene period. In the beginning of industri alization in the 1850s, the concentration of atmospheric carbon dioxide was as much as 280 parts per million of volume (ppmv). In 1998 it reached 365 ppmv: that is, it increased by 30 percent during the previous 150 years. Global mean temperature increased by about 0.7 °C between 1860 and the end of the 1990s.
- By the end of the 1930s, it had become clear that global temperature had increased since the end of the previous century. The warming was especially striking in North Europe, where, in 5-year averages, the local rise in temperature ranged between 1 and 3 °K.
- From reconstructions of climate based on proxy records, and according to the most recent information from the World Meteorological Organization (WMO), the twentieth century was probably the warmest in the last 1,000 years. The seven globally warmest years in the century occurred in the decade 1990–9. Every year in this decade was among the fifteen warmest years since 1860, when regular instrumental weather observations started.

2.2. Anthropogenic climate influences

In order to be able to better predict climate, it is important to distinguish between natural and anthropogenic influences on it. Many human activities result in release of substantial quantities of gases, both greenhouse and others, and also aerosols, particles, different chemical pollutants and so on, which change atmospheric composition and structure. Accumulated with time, these changes can become large enough that significant global changes, including climate change, can be expected. Here, “large enough” changes in the atmospheric concentrations of greenhouse gases (GHGs) can be defined by the rates of change and atmospheric lifetime of the principal GHGs. From the many studies on these matters, the following main statements can be taken into account (see also “Anthropogenic climate influences”).

- Carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) have both natural and anthropogenic sources, while chlorofluorocarbons (CFCs) are only produced industrially.
- Most of the GHGs have very a long lifetime in the atmosphere, so the amounts released at present will remain there for many years.
- Carbon dioxide seems to be the most important single contributor to greenhouse forcing and climate change, and the contribution from a number of other minor atmospheric constituents adds up to a substantial climate forcing.
- Stratospheric ozone plays two essential roles. First, it absorbs incoming solar ultraviolet radiation and protects the earth’s surface from its harmful effects.

Second, the decline of the stratospheric ozone layer constitutes a reduction in the greenhouse effect that is comparable to the increase in the effect directly contributed by the CFCs.

- Tropospheric ozone, produced mainly in urban air, has increased mostly in the northern hemisphere because of the high degree of industrial pollution. This increase also contributes to radiative forcing.
- Atmospheric aerosols injected into the atmosphere because of chemical and microphysical processes, both natural (due to volcanic eruptions, for example) and anthropogenic (mostly related to the combustion of low-quality coal), have the greatest influence on local and regional weather and climate. On a global scale, a substantial part of the current anthropogenic enhancement of the greenhouse effect is being hidden by the cooling associated with anthropogenic aerosols.
- Changes in land use as a result of human activities, especially those related to agriculture, urbanization and deforestation, also influence climate. Although these activities can contribute essentially to climate change through their influence on climate-forming factors, their role is not as significant as the changes in atmospheric composition which cause the enhanced greenhouse effect and global warming.

2.3. Modeling of global climate change

Climate system modeling is necessary, in order to understand the driving forces and mechanisms of climate changes, and to predict the future states of this system. A valuable approach in this respect is through physical models which, along with careful statistical evaluation plus observational validation, are still the most important tool for understanding and predicting the possible global climate changes (see also "Physical models of global climate change"). Today, a great variety of physical models exists, and they are constructed to work from global and continental down to regional and local scale, spanning time fluctuations from daily and annual cycles, over interannual and decadal, up to ice age cycles.

Climate in a physical model is represented by measurable quantities. Central are the state quantities (e.g. temperature), flux quantities (e.g. precipitation) and conversion quantities (e.g. absorption of radiation). Climate quantities are often presented as functions of space or of time.

A time dependent climate model can be used to simulate climate changes. There exist many types of natural climate changes: daily and seasonal cycles, and regular fluctuations on almost all scales (interannual and decadal up to astronomical cycles). Due to the complex interaction between climate subsystems, and specifically because of nonlinearities and chaotic behavior of their fluid elements, there are irregular fluctuations. Physical models suggest that most climate changes are due to very small deviations in fluxes that are opposite and thus tend to balance each other.

Since the main task of climate models is to simulate real climate, real climate must be known. So, in order to run a climate model, the first step is to provide the background of climate observations. Physical models of climate are mathematical equations that relate different elements to each other according to specific physical laws. For example, in the most simple, zero-dimensional, global climate model, the absorbed solar radiation is equated to the emitted terrestrial radiation. One-dimensional models for energy balance are constructed to describe quantitatively the energy situation of the whole earth. These include radiation and convection processes as well as the greenhouse effect. A more complex type of such models is the thermalwind one, where the balance between the vertical wind shear and the meridional temperature decreases towards the poles. These models represent the balance of net heating and zonal wind field for a rotating planet that is differentially heated.

The most complete, but also most complicated and computer intensive, models of the climate system are the three-dimensional circulation models of atmosphere and/or ocean called global circulation models (GCMs). They are based on the fundamental equations of motion and fluid dynamics. These models are solved over a grid of 1 to 5 spatial degrees in size and at time intervals of 20 to 30 minutes. Although very detailed in their domain, they need to be run with high quality boundary conditions. Recently, increased computer power has made it possible to couple ocean and atmospheric GCMs. The coupled models are also beginning to include land-surface models with interactive vegetation, and soon should include interactive chemistry models. But with the pressure to further increase their spatial resolution, the GCMs are still very slow and extremely expensive to run.

To study global warming, a series of models of all levels of complexity is used. To understand the differences in the behavior of models, intercomparison projects evaluate their results under controlled present day or past climate conditions. This provides some measure of confidence before investigating global warming with historically unprecedented boundary conditions. The future increase in GHG emissions and sulfate aerosols is put into a set of possible emissions scenarios, trying to take into account a variety of possibilities for industrial and social development, as well as political measures to limit the emissions. Here, not only the concentration of GHGs is important, but also the rate of increase, because it could potentially have a significant impact on the response of the climate system.

In summary, the presently existing physical climate models represent an impressive arsenal for further improvement of our understanding and better prediction of possible global climate changes. These models have reached a high level of sophistication over the last decades, providing the basis for numerical climate modeling: the only tool that enables quantitative simulation of the climate system.

2.4. The Intergovernmental Panel on Climate Change (IPCC)

The efforts for effective international co-operation on climate change issues date from the 1970s, when a more reliable analysis of a possible human-induced climate change became available (see also “The Inter-governmental Panel on Climate Change”). After the completion of some international assessments and reports, as well as the achievement of agreements between relevant international institutions, the IPCC was created jointly by the WMO and the United Nations Environment Programme (UNEP) to address the issue of a possible human-induced climate change in the future. A mere twenty-eight countries responded to the call to meet in Geneva in November 1988 in order to form the IPCC by electing individuals for the key positions in the Panel and its Working Groups (WG):

- WG I: Assessment of scientific information on climate change
- WG II: Assessment of environmental and socioeconomic impacts of climate change
- WG III: Formulation of response strategies.

It was further agreed that a prime target for the Panel would be to prepare a first assessment in time for the UN General Assembly in 1990. After intensive work and a lot of discussions, the IPCC First Assessment Report was produced and published. It provided important conclusions on recent climate and climate change impacts.

At the IPCC's meeting in Harare in November 1992, it was agreed that it would be desirable to have a second IPCC assessment ready about five years after the first one, in 1995. Difficulties were again encountered in the process of finalizing the IPCC Second Assessment Report (SAR). However, this Report was produced and published in time. Again, important conclusions were drawn about the state of the art in climate assessment, impact studies, and policies to address climate change (see also "Climate change assessments"). An essential statement in this Report has to be pointed out, namely that "the balance of evidence suggests . . . a discernible human influence on global climate." At its twelfth session in Mexico City in 1996, the IPCC decided to complete a Third Assessment Report by 2000–1. The thirteenth session of the IPCC took place in the Maldives in September 1997. A restructuring of the Panel was agreed, five vice-chairmen were elected, the leadership of the three working groups was changed, and their tasks were modified.

In the periods between the Assessment Reports, a number of Special, Supplementary and Technical Reports were produced by the IPCC. Also, the IPCC itself and its assessments served as background for the initiation and writing of the UN Framework Convention on Climate Change (FCCC) as well as the negotiations for its implementation. Being an organization under scientific leadership, the IPCC has an intergovernmental status, making it possible to separate the scientific assessment from political negotiations.

3. Potential large-scale effects of global warming

Because of the observed temperature increase, it can be considered that global warming is happening nowadays, and most probably it will continue in the near future. The potential large-scale effects of global warming have been studied intensively, and the response of specific natural systems is being examined. Below, the results from research on some of these effects are discussed in greater detail.

3.1. Effects of global warming on rangeland and degraded lands

Global warming will undoubtedly affect arid and semi-arid rangeland and degraded lands all over the world (see also "The effects of global warming on rangelands in Africa"). Since the ecosystems in these areas are highly dependent on climate, the predictions of warmer temperatures and mid-continental drying are therefore of great concern. For example, even a small change in rainfall, such as the recent Sahelian drought, can have significant and rapid effects on the drylands. Historical data show that small reductions in effective rainfall, coupled with intensive management of livestock or crops, can cause long-term reduction in the ability of these drylands to support production. In particular, drought, grazing, and agricultural practices can reduce land cover, and lead to soil erosion by wind and water. Further, this may result in a reduction in the productive potential of soil and other adverse effects.

Two types of change due to global warming are likely to occur in the areas of rangeland and degraded land. The first is the frequency of drought events, and the second is long-term shifts in rainfall magnitude. Generally, a slight shift in climate, especially in the frequency of extreme events, can lead to the overexploitation of the meager resources in these areas. In this way, it will contribute to the further degradation of the resource base on which local population depends (for example, in the Kalahari Desert of Southern Africa).

3.2. Effects of global warming on wetlands

The Ramsar Convention on Wetlands of International Importance of 1971 defined wetlands as "areas of marsh, fen, peatland or water whether natural or artificial, permanent or temporary, with water that is static or flowing fresh, brackish or salt including areas of marine water the depth of which at low tides does not exceed six meters" (see also "Effects of global warming on wetlands"). Wetlands may be found in a variety of locations such as uplands, along flood plains, around lake margins, in glaciated depressions, and in estuarine tidal marshes.

It is difficult to assess the impact of global warming on wetlands for two reasons. First, the impact may be direct or indirect. Second, the climatic consequences of global warming are not known accurately yet. The magnitude of global warming in future is also not well known, and the effects of global warming can be expected to vary with its magnitude and spatial pattern.

The factors that determine the amount of water availability in wetlands also determine to a large extent the characteristics, location, size, and geographical distribution of wetlands worldwide. From the global warming point of view, there are two main factors: first, the relationship between rainfall and evaporation, and second, the magnitude of the rise in sea level. The first factor will affect mainly inland wetlands, while the second one will mostly affect the wetlands in coastal zones.

Studies show that the impact of global warming on wetlands would be negative rather than positive. Many of the existing wetlands, both coastal and continental, would probably decrease in size, particularly the continental ones. There might be a significant change in the distribution patterns of the coastal wetlands, with some of the existing ones disappearing or decreasing in size, while new ones emerge. Water control projects to cope with the effects of increasing aridity in some areas may also affect the size of continental wetlands such as the inland deltas. For example, Namibia is reported to be seriously considering extracting up to 20 million sq. m of water from the River Okavango to meet the increasing demands for water. If such a development project is carried out, it would have a negative impact on the Okavango Delta in Botswana, with its wetlands rich in varied wildlife.

Given the environmental functions of wetlands, it is justifiable to be anxious about the possible impact of global warming and the accompanying climatic change on wetlands. The attempts to control the emission of GHGs due to various human activities would have positive results regarding wetlands. Additionally, relevant measures to be undertaken locally for the important wetland areas would be necessary.

3.3. Effects of global warming on mountains

Few assessments of the impacts of environmental change in general, and climatic change in particular, have been conducted in mountain regions (see also "The effects of global warming on mountains"). This is mainly because mountain orography is often too poorly represented in global or regional climate models for meaningful projections to be made, although recent progress in high-resolution models is leading to an improved situation. Also, due to the complexity of the physical, ecological, and social systems in mountains, and their mutual interdependence, significant problems arise when attempts are made to assess the potential impacts. In general, no single impact study would adequately represent the range of potential socio-economic responses to climate change in the mountain regions. A case-by-case approach is therefore essential, since the effects of climate change are likely to be different for different world mountain systems.

In Latin America, for example, the impacts of climate change are expected to occur in the more arid regions of the continent, which are often associated with the rain-shadow influences of the Andes ranges. In many countries of the region, water availability is expected to decline, which is likely to generate potential for international conflicts.

Water resources in tropical Asia will become increasingly vulnerable to increasing population growth, urbanization, industrial development, and agriculture. An impacts assessment study for a number of Himalayan basins contributing to the Ganges has shown that changes in the mean run-off in different sub-basins ranged from 27 to 116 percent, in a climate forced by a doubling of carbon dioxide concentrations relative to their pre-industrial levels. Shifts in the timing and intensity of the monsoon, and the manner in which the Himalayan range intercepts the available water masses of the atmosphere, will have major impacts on the precipitation as well as the timing and amount of run-off, in river basins such as the Ganges, the Brahmaputra, and the Irrawaddy.

In most temperate mountain regions, the snow-pack is close to its melting point, so it is very sensitive to changes in temperature. As warming progresses in the future, current regions of snow precipitation will increasingly experience precipitation in the form of rain. For every degree of increase in temperature, the snow line rises by about 150 m and, as a result, less snow will accumulate at low elevations than today, while there could be greater snow accumulation above the freezing level because of increased precipitation in some regions. Shifts in snow-pack duration and amount as a consequence of sustained changes in climate will be crucial to water availability for hydrological basins in the mountains.

Glaciers are possibly the most sensitive system to climatic change, because any changes in the ratio of accumulation to ablation of snow and ice, which are dependent on temperature and precipitation, will trigger glacier mass wasting. Glacier behavior thus provides some of the clearest signals of ongoing warming trends related to the enhanced greenhouse effect. Current glacier retreat is now beyond the range of natural variability recorded during the Holocene period.

Because temperature decreases with altitude by 0.5-1.0 °C per km, a first-order approximation concerning the response of vegetation in mountains to climate change is that species will migrate upwards to find climatic conditions in tomorrow’s climate that are similar to today’s. According to this hypothesis, the expected impacts of climate change in mountainous natural reserves would include the loss of the coolest climatic zones at the peaks of the mountains, and the linear shift of all remaining vegetation belts up-slope. Since mountain tops are smaller than bases, the present belts at high elevations would occupy smaller and smaller areas, and the corresponding species would have smaller populations and may thus become more vulnerable to genetic and environmental pressure.

3.4. Effects of global warming on marine ecosystems

In general, the global warming trend is discussed mainly from the terrestrial point of view, since the various manifestations of warming are more evident on the continents than in the ocean (see also “Effects of global warming on marine ecosystems,” EOLSS on-line, 2002). A marine approach to the problem of global warming is different in several aspects. First, the present system of meteorological and deep-water hydrological observations in the ocean is insufficient to make definite conclusions. Second, marine ecosystems are more specialized, their structure is more complicated, and cycles of organic matter are more dynamic than those of terrestrial ecosystems. This means that ocean organisms are rather sensitive to environmental changes. Third, owing to the uniformity of physical and chemical conditions on the wide ocean areas, geological history is more understandable here, and this makes it possible to reconstruct past climates and ecosystems more definitely than the continental ones.

The analysis of environmental changes in the geological past provides grounds to conclude that the ocean always acts as a giant thermostat moderating climate fluctuations on continents. Plankton communities which constitute the lower levels in the food chain can adapt to the whole range of physical conditions of the marine environment. Active marine species can migrate and find refuges owing to the integrity of the ocean water mass and absence of internal solid borders. So marine ecosystems as a whole are more stable and less vulnerable to climate fluctuations than continental ones.

In respect to marine ecosystems, global warming must be taken into account only in a wide context of accumulated anthropogenic impact. Generally, global warming is favorable for primary production and therefore for an increase in biological productivity on all ecosystem levels. However, other anthropogenic impacts, such as overfishing and marine pollution, act in the opposite direction, so future changes in marine ecosystems will depend mainly on human activity aimed at environmental protection and resource management.

3.5. Effects of global warming on water resources

The answer to the question how climate change, and global warming in particular, will affect hydrological processes and water resources is a very difficult one (see also "Effects of global warming on water resources and supplies"). Besides the difficulties of predicting climate change itself, roles are also played by the variation in hydrological characteristics and climate–water resource relationships, and by non-climatic factors, mainly land factors such as morphology, geology, soil, and vegetation cover. These factors are important in mediating climate variation and fluctuations in the hydrosphere. Human activity influences hydrological processes mainly through the change of land use in the processes of land cultivation, urbanization, and deforestation, where the effects can be commensurable with the effect of the expected climate change. In addition, some of the land factors, especially plant cover, are also dependent on climate: natural vegetation is always adapted to climate and forms its morphology in agreement with climate. Also, vegetation plays an active role in the formation of a climate and water regime. For given climate conditions, there is equilibrium between climate, water regime, vegetation, and the other land factors, so in the case of climate change, a new equilibrium of these ecological elements has to be established.

The problem of climate change is very important for water management as well, because it is also highly sensitive to climate variation across all timescales. Many tasks of water management in the present climate conditions arise because of climate variability: on some occasions humanity must fight against water abundance, and on others against water shortage. Water resources depend strongly on climate, and they vary from one region to another in relation to the spatial variation in climate. Some kinds of water demand are also climate-dependent, first of all the water demand of living systems, including human beings, animals, and crops. Historical experience shows that water consumption of living organisms rises with temperature rise, which means increased water demand in the conditions of global warming. Water management activities vary in their sensitivity to climate and are affected by climate events depending on their timescale. For example, soil moisture management, irrigation, and protection against floods are highly sensitive to within-year climatic events, especially the extreme ones. Since the frequency of such events increases due to global warming, there will be additional tasks for this kind of management. The reservoir systems, however, are more sensitive to the interannual variability of climate, while the deep groundwater or water transfer systems are susceptible to long-term climate fluctuations. The water management infrastructure built in the past (for flood protection, irrigation, and so on) has evolved within limited weather variability. As climate changes, a mismatch will appear between climate and the existing infrastructure, making water management a more complicated and difficult problem.

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Biographical Sketch

Antoaneta Yotova was born in 1956. She graduated in Physics, with a specialization in Meteorology, from Sofia University, Bulgaria. Since 1979 she has been a Research Associate in the Meteorology, Information Services, Composition of Atmosphere and Hydrosphere Departments of the Bulgarian National Institute of Meteorology and Hydrology (NIMH). Her research is in the fields of general and applied climatology, including topics such as climate variation and change, greenhouse gas emission estimation, and climate and energy interaction, and has resulted in about thirty scientific publications to date. She has been Chief Scientific Investigator for the Bulgarian Case Study in the framework of the Inter-Agency Joint Project DECADES (1994–8). She has also taken part in a number of other national and international projects in her area of expertise carried out at the NIMH.