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Clouds, aerosols and biogeochemical cycles: risks of non-linear climate change

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Abstract

In this paper part of an investigation is described into risks for climate change which are presently not adequately covered in General Circulation Models. The investigation included the interaction with biogeochemical cycles, the effects of clouds and aerosols, ice flow instability, albedo instability and modified ocean circulation. In this paper our results for clouds and aerosols and for biogeochemical cycles are reported.

1. INTRODUCTION

In the concept of climate change as a result of the enhanced greenhouse effect it is generally assumed that the radiative forcings from increased concentrations of greenhouse gases (GHG) will result in a proportional or quasi-linear global warming. Though correlations of this kind are known from palaeoclimate research, the variability of the climate seems to prevent the direct proof of a causal relation between recent greenhouse gas concentrations and temperatures observations.

In order to resolve the issue the use of General Circulation Models (GCMs), though still inadequate at present, is indispensable.

Around the world some 10 leading GCMs exist which have been the subject of evaluation and intercomparison in a number of studies (AMS, 1994; Cess *et al*, 1993; Boer *et al*, 1992; Gates *et al*, 1992; Randall *et al*, 1992; Cess *et al*, 1990; Cubasch and Cess, 1990). GCMs represent several aspects of present climate reasonably well, but systematic deviation of observations exist for upper troposphere temperatures and tropical lower stratosphere temperatures. Consequent errors in zonal wind distribution produce differences in precipitation patterns. Also, the reliability of simulated polar climates remains low. The use of GCMs is further limited because of their course spatial resolution; this leads to a reduced performance in the prediction of regional climates.

A discussion on the causes of their weak points in simulating present and past climates shows that the depiction of clouds is a major weakness of GCMs. Uncertainties extend to cloud formation, in particular as a function of altitude, and to cloud properties, while the sensitivity of the models for these variables is high. A second element which is virtually absent in GCMs are the feedbacks from natural biogeochemical cycles. All these cycles are influenced by man in a number of ways. Apparently, not all relevant processes have been included in the GCMs. That situation constitutes a risk, since it cannot be ruled out that a missing process could cause or trigger a non-linear climate change. In addition, if global temperatures start to rise, we do not know too well which responses we will see. So we might be surprised by non-linear changes.

We report here the result of an investigation aiming to identify processes which potentially could provide a risk for such a non-linear change.

2. METHODOLOGY

In order to collect as many entries as possible with a relevance for the topic of interest the investigation was directed to all major areas of research with respect to climate and climate change. The state-of-the-art of the General Circulation Models stands at the base of our investigation. The following areas which either are inadequately covered in GCMs or are outside the focus of the GCM-based climate research have been selected for a separate screening on potential non-linear effects:

- global change and biogeochemical cycles
- clouds and aerosols
- ice flow instability
- albedo instability
- ocean circulation patterns

In the present paper we will, starting from the body of knowledge which is absorbed within GCMs, communicate our estimates for non-linearities in climate change resulting from the effects of clouds and aerosols, and the effects of global change processes on biogeochemical cycles. Our estimates on albedo and ice-flow instability and on modified ocean circulation will be published elsewhere (Van Ham *et al*, 1995a). Full details of this work will be in our final report for the National Research Programme on Global Air Pollution and Climate Change (Van Ham *et al*, 1995b).

3. CLOUDS AND AEROSOLS

The general uncertainty on the magnitude and even the sign of some of the different feedback mechanisms through cloud formation, and its interaction with aerosols constitutes a risk for major positive feedback. Clouds exert an overall negative forcing (Ramanathan *et al*, 1989; Harrison, *et al*, 1990; Ardanuy *et al*, 1991), but the net effect varies with altitude and cloud type: clouds in the upper troposphere (cirrus-type) tend to a net positive forcing while lower clouds (cumulus, stratus and stratocumulus) exert a negative forcing. The uncertainty in the balance between low, medium and high clouds is reflected in an uncertainty in the trend of the overall effect of GHG increase on global mean temperatures.

Most GCMs predict a decrease in the fraction cloud amount (average 4±2.5% decrease). Without further specification of cloud types, however, it is not clear whether this decrease acts as a positive or negative feedback. Since cloud formation could take a path different from the one which is outlined in most GCMs the situation is even more uncertain. Instead of the generally predicted global warming between 1.5 and 4.5 °C, with a central value of 2.5 °C for a doubling of the CO_2-concentration (IPCC, 1990; 1992; 1994), the greenhouse gas forcing could also express itself as an increase in average cloud coverage, the effects of which (food production, hydrological aspects, recreation, etc) have not been very well quantified.

In this respect it is crucial to monitor any trends in cloud cover worldwide. Unfortunately, we do not have a long history of reliable cloud coverage observations (London, *et al*, 1991; Warren, *et al*, 1986; 1988). In the period 1952-1981 observations from ships have shown that over the latitudes 20°N-20°S of the tropical oceans cirrus and cumulonimbus cloud types have increased while cumulus and stratus types decreased or remained nearly constant. The net effect in this area has been estimated to come down to an increase in greenhouse forcing. Reliable databases of cloud observations over land includes data which date back as far as 1971. The significance of these analysis is still of minor value, due to the relatively short period and the spatial limitation of the study.

Due to the uncertainties in this area it is not possible to quantify a risk.

4. BIOGEOCHEMICAL CYCLES AND GLOBAL CHANGE

Apart from the enhanced greenhouse effect several more processes of global change are now apparent: stratospheric ozone depletion, land use change, deforestation (causing in some areas erosion and desertification), acidification and changes in water resource management. All these processes are connected in several ways to the natural biogeochemical cycles: mankind is increasing the turnover of these cycles through emissions to air, surface water, soils and the marine environment; in addition, global change processes have apparent consequences for the natural sources and sinks of most cycles. Some of these interactions constitute additional risks, which are outlined below.

4.1. Greenhouse induced stratospheric ozone depletion

Stratospheric cooling, due to the enhanced greenhouse effect, could result in conditions which favour the formation of an Arctic ozone hole (Austin *et al*, 1992). The report of Austin *et al* suggests that a doubling of CO_2 could already have a substantial effect. The probability depends on the relative timing of the growth rate of total greenhouse gas concentrations and the atmospheric loss rate of ozone depleting substances (ODS). The risk could be enhanced by volcanic eruptions, which further the heterogeneous chemical reactions leading to ozone loss. As a result of the phase-out of ODS the period of highest risk probably falls within the forthcoming 3 to 5 decades. The effect would be an increase in UV-B levels in the northern hemisphere and could also cause a change in the stratospheric circulation patterns. The exact significance of such a change is unclear at present.

4.2. Feedbacks through modification of natural emissions

In table 1 the impact of global change processes has been estimated for major source strengths of natural emissions in a number of cycles.

Table 1.
Summary of feedbacks through biogeochemical cycles (biogenic emissions only); the scores are based on the expected effect on the atmospheric concentration of each component.

Aspect of global change	CO_2	CH_4	NMHC	CO	DMS	CH_3Cl CH_3Br	N_2O	NO
Global warming								
• SST	+	+	+	+	+	+	?	0
• Air	0	-	-	-	0/-	0/-	?	-
Soil humidity reduction	+	0	0	0	0	0	0	0
UV-B increase (OH; primary production)	+	-	-	-	-	-	0	-
Acidification	+	0	0/-	-	0	0	0/+	0
Eutrophication Fertilization	-	0	0/+	0/+	+	+	+	+
Land use change and Water resource management	+	-	-	-	0	0	-	0
Overall effect	+	0/-	0/-	0/-	+/-	+/-	0	0

\+ positive feedback: the indicated aspect of global change results in increased emission of the respective GHG
\- negative feedback
0 neutral: no effect expected or two counteracting effects
? no estimate made

It is seen that most of the above-mentioned processes of global change result in additional CO_2-emission or reduce the global CO_2-absorption capacity, thus providing a positive feedback to radiative forcing.

The supposed positive feedback of methane through the melting of permafrost in a warmer climate (Mellilo, J.M., 1990) is expected to be partly compensated for by gradual drying and afforestation of former tundra areas (Ihle, 1993).

The accumulated effect of stress on forest ecosystems, in combination with deforestation, could reduce the total forest area in the world as well as forest vitality. The resulting decrease of emissions of volatile organic components (VOC) might reduce tropospheric ozone formation worldwide, thus providing a negative feedback for global warming. It should be remembered, however, that the effect of a decrease of VOC-emissions from forests could be counterbalanced by an increase in man-made VOC-emissions.

5. CONCLUSIONS

From the body of information in the respective literature it can be derived that clouds are the major uncertainty with respect to future climate and global warming: clouds could counteract global warming, but it should be realized that in doing that a more cloudy world results.

Present global change processes nearly all tend to contribute to either increased emissions of CO_2 or decreases in CO_2-sinks. They do not seem to provide major increases in the source strengths of other greenhouse gases. There is a certain risk for loss of stratospheric ozone as a result of the enhanced greenhouse effect.

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