Assessment of climate change impact in high-latitudinal regions

EDUARD A. KOSTER
Institute of Geographical Research (IRO), University of Utrecht

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The main equilibrium changes in climate at doubled atmospheric carbon dioxide concentrations deduced from general circulation models indicate a global average warming in between 1.5 and 4.5°C, with a »best guess» of 2.5°C, a surface warming at high latitudes that is greater than the global average in winter but smaller than the global average in summer, increases in precipitation at high latitudes throughout the year, and a diminishing of the area of sea-ice and seasonal snow cover. Regional climate scenarios, e.g. for the Fennoscandian region simulate mean winter temperature increases of even 5—6°C; however, estimates of regional changes, particularly those for precipitation and evaporation are still very unreliable. The potential consequences of greenhouse-induced climate changes on the environment have been tentatively identified. After a review of climate variability in the past, including abrupt and drastic temperature changes due to natural causes, the attention is focussed on specific climate-sensitive processes and phenomena, like cryospheric processes (glaciers, snow cover, permafrost degradation), slope stability, changes in northern peatlands, potential shifts in vegetation zones and other ecosystem responses. Uncertainties in the dynamic response of geomorphic-hydrologic-ecologic processes when assessing the potential impact of climate change on ecosystems and landscapes lead to research recommendations.

Eduard A. Koster, Institute of Geographical Research, University of Utrecht, Heidelberglaan 2, P.O. Box 80.115, 3508TC, The Netherlands.

The earth's climate has always been changing, but current changes are unique in that they are superimposed upon a landscape which has already been greatly altered by human activity. There is still a considerable amount of uncertainty about the nature and magnitude of greenhouse-induced climate change. Certain is, however, that man's impact on the atmosphere-geosphere-biosphere system has reached a global level. Most of the currently available numerical models of the global climate are now in general agreement that the increasing concentration of CO_2 and other greenhouse gases (like methane, nitrous oxide, CFC's and ozone) will cause a global warming of several degrees by the time their overall concentration is equivalent to twice the pre-industrial concentration of atmospheric carbon dioxide. The boreal and subarctic regions are thought to be particularly susceptible to regional or global changes in the environment. The seasons that characterize the climate of temperate regions are exaggerated in northern regions in both duration and amplitude, with extreme summer-to-winter ranges of temperature, an abbreviated growing season, and very large year-to-year variations in temperature. Global greenhouse warming is expected to be greatest at high latitudes. Especially winter warming is expected to be much more than the global annual average.

For the assessment of the impact of these anticipated climatic changes regional climate scenarios are needed. However, regional climate scenarios that are obtained by spatial and temporal interpolation of global climate models do not represent the actual climate (present CO_2 levels) properly, nor do they give sufficient information on those climate parameters, which are especially relevant to abiotic and biotic processes. Moreover, fundamental knowledge on climate-sensitive processes operating in landscape ecosystems is still very incomplete. Nevertheless, the potential consequences of greenhouse-induced climate changes on the environment and on society are of such enormous magnitude that it is a wise policy to stimulate not only cooperative research on climate change and landscape functioning, but also the implementation of adaptive and preventive measures.

For example, significant changes in sea-ice extent and thickness, in land-ice mass and snow cover thickness and duration and in permafrost regimes can be expected and consequently large-scale gradual adjustments of (semi-)natural ecosystems (geomorphic, hydrologic and ecologic processes) will probably take place.

In response to growing public and political interest in climate warming and its potential consequences the Intergovernmental Panel on Climate Change (IPCC) was formed in 1988 by the United Nations Environment Program (UNEP) and the World Meteorological Organization (WMO). Very recently the report of Working Group I of IPCC, assessing the scientific information on climate change, has appeared (Houghton et al. 1990). Most of the information in the following overview is based upon this authoritative and comprehensive report. Concerning the likely impact of climatic warming a case study is presented on the complex interrelationships in the atmosphere — »buffer layer» — permafrost system, which is partly based upon one of the chapters of the report by Working Group II of IPCC (Assessment of environmental and socio-economic impacts of climate change) and which will be published shortly (Street and Melnikov, in press). Preceeding these reports two European conferences on the impact of climate change were convened in The Netherlands, partly focussing on impact analysis of climate change in the Fennoscandian part of the Boreal/(Sub)Arctic zone (Koster and Lundberg 1987; Koster and Boer 1989). Preliminary studies related to geomorphic, hydrologic and ecologic responses to climate change as well as studies on impacts on agriculture, forestry, water resources and nature conservation were discussed during these meetings (see also Boer et al. 1990; Boer and de Groot, 1990). The strong need for integrative research following the IPCC findings is emphasized by the recently published International Geosphere-Biosphere Programme: A study of global change (IGBP 1990), which will undoubtedly play a crucial role in future research.

Climate variability in the past

When considering future climate change, it is clearly essential to look at the record of climate variation in the past. It enables insight in the natural climate variability both on long- and short-term time scales, it provides information on the spatial distribution of former temperature changes and it can help in understanding the causal relationships between climate change, atmospheric composition and terrestrial and marine environmental conditions. Global surface temperatures have typically varied by 5—7°C through glacial-interglacial cycles, with large changes in ice volumes and sea level, and temperature changes as great as 10—15°C in some middle and high latitude regions of the Northern Hemisphere have been reconstructed. Paleoclimatological reconstructions based upon proxy data have revealed that not only former temperature maxima showed large regional differences, but that temperature deviation were neither synchronous. For example, during the Eemian or Mikulino interval the northeastern part of Europe experienced a temperature increase of about 6—8°C, while in the northernmost regions of Siberia the temperature apparently increased by up to 12°C. Global temperature increase during that interval probably was not more than 2°C. In the Holocene climatic optimum global mean temperatures probably were little more than 1°C higher than at present, but temperature increases of 3—4°C have been reconstructed for northwestern parts of the USSR. Although there is ample evidence for this mid-Holocene (5,000—6,000 BP) temperature increase, especially in summer, carbon dioxide levels appear to have been quite similar to those of the pre-industrial era at this time. The most reliable information on past temperature, atmospheric carbon dioxide and methane concentrations is obtained by the analysis of polar ice cores. Measurements going back 160,000 years show that the temperature, as deduced from deuterium concentrations, paralleled the carbon dioxide and methane concentrations in the atmosphere. Although the details of cause and effect are unknown, calculations indicate that changes in these greenhouse gases were part, but not all, of the reason for the large (5—7°C) global temperature swings between glacial and interglacial periods. In other words: these climate changes would be triggered by insolation changes with the relatively weak orbital forcing being strongly amplified by possibly orbitally induced changes in greenhouse gases. The long-term climate variability is clearly illustrated in Figs. 1 and 2. Atmospheric carbon dioxide reached about 300 ppm during the Eemian optimum and subsequently dropped to values of 180—200 ppm during the last glacial maximum (18,000 BP).

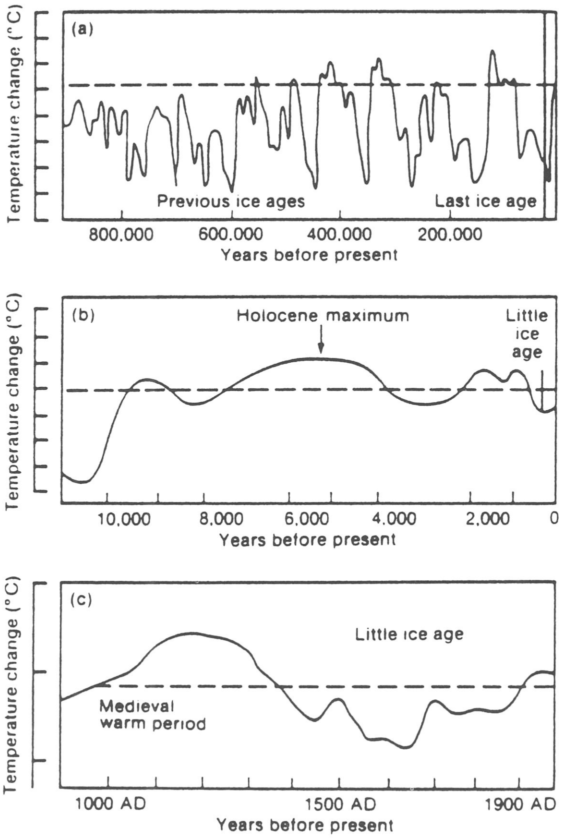

Fig. 1. Schematic diagrams of global temperature variations since the Pleistocene. The dotted line nominally represents conditions near the beginning of the twentieth century (from Houghton et al., eds. 1990).

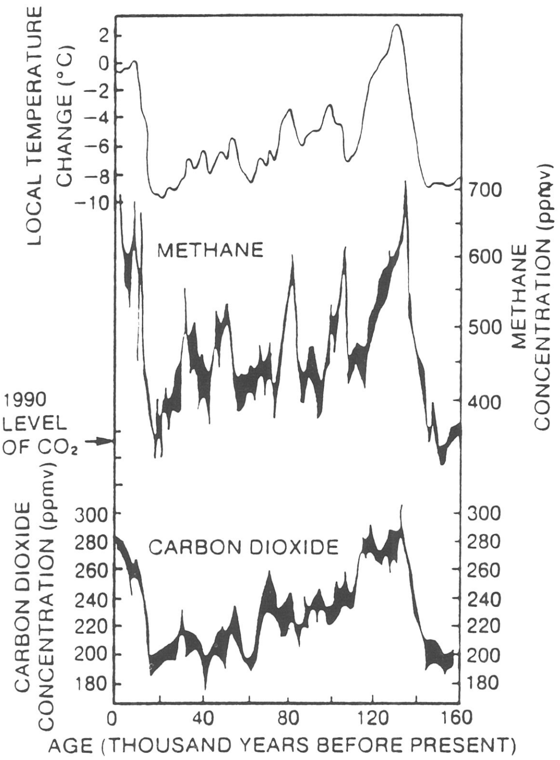

Fig. 2. CO_2 concentrations (bottom), CH_4 concentrations (middle) and estimated temperature changes (top) during the past 160,000 years, as determined on the ice core from Vostok, Antarctica. Temperature changes were estimated based on the measured deuterium concentrations. Present day concentrations of carbon dioxide are indicated (from Houghton et al., eds. 1990).

Present day carbon dioxide concentration are already much higher than those ever measured in ice cores.

To illustrate the strong natural variability of climate it must be mentioned that ice core studies on Greenland ice have revealed that during the last glaciation, CO_2 concentration shifts of the order of 50 ppm may have occurred within less than 100 years, parallel to abrupt, drastic climatic events (temperature changes of the order of 5°C). W. Dansgaard and his colleages have even documented a regional warming of about 7°C in South Greenland which was completed in about 50 years, marking the abrupt termination of the Younger Dryas interstadial. More or less similar rapid changes in climate variables have been observed around 13—12,600 BP, 11,000 BP and (again) 10,000 BP in other regions. However, these rapid changes cannot be directly related to orbital forcing or to changes in atmospheric composition. Therefore, they cannot really be used as analogues to future climate change. On the other hand, paleoclimatological reconstructions can provide useful insights into climate processes, and can especially assist in the validation of climate models.

More recent evidence of temperature variation has been found in Europe and the North Atlantic region during the Medieval Climatic Optimum (about AD 950—1250) and during the Little Ice Age of which some of the observed global warming since 1850 could just be a recovery. Although the instrumental record of surface temperaturesis obviously far from perfect, it is believed that a real warming of the globe of 0.3—0.6°C has taken place over the last century (Fig. 3); any bias due to urbanisation, influencing the record, is likely to be less than 0.05°C. The overall temperature rise has not been steady and the regional diversity has been and still is great. Although

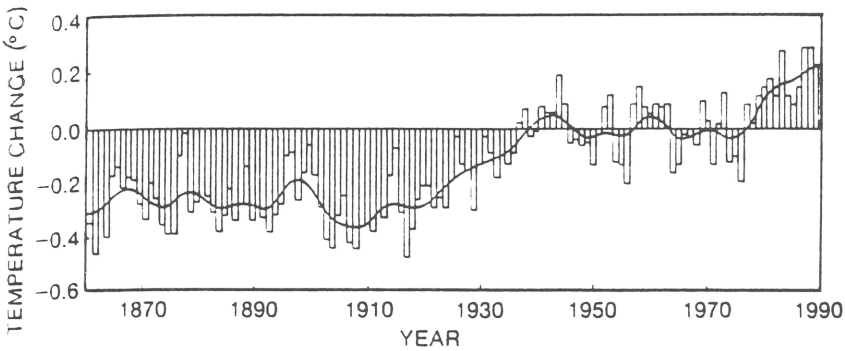

Fig. 3. Global-mean combined land-air and sea-surface temperatures, 1861—1989, relative to the average for 1951—1980 (from Houghton et al., eds. 1990).

this temperature rise is supported by a worldwide recession of mountain glaciers, it is by no means certain that it is caused by the enhanced greenhouse effect. In other words, the »climate signal» has not been detected yet. This is further illustrated by the fact that, for example, the temperature record in a region like Northern Sweden strongly contrasts with what could be expected based on the enhanced greenhouse effect. In spite of an increase in atmospheric CO_2 content from 310 to 350 ppm during the last fifty years, the Swedish record shows a decrease in mean annual temperatures of about 1°C (Fig. 4). This cooling trend is even more pronounced in winter temperatures. Eriksson (1989) suggests that the »clouds-factor», which could not be incorporated in previous GCM's like GISS, seems to have a larger effect upon the radiation than greenhouse gases, at least if looked upon from a regional basis.

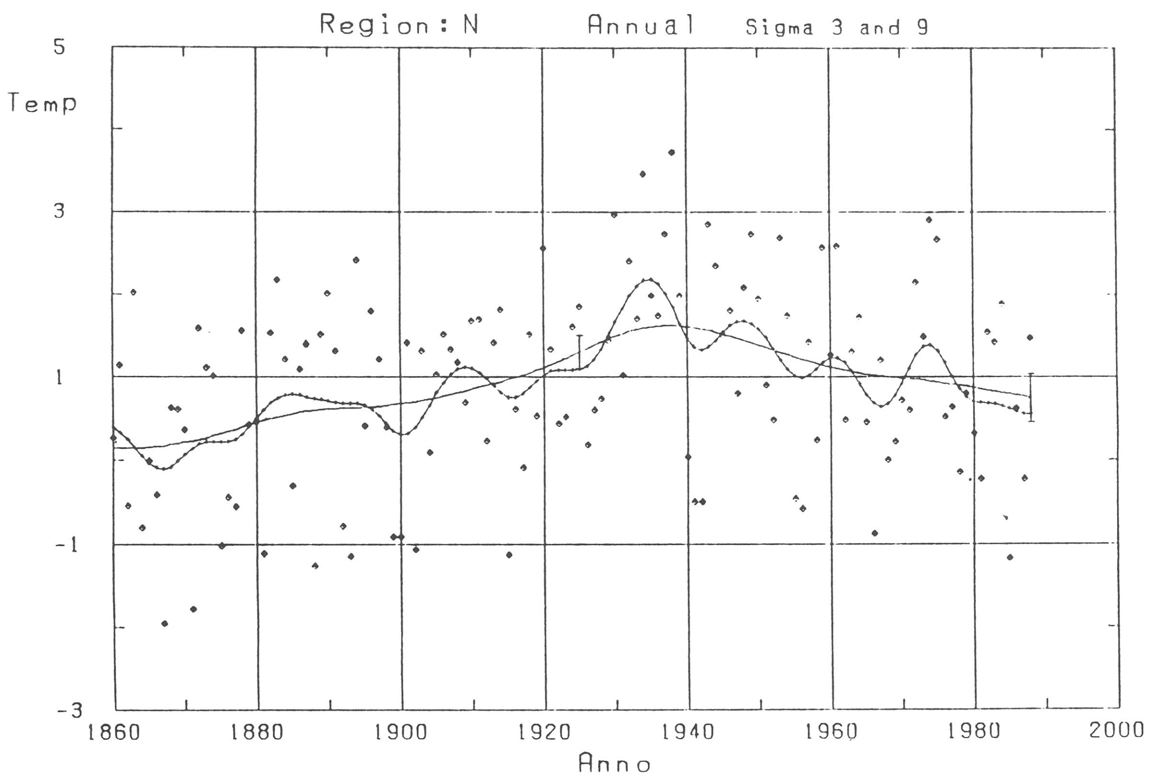

Fig. 4. The annual mean temperature 1860—1987 in the northern part of Sweden along with two low-pass filtered curves (by B. Eriksson in Koster & Boer 1989).

Assessment of climate change

Essentially, there are two types of climate scenarios. Those based on numerical models and those based on regional and seasonal patterns of past warm climates. It has already been indicated that analogues of future greenhouse-gaschanged climates have not really been found. Numerical models range from relatively simple zero-dimensional energy-balance to more sophisticated coupled atmosphere-ocean general circulation models (GCM's). All these models show substantial changes in climate when CO_2 concentrations are doubled, even though the changes vary from model to model on a sub-continental scale. The main equilibrium changes in climate deduced from these models indicate a global average warming in between 1.5 and 4.5°C, with a »best guess» of 2.5°C, a surface warming at high latitudes that is greater than the global average in winter but smaller than in summer, increases in precipitation at high latitudes throughout the year, and a diminishing of the area of sea-ice and seasonal snow cover (Houghton et al. 1990). In spite of various uncertainties a rate of increase of global mean temperature during the next century of about 0.3°C per decade (with an uncertainty range of 0.2 to 0.5°C per decade) is predicted under the IPCC »business-as-usual» scenario concerning emissions of greenhouse gases (Fig. 5). Consequently, based upon estimates of thermal expansion of the oceans and increased melting of mountain glaciers and small ice caps, an average rate of global mean sea level rise of about 6 cm per decade over the next century (with an uncertainty range of 3—10 cm per decade) is predicted. This would lead to a rise of 65 cm by the end of the next century (Fig. 6). By comparison, global mean surface air temperature has increased by 0.3—0.6°C and sea level by 10—20 cm over the last hundred years.

Knowledge of the global mean warming and change in precipitation is of limited use in determining the impacts of climate change. For this regional and seasonal changes are needed. Regional scenarios may be generated from GCM's or from historical instrumental data, but both methods have severe limitations (Hulme et al. 1990). Therefore scenarios, should be regarded as a *possible* climate outcome for North-

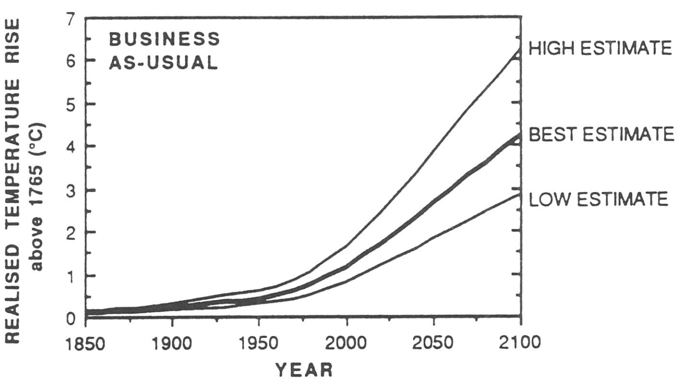

Fig. 5. Simulations of the increase in global mean temperature from 1850—1990 due to observed increases in greenhouse gases, and predictions of the rise between 1990 and 2100 resulting from the »business-as-usual» emissions (from Houghton et al., eds. 1990).

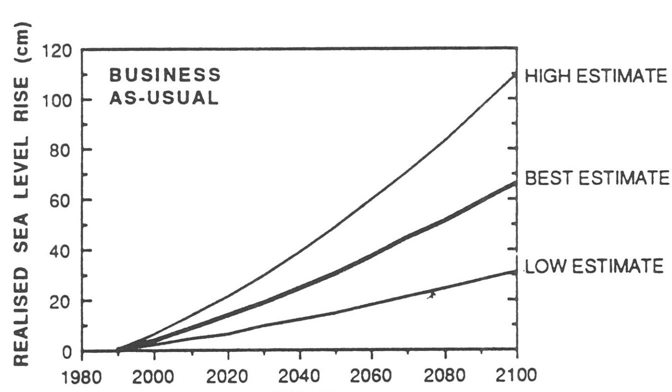

Fig. 6. Sea level rise predicted to result from the »business-as-usual» emissions, showing the best estimate and range (from Houghton et al., eds., 1990).

Table 1. Simulated climate change in the Fennoscandian region due to a doubling of the atmospheric CO_2 content, according to a scenario derived from the GISS-model (by R. Heino in Koster & Lundberg, 1987).

Climate parameter	Climate change	
	Increase + Decrease —	Magnitude
* mean annual temperature	+	4—5°C
* mean winter temperature	+	5—6°C
* mean summer temperature	+	2—3.5°C
* annual temperature amplitude	—	2—4°C
* length growing season (daily mean temp. ⩾ 5°C	+	70—150 days
* effective temperature sum (threshold ⩾ 5°C	+	500—1000 degrees
* length thermal winter (daily mean temp. ⩽ 0°C)	—	2—4 months
* length thermal summer (daily mean temp. ⩾ 10°C)	+	2—3 months
* number heating degree days (daily mean temp. ⩽ 17°C)	—	30—40 %
* mean annual precipitation	+?	150—300 mm?
* precipitation excess	+?	10—50 %?

ern Europe under coubled CO_2 conditions rather than as a *probable* outcome.

Nevertheless, for the sake of argument and to allow »what-if» impact scenarios, an example is given here of a regional climate scenario for the Fennoscandian region. This scenario is derived from the GISS model by spatial and temporal interpolation and the simulated temperatures for the $2 \times CO_2$ situation have, moreover, been adjusted by adding the difference between the values of the $2 \times CO_2$ and $1 \times CO_2$ experiment, to the actually observed values from the standard normal period 1931—1960 (Boer et al. 1990). It should be stressed that the level for the global temperature rise obtained by the GISS model falls in the upper part of the temperature range predicted by IPCC. In contrast to temperature, the simulated precipitation agrees much less with actual observations, and should therefore be regarded with much scepticism. The results of this simulation experiment are presented in Table 1. Once more, these data can be used as a basis for impact scenarios, but must certainly not be regarded (yet) as predictions.

Landscape ecological impact of climate change

Studies of the impact a climatic change might have a abiotic processes operating in terrestrial ecosystems are essentially based upon three methods of scientific approximation of the problem. Data from various sources (analogue studies, monitoring studies and modelling studies) dealing with quantitative relations between process parameters and climatic parameters are scarce and usually have not been collected specifically for climate impact assessment analysis. Table 2 summarizes the advantages and disadvantages of three basic approaches.

The following overview of climate-sensitive processes and phenomena is based upon the findings of the Noordwijkerhout and Lunteren conferences (Koster and Lundberg 1987; Koster and Boer 1989), and is summarized in Table 3.

Cryospheric processes and phenomena

In high latitude (as well as in high mountain) areas important effects of climate change will be through the alteration of freeze-thaw processes and through changes in the occurrence of glacier-ice, ground-ice, snow, sea- and lake-ice. Changes in cryospheric processes may have a large range of side-effects on geomorphological events such as slope failure, mass wasting and thermokarst, on hydrological events like overland flow, run-off and flooding, on soil thermal and moisture regimens and thus on vegetation and wildlife habitats.

Mountain glaciers are among the clearest and most easily recognizable indicators of climate change, since their extension has a direct link to summer temperature and to winter precipitation. The nature and distribution of permafrost is ob-

Table 2. Evaluation of scientific approach methods for studying the impact of climate change on abiotic processes (after Eijbergen & Imeson 1989).

ANALOGUE STUDIES

advantages:

* the (bio)geological record provides a solid base for establishing trends between the »end-members» of process-response systems
* paleogeomorphological data allows one to study the response and recurrence time of specific processes and thus indicate threshold values
* particularly useful for validation and improvement of existing climate models

disadvantages:

* low time resolution in the (bio)geological record
* historical records are too short to indicate patterns of landscape evolution
* short-term event sequences may provide a misleading impression of long-term variability of processes

PRESENT-DAY ON-SITE MONITORING STUDIES

advantages:

* possibilities of quantification and statistical manipulation
* detailed knowledge of local significance on impact-process response
* knowledge about the physical basis of processes

disadvantages:

* limited representativity for larger regions and limited extrapolation in time
* records are often too short to cover extreme events with longer recurrence intervals
* methods are time and money consuming

MODELLING AND SIMULATION

advantages:

* allows quantification and statistical manipulation of past, present and future climate patterns and their impact
* general insight can be obtained of process-responses to changes in climate parameters
* input of data and usage of parameters can be simulated if real figures are not available
* relatively low costs and quick results

disadvantages:

* oversimplification, due to the limited number of parameters which can be simulated
* output depends strongly on how the input variables are chosen

Table 3. Natural processes related to the impact of climate change in alpine and high-latitudinal regions.

At the Noordwijkerhout Workshop (Koster & Lundberg, 1987) it was concluded that climate change in the temperate and cold regions of Europe will result in adjustments of interrelated ecological-hydrological-geomorphological processes. These adjustments will lead to:

* problems in soil degradation and erosion on agricultural land
* alterations in biochemical cycles
* increased slope instability
* adjustment of river and lake basins
* alterations in sediment and water output from glaciated areas
* permafrost degradation

At the Lunteren Conference (Boer & de Groot, 1990) a number of specific topics for high-latitude and high-altitude environments have been indentified with respect to the impact of climate change:

* cryospheric processes and phenomena
  — retreat of mountain glaciers
  — permafrost degradation
  — changes in snow cover extent and duration
* slope processes and mass movements
  — changes in natural hazards due to slope instability
* accumulation and decomposition of peat and litter
  — changes in structure and functioning of terrestrial ecosystems
* shifting vegetation zones, timberline ecotones
  — northward and upward shifting of species

Through several, possibly positive feedback mechanisms (e.g. sea-ice/snow/albedo, tundra's as a potential source of CO_2 and CH_4) initial rise of annual temperatures in high-latitude regions may accelerate the global warming process.

viously strongly climate dependent, as will be more fully discussed in the next chapter. The thickness, extent and duration of snow is a major factor in the ecological functioning of northern environments as it influences the thermal soil regime, the slope stability, the length of the growing season for plants and lichens, as well as the soil moisture conditions and seasonal runoff patterns. Whether or not the frequency and intensity of mass movements will change, cannot be indicated as present climate models do not provide information on extreme meteorological events.

(Semi-)Natural ecosystems

The direct effects of increased CO_2 concentrations and the indirect effects of temperature increase on photosynthetic rates, growth rates, productivity rates and water-use efficiency of plants are incompletely understood. The same applies to the uptake or loss of carbon, presently occurring in Boreal/(Sub) Arctic regions in enormous quantaties. Breakdown of northern peatlands and the subsequent emission of carbon dioxide and methane forms one of the important unknown feedback mechanisms in the climate system. Potential shifts of vegetation zones and timberline ecotones have been simulated, but these studies are still fraught with equally many uncertainties. If the presumed climate warming occurs considerably faster than the migratory rates of plants and animals, the consequences might be that new strategies are required for nature conservation.

Agriculture, forestry, water resources

Concerning the possibly beneficial effects of climate change on crop plants productivity, forest production as calculated from changing site quality indices and decreased flood discharges influencing water power production, the reader is referred to the discussion paper by Koster and Boer (1989).

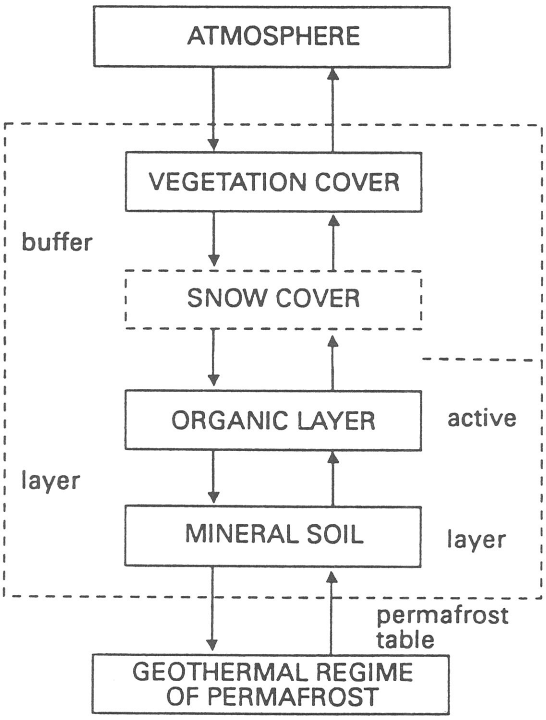

Fig. 7. Boundary layer interactions affecting the ground thermal regime (by J.N. Luthin and G.L. Guymon in Koster & Boer 1989).

Impact of climate change in permafrost region — a case study

Not only are permafrost ecosystems considered to be particularly sensitive to climatic warming, but the changes that may occur there will have a profound influence on the climate system itself due to feedback mechanisms related to biomass production and decay in the extensive tundra and taiga zones. Northern Hemisphere land areas of approximately 7.6 and 17.3×10^6 km^2 are underlain by continuous respectively discontinuous permafrost (Street and Melnikov, in press). The analysis of permafrost temperature as a function of depth (geothermal profile) appears to yield a temporally integrated record of mean annual ground surface and air temperature changes in the past: e.g. temperature profiles measured in permafrost in the Arctic Coastal Plain of Alaska indicate a variable but widespread secular warming of the permafrost surface, generally in the range of 2 to 4°C during the last few decades to a century, which is in agreement with the regional meteorological record.

However, the assessment of the effects of climate change on permafrost is very complicated, as ground temperatures are influenced by site characteristics, which are interrelated with climate. Variations in these characteristics of the so-called »buffer layer», like snow cover, vegetation, organic layer, surficial hydrology and ground thermal properties may either enhance or counter-act each other (Fig. 7). The interactions in the atmosphere — »buffer layer» — permafrost system, which in certain instances may lead to permafrost degradation, in other cases to permafrost aggradation, are illustrated in Fig. 8.

Many thousands of square kilometres of permafrost are within 1—2°C of the melting point and are therefore highly vulnerable to climate warming. Response times of the active layer to warming are of the order of decades, but response times near the base of (deep) permafrost seem to be of the order of hundreds to thousands of years. Simulations indicate, that e.g. rapid thaw depth increases of 41 % and 71 % would occur at Barrow (Northern Alaska) for air temperature increases of 3 and 6°C year-round. Simulations based on a 2°C increase in global mean air temperature, considered to be equiva-

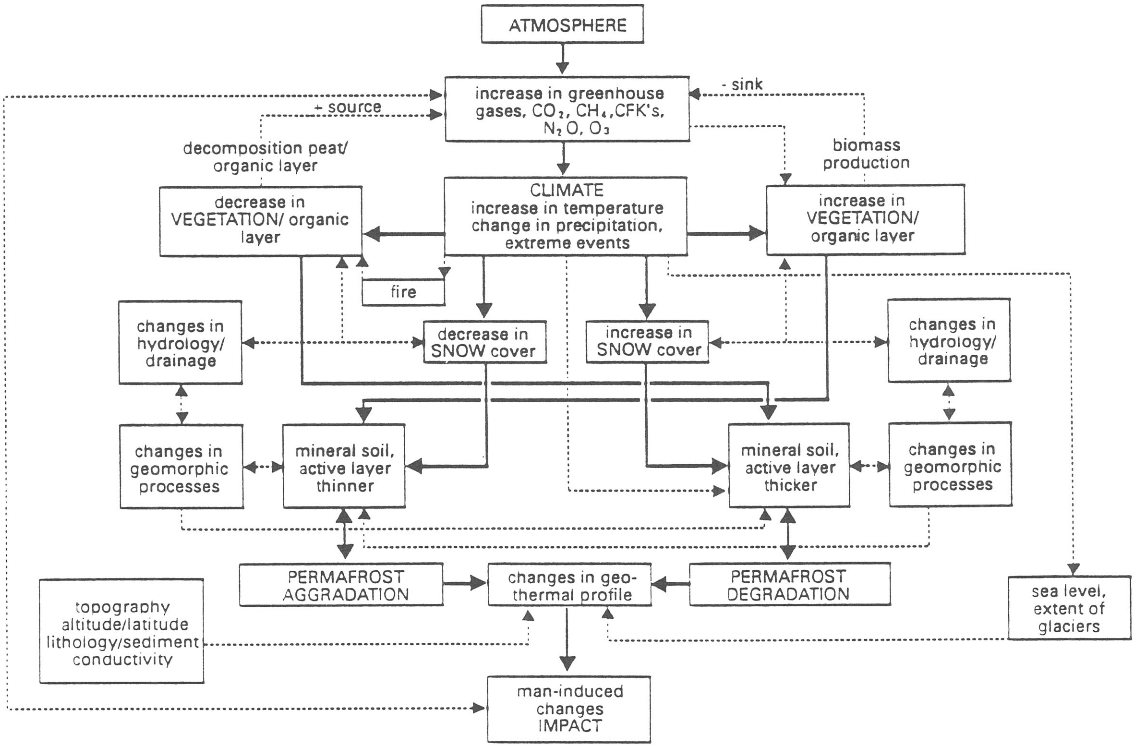

Fig. 8. Schematic representation of the interactions in the atmosphere — »buffer layer» — permafrost system (by M.E. Nieuwenhuijzen and E.A. Koster in Koster & Boer 1989).

lent to a 7—9°C temperature increase in winter and 4—6°C in summer in the latitudinal zone 55—70°N in the USSR, suggest a 15—20 % reduction in areal extent of near-surface permafrost after 50 years in Siberia. If ice-rich permafrost degrades, widespread terrain disturbance and instability will result, including thaw settlement (subsidence) and ponding of surface water (associated with thermokarst), and slope failures. In practical terms this could lead to major concerns for the integrity and stability of roads, railways and other foundations. In general, widespread permafrost degradation will have enormous socio-economic consequences for northern regions.

Uncertainties and recommendations

The IPCC report (Houghton et al., 1990) has identified several areas of scientific uncertainties and shortcomings. The most critical ones are summarized in Table 4. The level of uncertainty is strongly amplified if one tries to analyse the impact of climate change, as was strongly emphasized during the Lunteren conference (Koster and Boer 1989; Table 4). Narrowing the uncertainties in future climate change prediction and in its impact requires internationally coordinated research programmes like IGBP (1990).

Finally, some specific research recommendations — without any pretence to be complete — with respect to alpine regions and the Fennoscandian region are presented in Table 5. The Fennoscandian region offers interesting opportunities for comparative research in different climatic environments, since it covers a large latitudinal and altitudinal range and includes a variety of climate gradients. It is also excellently suited for studies on the environmental impact of climatic changes that occurred in the past, due to the well documented historical record as well as the extensive (bio)geological record in natural archives, like peat formations, lake deposits and other proxy data.

Table 4. Major uncertainties in understanding of the climate system and in assessment of climate change impact.

Major uncertainties in predictions particularly with regard to the timing, magnitude and regional patterns of climate change, are due to incomplete understanding of (acc. to Houghton et al., eds. 1990):

* control of greenhouse gases by the Earth system (sources and sinks)
* control of radiation by clouds
* changes in precipitation and evaporation
* ocean transport and storage of heat
* ecosystem processes
* response of polar ice sheets

The assessment of landscape ecological of climate change in Fennoscandia is strongly limited by (acc. to Koster & Boer 1989):

* a lack of regional climate scenario's (based on GCM's)
* disagreement of »regional climate scenario's» produced by spatial and temporal interpolation of global climate scenario's with actually occurring regional climatic trends
* the fact, that data collections on many relevant landscape ecological processes are still not available
* meteorological records, which are still incomplete in many instances
* a still primitive methodology for handling data sets on complex landscape ecosystems; moreover, at best some quantitative information is available on more or less isolated parts of the landscape ecological system
* finally, the understandable hesitance of some Fennoscandian scientists to become involved in impact scenario's based on the assumption of a (relatively strong) climatic warming, as current regional trends indicate a cooling

REFERENCES

Boer, M.M. and R.S. de Groot (eds.), *Landscape-ecological impact of climatic change.* Proceedings of a European Conference, Lunteren, The Netherlands, 3—7 December 1989. IOS Press, 429 pp.

Boer, M.M., Koster, E.A. and H. Lundberg, 1990. Greenhouse impact in Fennoscandia — Preliminary findings of a European Workshop on the effects of climatic change. *Ambio* 19/1, 2—10.

Eriksson, B., 1989. Temperature records from Sweden — regional versus global trends. *In:* Koster, E.A. and M.M. Boer (eds.) *Landscape ecological impact of climatic change on Boreal/(Sub)Arctic regions, with emphasis on Fennoscandia,* 15—23.

Eijbergen, F.A. and A.C. Imeson, 1989. Geomorphological processes and climatic change. *Catena* 16, 307—319.

Houghton, J.T., Jenkins, G.J. and J.J. Ephraums

Table 5. Research recommendations with respect to alpine regions and the Fennoscandian region, identified and discussed during the European Conference on landscape ecological impact of climatic change, Lunteren, The Netherlands, 3—7 December 1989.

Research recommendations:

* Continue long time series of glacier observation and complete the global network
* Enhance integrated research on the effects of glacier size fluctuations on the (upper and lower) drainage basin dynamics
* Establish monitoring programmes (measurements of borehole temperatures) in high-latitude and high mountain permafrost regimes; direct special attention towards areas that have shown to be sensitive to the 20th century warming
* Measure and model the heat and energy balance of permafrost
* Conduct integrated research on the impact of permafrost changes on terrestrial and coastal ecosystems, that is, on the interrelations in the atmosphere — »buffer layer» — permafrost system
* Continue long time series of snow cover extent and duration, both by field monitoring and remote sensing
* Determine how variations in snow cover thickness and duration affect plant growth, food chains and wildlife migration
* Continue studies on the frequency and intensity of mass movements in relation to extreme meteorological events
* Promote research in the footslopes of high mountain regions aimed at better hazard (flooding, slope failure) appraisal
* Studies leading to accurate prediction of peat storage and loss under future conditions of global change should receive priority, including studies of thermal and hydric regimes of peatlands
* Factors affecting peat accumulation, decomposition, CO_2 production and methane production are needed; field research should include the effects of field manipulations of temperature and moisture on methane generation and CO_2 flux; refinement is needed of the areal extent and carbon content of northern peatrich ecosystems
* Peat cores should be analysed to determine relationships of peat accumulation or degradation under former varying climatic conditions
* High mountain and high latitude tundra-like ecosystems are particularly well suited for biological monitoring since they have a worldwide distribution, are largely unaffected by direct, local human intervention, and because they appear to be especially sensitive to climate change; previous IBP research sites are recommended for preservation and study and could form the basis for an international system of Global Biomonitoring Sites (GBS)
* Research transects should cover the latitudinal extent of boreal and tundra regions of Fennoscandia, and the altitudinal and longitudinal extent of the Alps

(eds.), 1990. *Climate change The IPCC Scientific Assessment* (Report prepared for IPCC by Working Group 1). Cambridge University Press, 364 pp.

Hulme, M., Wigley, T.M.L. and P.D. Jones, 1990. Limitations of regional climate scenarios for impact analysis. *In:* Boer, M.M. and R.S. de Groot (eds.) *Landscape-ecological impact of climatic change,* 111—129.

I.G.B.P., 1990. *Global Change, Report No. 12.* The International Geosphere-Biosphere Programme: A study of global change. The initial core projects.

Koster, E.A. and M.M. Boer (eds.), 1989. *Landscape ecological impact of climatic change on Boreal/(Sub)Arctic regions, with emphasis on Fennoscandia.* Report prepared for the European Conference on Landscape ecological impact of climatic change, Lunteren, The Netherlands, 3—7 December 1989, 150 pp.

Koster, E.A. and H. Lundberg (eds.), 1987. *Impact analysis of climatic change in the Fennoscandian part of the Boreal and Subarctic zone.* Report prepared for the European Workshop on Interrelated bioclimatic and land use changes, Noordwijkerhout, The Netherlands, 17—21 October 1987, 84 pp.

Maxwell, J.B. and L.A. Barrie, 1989. Atmospheric and climatic change in the Arctic and Antarctic. *Ambio* 18/1, 42—49.

Nieuwenhuijzen, M.E. and E.A. Koster, 1989. Assessing the effects of climatic change on permafrost — A short literature survey. *In:* Koster, E.A. and M.M. Boer (eds.) *Landscape ecological impact of climatic change on Boreal/(Sub)Arctic regions, with emphasis on Fennoscandia,* 79—93.

Street, R.B. and P.I. Melnikov, in press. *Seasonal snow cover, ice and permafrost.* Chapter 7 of Report from Working Group II to IPCC. Likely impacts of climate change.