Environment and Development

KlimaProg - Research programme on climate and climate change

Programme plan
2002-2011

The Research Council of Norway

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Foreword

KlimaProg – Research Programme on Climate and Climate Change is a continuation of the *Research Programme on Changes in Climate and the Ozone Layer*. The scientific area represented by the programme is both a politically important field and one with a great need for knowledge. In a governmental research notice (Forskningsmeldingen, St meld nr 39 (1998-99)), the subject area is discussed as a part of the investment in research in the intersection between energy and environment. The problems associated with climate and ozone layer changes are long term and to a large degree of a basic research nature. This also means that the research activities must be long term.

In this context, a programme development group was appointed in summer 2000 with a mandate to formulate a proposal for a programme plan for a continuation of the *Research Programme on Changes in Climate and the Ozone Layer* for the ten-year period 2002-2011. (The mandate text and composition of the group is provided in the Appendix.). The programme development group was requested to formulate a concise plan that outlines the scientific basis for Norwegian climate and ozone research for the given ten-year period by concretely defining the programme's objectives, superior scientific priorities and content, as well as a superior governing plan for its accomplishment.

The program development committee's proposal was taken under consideration and approved by the board of the Division of Environment and Development on 14 December 2000.

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Summary

KlimaProg – Research Programme on Climate and Climate Change is a continuation of the *Research Programme on Changes in Climate and the Ozone Layer*. The plan applies to the ten-year period 2002-2011, with possible adjustments halfway through the period.

The programme covers natural science research that seeks to increase the understanding of the climate system and climate changes. It is a focused and goal-oriented programme with the intention to deliver results that lend themselves to further application. The programme does not contain studies of the biological, ecological, technological, social or economic *effects* of climate changes. Other programmes will cover these research problem areas. *KlimaProg* will nonetheless establish close connections with these programmes in order to ensure that the scenarios and results that come out of the programme are adapted to the users' needs. This will take place at both the programme board and researcher level.

Overall objective

KlimaProg shall ensure Norwegian natural science climate research at the highest international level. The programme shall enable Norwegian researchers to conduct research that leads to substantial research breakthroughs in at least three of the prioritised research challenges outlined in the programme plan.

Specific objectives

- *KlimaProg shall lead to targeted research on the prioritised research challenges outlined in the programme plan.*
- *KlimaProg shall ensure production of results that are applicable for user groups, including for effects research and for users in management and trade and industry.*
- *KlimaProg shall ensure a good national division of labour such that the best national expertise in the various research areas is utilised.*
- *KlimaProg shall ensure effective dissemination of results.*
- *KlimaProg shall ensure recruitment of talented climate researchers.*

Prioritised research tasks

The programme defines a series of scientific problem areas to be addressed. These are based on the *IPCC Third Assessment Report (TAR)*, on an evaluation of important national and global research challenges, and on Norwegian research expertise:

1. *Detection of ongoing climate changes, understanding of their causes and how they can be related to natural and anthropogenic forcings*
2. *How will the climate develop in our region, and to what degree are climate changes in our region influenced by effects from remote regions?*
3. *How large is the probability of abrupt changes in the climate system, particularly those associated with the ocean circulation? Which processes cause abrupt changes, and how large are the forcings needed to set off such changes?*
4. *Why do large-scale climate changes of regional or global character arise on time scales from 10 to 1000 years? How do such changes affect the present-day climate developments? What is the climate system's sensitivity to various natural and anthropogenic forcings that operate on longer and shorter time scales?*

5. *What is the origin of the interannual to decadal variability in North Atlantic/Arctic system, and is it possible to predict this?*
6. *Improved understanding of key processes, particularly those associated with feedback processes and non-linear phenomena, in the climate system.*
7. *Improved understanding of exchanges of greenhouse gasses (particularly carbon, methane and nitrous oxide) between terrestrial systems, the atmosphere and the ocean, and how the exchanges and greenhouse gas forcings are changed under global warming.*
8. *How will greenhouse gases and aerosols be affected by physical and chemical processes in the atmosphere?*
9. *What role does ozone have as a greenhouse gas today, and what role will it have in the future?*

These prioritised research tasks represent questions of great importance for the future development of society. They cover substantial research challenges that require a comprehensive investment of financial and intellectual resources over a long term. The character of the research problems demands far-reaching cooperation across institutional and disciplinary boundaries. Large cross-institutional national or regional projects will therefore still be prioritised, and the research in the programme will be closely integrated with international programmes under the direction of the IGBP and WCRP, EU framework programmes, as well as national programmes and research groups in the USA and northern Europe.

The programme plan outlines the scientific prioritisation that should be made assuming three different funding scenarios (*status quo (26 mill kroner per year)*, *substantial increases*, and *reductions*). It indicates which areas should be maintained or strengthened, and what the consequences of a reduced budget would be for the climate research. In order to reach the highest governing objectives – ensure research at the highest international level and ensure efforts across the range of the central research challenges – a plan for funding increases will be necessary.

The natural science climate research is strongly dependent on a well-functioning infrastructure consisting of advanced instrumentation for field and laboratory studies; high quality measurements and observations; a number of long times series of climate observations; infrastructure for field observations, in particular sea- and ice-going research vessels; access to remote sensing systems; and prioritised access to large-scale supercomputing. It is an underlying assumption for reaching the goals in *KlimaProg* that this infrastructure exists, is expanded and given financial priority in the relevant management organisations and research institutions' budgets as well as in the other programmes in the Research Council.

1. Introduction

Background

Based on reconstructed climate parameters over the last 1000 years and observed climate parameters and climate model simulations over the last 150 years, the IPCC concluded[1] that there has been a demonstrable change in the global climate as a result of anthropogenic (human-induced) emission of so-called greenhouse gases and aerosol particles. These global changes are manifested as increased surface temperature, changes in precipitation patterns, reduced snow cover on land and reduced ice extent on land and the oceans, a global increase in sea level, indications of changes in the large-scale atmospheric and ocean circulation patterns, and indications of greater variability in the climate system. Furthermore, the ozone layer, particularly in the Polar Regions, has undergone large changes in the 1990s, with record low stratospheric ozone in both the Antarctic and Arctic, while the concentration of tropospheric ozone has continued to increase. This has led to an increased UV-radiation level and perhaps a feedback in the climate systems through stratospheric cooling.

Global climate simulations indicate that the strongest warming will occur in the high northern latitudes, that the extent of sea ice in the Arctic will be strongly reduced over the next couple of decades, that reduced inflow of Atlantic Water to the Nordic Seas cannot be ruled out, and that the frequency of extreme weather will increase. Therefore, Norway has a special interest in climate research in that changes in the global climate system can have exceptional consequences for Norway and adjacent ocean and land areas, including economically and socially important business activities such as fishing, aqua culture, forestry and land use, and the energy sector.

Even though Norway is a small nation in terms of population and area, Norway has developed a superior responsibility to contribute to global climate research because of its extraction and export of oil and gas[2]. Norway's geography provides the possibilities and responsibility to monitor a broad range of climate parameters in an area that covers a broad latitudinal band (including the Arctic and parts of Antarctica) in a globally key region for climate changes. Climate research is also a prerequisite for Norway to contribute to the comprehensive international climate activities that are in progress. High-quality future scenarios for Norway's climate system, together with Norwegian participation and potential to have an influence in international climate activities, depend on climate research at a high international level.

In addition to the distinct, regionally significant, climate changes in our area, the global nature of climate change is a challenge. We have both an international obligation and a national interest in understanding the full range of global changes. This is because there are many examples of how the climate system contains remote effects (e.g., "tele connections"), where changes in one place affect the climate far away, and because the social consequences of climate changes will have on effect on a global scale. Accordingly, Norwegian climate research should not be laid out too narrowly, and first and foremost

[1] "The balance of evidence suggests a discernible human influence on global climate" (IPCC Second Assessment Report, Summary for Policymakers, 1996), and "There is now stronger evidence for a human influence on global climate than at the time of the Second Assessment Report" (IPCC Third Assessment Report, Summary for Policymakers, dated 22 October 2000).

[2] Norway's emissions of CO_2 comprise ca. 1.7‰ of the global emissions, while Norway's export of oil and gas comprise 2.5% of the global emissions.

should be focused on contributing high quality to improving understanding of climate changes in a global perspective. On the other side, a number of the central climate processes in our region are of great global importance, something which creates good synergy between national research niches and strategies within climate research and the requirements in order to achieve an improved understanding of the global changes. Included in this is an obligation to participate in building up climate change expertise in the lesser-developed countries.

What the programme covers and does not cover

KlimaProg covers natural science research that has the goal of increasing understanding of the climate system and climate changes. It is a goal-oriented programme that is focused on solving clearly defined research problems with results that can be further applied. In the following chapters, it will be clarified which research problems can be addressed and covered under different budget alternatives. The research that the programme covers will, despite focusing on results that can be applied, to a large degree be basic research, and the bulk of the research will described as *strategic basic research*.

The programme has changed name from the previous programme on *Changes in Climate and the Ozone Layer*. This has occurred because of a desire to focus on *climate* problems. The ozone layer research is retained in the programme, though is now considered as an integrated part of the overall set of climate problems. This is in accordance with the latest report from the WMO/UNEP on the ozone layer, which concludes that climate and ozone layer problems are linked together.

The programme does *not* contain studies of the consequences or effects of climate changes (hereafter called effects studies), neither biological/ecological, technological, social nor economic – these problem areas will be covered by other programs. Nonetheless, the programme has as one of its most important ambitions to provide a solid foundation for effects studies by working to provide climate reconstruction, predictions and scenarios that contain the parameters that are relevant for these studies. Some hydrological and geological effects of climate change that in themselves may hold information on the magnitude and nature of the climate changes will in some cases have a place within the programme – for example, information on the frequency and magnitude of avalanches and floods under different climatic conditions.

KlimaProg is thus a programme for natural science studies of the climate system and climate changes. It will be the central provider of the premises that will serve as the basis for social science, natural science or technological effects studies, to deliver, among other things, specific scenarios that the effects studies will use as a basis. There is therefore a need for a strong coordination of *KlimaProg* with other climate research programs. This will ensure that the scenarios are user oriented, and contain the central parameters demanded by the effects studies. This should occur through coordination at the programme management level between the programmes, and through common meetings and workshops that ensure two-way communication between researchers in the programmes. Furthermore, dissemination of the research results from the programme, in addition to containing public-oriented initiatives, will specifically constitute for reaching important user groups of climate research within management and trade and industry.

KlimaProg will not contain research about future scenarios for emissions of greenhouse gases. This research and the development of revised emissions scenarios will nonetheless be

significant in the research that is concerned with the prediction of the expected climate development. The programme must therefore establish good connections with national and international activities that work with emission scenarios.

KlimaProg will be strongly dependent on a well-functioning infrastructure that covers the acquisition of important climate parameters. It will lie primarily outside of the programme's framework to finance the climate monitoring (see Chapter 6), which is assumed to be funded through other budgets. A complete separation between monitoring and operational activities on the one hand, and research that utilises the observations on the other, is not possible to establish. Accordingly, it will be natural that some series of critical measurements will be carried out within the programme.

2. Knowledge requirements

With sea-surface and air temperatures 5-10°C above the mean temperature for comparable latitudes, the climate of Norway and the adjacent ocean areas is special in a global context. The main reason for our special climate is a substantial supply of warm and humid air from the North Atlantic, together with a supply of warm water masses into the Norwegian Sea. In addition to unusually high ocean and air temperatures, our climate is characterised by large gradients and high variability. In fact, Norway the adjacent ocean and land areas including the Svalbard region have the highest natural climate variability among areas in the Northern Hemisphere. The mechanisms behind the natural variability are poorly known, and there is a strong need for better knowledge for this if the future development of climate is to be predicted with adequate accuracy.

In the last 20 years, the ozone layer weakened over the high northern latitude areas. This is due to special meteorological conditions, with low temperatures and polar stratospheric clouds that provide the right conditions for activating the ozone-depleting substances in the atmosphere. There is a strong coupling between reduced ozone and temperature in the stratosphere that links changes in the stratospheric ozone layer to changes in climate. There is a need for further studies of chemical processes, studies of processes that determine the exchange of air between Polar Regions and the mid-latitudes, and of the coupling between ozone and climate in order to be able to estimate future ozone changes.

The above-mentioned relationships make scenarios of the future climate in Norway and adjacent areas including the Svalbard region burdened with considerable uncertainties. Central issues that require long-term research efforts include:

- *the possibility for reduced intensity and heat supply from the North Atlantic ocean current system (i.e., the intensity of the* North Atlantic current*);*
- *the possibility for changes in the intensity of climate variability, including changes in atmospheric and oceanic currents, in air and ocean temperature, and in precipitation;*
- *the possibility for reduced sea ice in the Arctic; and*
- *knowledge about how much of the climate changes are caused by natural and anthropogenic forcings, respectively.*

Although Norwegian climate research will be centred on research questions associated with Norway and adjacent areas, climate changes are global in nature. It is therefore necessary to study global processes that cause changes in greenhouse gases and aerosols and their influence on the climate on different scales in order to understanding the development of climate (and climate variability) in Norway and adjacent ocean areas. For the same reason,

it is necessary to study and model coupled atmosphere and ocean dynamics on a global scale in order to increase understanding of the development of climate in our region.

Strengthening of the national climate expertise and the results from the research will be important for management. The expertise and results will also be of strategic use for industrial planning and development, and they will form the basis or departure point for biological, hydrological, socio-economic and climate policy effects studies. Considerable contact with the users of climate research is important, and organising the conditions at the researcher level can help to ensure this.

In order to be able to improve the climate scenarios and reduce the uncertainties in the prognoses that will be the departure point for the effects studies, it is necessary to:

- *maintain and improve observations and time series of key parameters in our climate system;*
- *strengthen knowledge on central processes and work with models that describe future climate changes;*
- *improve the level of knowledge on previous climates (paleo climate) and climate variability, and to improve the precision of the descriptions and interpretation of the dynamics of such climate changes;*
- *improve description, understanding and modelling of exchanges between ocean, snow and ice, and the atmosphere in our region (and on a larger scale, if necessary) for the present-day climate;*
- *improve the understanding of the natural climate variability in our area for the present-day climate;*
- *reduce the uncertainty in simulations of the mean state and variability in our climate system for future climate scenarios;*
- *improve the understanding of sources and sinks of the most important greenhouse gases, and develop more accurate estimates of the future change in atmospheric concentrations of these;*
- *improve description of the direct and indirect effects of atmospheric aerosols on the climate in our region; and*
- *improve the understanding of the role of clouds and water vapour in the climate system.*

In order to ensure high quality, results-oriented research, it is necessary to have international cooperation at the research level and active participation in international climate research programmes. This, in addition to active research dissemination and close communications with the disciplines that use results from natural science climate research, is described in Chapters 3 and 4.

The *IPCC Third Assessment Report (TAR)* specifies the following four areas as particularly central in order to better understand and identify future climate changes: 1. Ensure observations of central climate parameters. 2. Reduce uncertainties in the future development of atmospheric concentrations of greenhouse gases and aerosols, including biogeochemical storage and cycling of these components. 3. Better understanding of non-linear processes in the climate system, including the role of clouds, El Niño – Southern Oscillation (ENSO), thermohaline ocean circulation and sea ice. 4. General improvement of global and regional climate models.

Prioritised research tasks

Based on national interests and requirements on areas and niches where Norway presently has strong expertise at a high international level, and on needs for activity and research expressed by the IPCC, the following research problem areas are considered to be the most central for climate research in Norway over the next ten years (with some adjustment proposed after five years). Chapter 5 explains which of these will be prioritised under various budget alternatives and how the level of funding will influence the degree to which these research tasks can be solved.

1. Detection of ongoing climate changes, understanding of the causes and how they can be related to natural and anthropogenic forcings.

Analyses of continuous high-quality observations of central climate parameters in the atmosphere, on the land, on the ocean surface and in the ocean play a key role in climate research. Such analyses are necessary in order to establish whether the climate system is changing character in the form of, for example, altered frequency of extreme weather. It is also necessary to analyse the climate system in order to identify patterns that can be related to natural or anthropogenic forcings in order to develop and validate a theoretical foundation for the observations, and in order to validate regional and global climate models. In this research, it is particularly necessary to make use of long climatic time series. Without such observations it is impossible to distinguish human-induced climate change (e.g., trends) from natural variability in the climate system. On account of Norway's location and particular interests for high-latitude climate processes, the analysis of sea ice, land ice, permafrost and snow cover will come in addition to analysis of standard climate parameters such as air pressure and temperature, precipitation, radiation balance, greenhouse gas concentrations, ocean temperature and salinity.

2. How will the climate develop in our region, and to what degree are climate changes in our region influenced by effects from remote regions? Included under this – develop scenarios that will form the basis for effects studies.

A central problem for climate research is to demonstrate or at least say something about the probability that climate system will change character depending on how the greenhouse effect is enhanced. For Norway, it is particularly important to clarify whether global warming will lead to a shift in our climate system, or whether the natural variability changes character. Because the climate system is global, one cannot ignore that changes far from Norway can have consequences for the climate around Norway, or vice versa. It is therefore necessary to have research on both regional and global scales in order to be able to say something about the development of the climate in our region. In addition, Norway and the adjacent areas are characterised by large geographic variations in both the mean state and variability (including extremes) of climate parameters. Therefore, special analyses and modelling tools are necessary in order to be able to provide regional climate scenarios with the desired quality. It is scenarios such as these that will be used in effects studies and in national and international climate policies, so the quality of these scenarios will directly impact the relevance of the effects research and climate policies. In order to ensure that *KlimaProg* will be able to satisfy the effects studies with relevant scenarios, it is important to have a dialog with users during planning of the project.

3. How large is the probability of abrupt changes in the climate system, particularly those associated with the ocean circulation? Which processes create abrupt changes, and how large are the forcings needed to set off such changes?

It is known from paleoclimatic datasets that there have been very strong and rapid climate changes. There have been large shifts in the mean state over periods as short as a couple of decades. The existing knowledge suggests these are set off or enhanced by abrupt changes in heat transport in the North Atlantic, but that the effects are large over the entire Northern Hemisphere, and possibly even global. Likewise, a number of climate modelling experiments show that this sort of change can be

a consequence of a continued human-induced climate effects. There is a strong need to create a better understanding of such changes. If these should happen, they will result in very large shifts in our region. A better understanding must be based on better knowledge on the factors that caused such changes in earlier periods, reconstruction of the geographic distribution, better understanding of the central mechanisms tied to deepwater formation and ocean circulation in the high northern latitudes, and a strong improvement of the way that such processes are represented in climate models.

4. Why do large-scale climate changes of regional or global character arise on time scales from 10 to 1000 years? How do such changes affect the present-day climate developments? What is the climate system's sensitivity to various natural and anthropogenic forcings that operate on longer and shorter time scales?

Human-induced climate changes occur in interplay with the natural climate variability. It is believed that the changes will also happen largely by the appearance of known forms of variability, for example, that the climate system can to a large degree be set in a particular state. There is accordingly a great need for knowledge on the natural variability. Such knowledge will be able to provide the answer as to whether the observed spatial and temporal changes occur as a part of underlying natural trends, and it will provide answers on the sensitivity of the climate system to external and internal forcings. The orbital changes that cause the ice ages provide the basis to study how the climate system has reacted in situations where the external forcing is known. This will provide knowledge both on linear responses to radiation changes and on the numerous feedback processes that enhance the radiative forcings (ocean, snow and ice, vegetation, greenhouse gases and aerosols). Regarding shorter time scales, it is still uncertain whether there is periodic behaviour in the natural climate variability and whether changes such as the "Little Ice Age" and similar phenomena are due to internal or external processes in the climate system. A considerably better understanding is needed regarding whether this type of medium-strength climate change is part of an inherent cyclicity in the climate system, and what role is played by changes in solar radiation, solar activity and volcanism.

5. What is the origin of the interannual to decadal variability in North Atlantic/Arctic system, and is it possible to predict this?

The climate (wind, temperature, precipitation, and ocean currents, temperature and salinity) of Norway and the adjacent area exhibits strong variability on interannual to decadal time scales. Changes in the strength of the centres of action for this variability will have direct consequences for both the marine and terrestrial climate. It is therefore important to improve the knowledge on this variability, and to define and understand climate indices that can be used for effects studies. The North Atlantic/Arctic Oscillation (NAO/AO) index is central on decadal time scales, but there is variability on other time scales as well. An increased knowledge on the natural variability can only be done with extensive examination and analysis of climate observations and climate modelling. It is expected that substantial national efforts, combined with international cooperation, will give improved insight into the natural variability in our climate system over the next ten years, and that we within this time will be able to say something about the extent that the natural variability can be forecast. If it turns out that the NAO/AO and other climate variations can be forecasted, this would have great significance for atmosphere and ocean modelling, for prognoses of the development of fish stocks, and for weather development several months ahead of time. This would also be able to influence our understanding of the correspondence between climate changes and the important processes in the stratosphere that affect the ozone layer in the Arctic.

6. Improved understanding of key processes, particularly those associated with feedback processes and non-linear phenomena, in the climate system.

Many processes in nature respond to small external changes with large changes. At the same time, analyses of past climates show that large variations in climate system have occurred over just a small number of years. It can therefore not be ruled out that the climate system may be able to change character over a short time period. There is particular uncertainty tied to: the role of clouds

and the amount and distribution of water vapour depending on how the greenhouse effect is enhanced; to natural climate oscillations such as the El Niño – Southern Oscillation (ENSO); to the stability of the North Atlantic thermohaline circulation; to the melting of sea ice; and to changes in the surface albedo. All of these processes have the potential to enhance an external influence. It is of both national and international interest to better understand these processes such that, for example, threshold values can be stated for increases in human-enhanced greenhouse effect where parts of the climate system can react with large changes. Increased understanding of these processes requires observational programmes, theoretical analyses of observations and processes, and process- and large-scale modelling. Given the importance and dimension of the challenges, international cooperation will be a prerequisite to significantly raise the level of knowledge over the next ten years.

7. Improved understanding of exchanges of greenhouse gases (particularly carbon, methane and nitrous oxide) between terrestrial systems, the atmosphere and the ocean, and how the exchanges and greenhouse gas forcings are changed under global warming.

In addition to uncertainties associated with the magnitude of the present and future emission of greenhouse gases, there are large uncertainties regarded how the natural sources and sinks of greenhouse gases will react to climate changes. The large yearly fluxes of greenhouse gases between the atmosphere and the terrestrial and marine sources and sinks of greenhouse gases can be several orders of magnitude greater than the human-induced emissions. There are large uncertainties in the understanding of the magnitude of the different sources/sinks and their geographic distribution. This applies to both marine and terrestrial areas. The uncertainties are even larger regarding how the exchange between the atmosphere and the marine and terrestrial carbon reservoirs will be affected by climate changes. It is unclear whether the effects of global warming will decrease or increase the natural sinks of greenhouse gases, and accordingly whether this will increase or reduce greenhouse gases loading. A change in the large yearly fluxes of CO_2 between ocean and atmosphere will significantly affect greenhouse gas concentrations in the atmosphere on a global scale. For the fluxes between the atmosphere and soil and biosphere on land, there are large uncertainties associated with whether changes in carbon storage will be of temporary or transient character or whether they will be stable on a long time scale – something that has significance for the development of climate. Work must be done to reduce the uncertainties since these have great significance for predictions of the future development of the climate and for compliance with climate agreements. In order to achieve this objective, a combination of modelling and observations is needed, and this will require extended international cooperation.

8. How will greenhouse gases and aerosols be affected by physical and chemical processes in the atmosphere?

In addition to their direct emissions, several important greenhouse gases and aerosols are affected by chemical and physical processes in the atmosphere. Of the greenhouse gases, this is especially so for methane, which breaks down effectively through chemical oxidation in the troposphere. Changes in the emission of pollution gases (NO_x, CO, VOC) and future climate changes (e.g., changes in temperature, water vapour, cloud amount, and incoming radiation) will affect oxidation rates and through this the concentrations. Future changes will therefore largely depend on how the oxidation process changes. In addition to the direct effect of the particles on radiation, particles have an indirect effect by affecting clouds. The indirect effects of particles on radiative forcings are potentially very important, and are expected to provide a cooling, although the uncertainties associated with calculations of indirect radiative forcings are large (IPCC). In addition, there will be large regional variations in radiative forcings from the indirect effects. It is of great significance to regional and global climate scenarios to get a better understanding of these mechanisms. Future changes of chemically active climate components will almost certainly be very different from that which can be expected from changes in the emissions of the primary components. Because some of the most important climate components (methane, ozone, particles) and atmospheric processes are complicated and somewhat poorly known, it is necessary for further studies of the interaction

between atmospheric processes and greenhouse gasses and particles, and quantification of the radiative forcing of the different components and how this varies spatially and temporally.

9. What role does ozone have as a greenhouse gas at present, and what role will it have in the future?

Ozone is in its own class among the greenhouse gases in that it is a secondary component that is formed by chemical reactions in the atmosphere. It has a short residence time and varies both temporally and spatially. It is dependent on both the amount and distribution of emissions of polluting gases. Changes in tropospheric ozone are estimated to have provided the third largest global contribution to radiative loading up to the present day. The regional contribution, for example, over Europe is particularly large. The ozone layer in the stratosphere has been reduced significantly in the last 20 years. This has led to a change in the radiative forcing that affects the climate. In the same period, reductions in the ozone layer have led to a considerable increase in harmful UV radiation at the ground. This will affect biological systems on the ground and in the ocean and oxidation processes in the atmosphere. The large uncertainties that are associated with how ozone formation in the troposphere will be changed and how the stratospheric ozone layer is affected as a result of emissions of greenhouse gases and gases that deplete ozone warrant further studies of the change in tropospheric ozone and the change in stratospheric ozone and what significance it has for UV radiation at the ground.

3. Expertise, relationship to international research and recruitment

Climate research is cross disciplinary in nature and is concerned with processes from micro- to global-scales. Climate research is therefore characterised by cooperation across scientific disciplines and national boundaries. The cross-disciplinary research and the international cooperation within climate research is expected to be further strengthened in the next ten years.

Norwegian expertise

Norwegian climate research presently has leading international groups within research areas that include physical and chemical processes in the atmosphere, including the direct and indirect roles of methane, ozone, aerosols and clouds; within the analysis of remote sensing data to detect changes in the extent of sea ice, snow and glaciers; within the evaluation of processes important for the climate development and the observation of atmospheric temperature and humidity distributions; within observations of the importance of ocean circulation for climate changes in the Nordic Seas; and within analysis and interpretation of paleoclimatic observations. In addition, Norway has a growing, international-calibre research environment within climate modelling and dynamical and empirical downscaling of global climate models, within parameterisation of clouds (radiation and microphysics) in climate models and within studies of the high-latitude marine carbon system.

In Norway, there is also expertise on climate changes coupled to ocean and atmospheric processes and paleoclimate in the Antarctic. This should be developed both as a central part of Norwegian Antarctic research, and as a part of a niche strategy in which Norwegian climate research should be strong in climate changes in the high latitudes.

In general, the primary research areas described in Chapter 2 are attended to by existing research expertise in Norway. In order to maintain and strengthen the position of Norwegian climate research internationally, it is therefore suggested to strengthen mainly the activities within existing research groups. The efforts should be placed within prioritised

niches where we have strong research environments or where a particular expansion may be wanted based on governing national considerations. Expansion into new areas should however occur primarily under a substantial increase of the economic framework for research (see Chapter 5 below). This niche strategy is necessary if Norway is to have leading international research groups in the future.

International participation and cooperation

Leading research groups are characterised by frequent scientific publication in recognised international research journals, by popular scientific dissemination of their own and related research, and by participation in international projects and programmes. On the basis of the present-day funding levels of natural science climate research in Norway, the most central climate research can be considered to be under financed. Therefore, a broad cooperation between Norwegian and international research groups is necessary. International cooperation is also desirable in that, in addition to increased research activity, it will propel the quality and knowledge of the research.

International cooperation today is largely channelled through the EU framework programmes and through participation in large international programmes such as the WCRP and IGBP. This cooperation will, in practice, also mean that Norwegian researchers, and accordingly the research itself, are closely associated with the large climate centres in Europe. This is a positive and effective way to transfer niche knowledge to the larger centres. In addition to internationalisation on a European level through EU framework programmes and British/northern European research, Norwegian climate research should also be active in relation to research environments in the USA, where several climate research programs are being planned. In order to optimise the outcome of the Norwegian research, it is recommended that ongoing cooperation projects with international groups should be one of the factors when evaluating proposals to *KlimaProg*.

International cooperation also takes place at the governing level through participation in international programmes, projects and panels (for example, CLIVAR, ACSYS/CLIC, PAGES, IGAC, JGOFS/SOLAS, IPCC, OOPC and WMO Ozone Assessments). This participation presently happens largely at random. This should be changed such that Norway actively takes part in existing research programmes and development and participation in new research programmes. In this way, it can also be ensured that research questions that are of particular significance for Norway and adjacent areas receive a central role in the programmes.

As a means to strengthen this association, the programme board should appoint small national committees for the most central programmes/projects, with responsibility for flagging Norwegian interests in the programmes/projects and forwarding information to the programme board and relevant research groups in Norway. The researchers in the topical committees should have their actual expenses covered in connection with this work.

In connection with participation in international projects, it is important to emphasise that changes in, for example, the European and American research policies can have large consequences for Norwegian climate research. Funding from, for example, the EU framework programme has shown itself to be very unpredictable. It is therefore necessary that the national funding of climate research has a certain amount (see Chapter 5), and that funding is long term.

Recruitment

Climate research on an international level assumes consistent researcher recruitment. Recruitment can be ensured by several means: active research dissemination is necessary in order to increase the visibility of climate research in Norway and the importance of the research. This research dissemination should have a goal to reach students at the elementary, secondary and university levels. In addition, it is necessary to provide scholarships to doctoral students and post-doctoral scholarships to particularly well-qualified candidates in order to continue with climate research. Support for foreign climate researchers on a post-doctoral and higher level should also be given where these researchers do their work in Norway, are associated to Norwegian research groups, and will raise the level of Norwegian climate research. Likewise, Norwegian climate researchers must be encouraged to undertake lengthy research stays with leading foreign research groups, such that research stays are a central part of the research education for Norwegian climate researchers. The leading Norwegian research groups should have a sufficient scientific "centre of gravity" and research resources to make them attractive to foreign researchers.

4. Objectives and means

Overall objective

KlimaProg shall ensure Norwegian natural science climate research at the highest international level. The programme shall enable the researchers to conduct research leading to substantial research breakthroughs on at least three of the prioritised research challenges in the programme plan (see Chapter 2).

Norwegian climate research shall be characterised by research at a leading international level. This necessitates that the programme is able to focus the effort on the prioritised research tasks, and to provide the best applicants sufficient long-term funding. The degree to which the objectives can be achieved will also depend on the programme's funding framework (see Chapter 5) and that the external assumptions about necessary infrastructure (e.g., supercomputing) financed through other budgets are fulfilled (see Chapter 6). Since the national funding of climate research generally is not sufficient to ensure this goal, international project cooperation is necessary. International cooperation should therefore be stressed in evaluating the applications. Quality should be the most important factor during the evaluation of the programme activities halfway through the programme and at the end of the programme.

Specific objectives

- *KlimaProg shall lead to targeted research on the prioritised research challenges outlined in the programme plan.*

In order for to make it possible to reach the overall objective, it is necessary to concentrate the efforts on the prioritised research areas in Chapter 2. This does not preclude supporting other research problem areas, but the starting point should be that at least 70% of the funding goes to the prioritised research areas. The remaining portion should go to other high-quality targeted research having the goal of a better understanding of the climate system or improved modelling of the climate system. It is also an advantage if this research is related to the prioritised research areas. An adjustment of the prioritised research areas should be undertaken halfway through the programme period.

- *KlimaProg shall ensure production of results that are applicable for user groups, including for effects research and for users in management and trade and industry.*

User groups include, among others, management and research groups within biological, technological, socio-economic and climate policy disciplines. It is important to have a considerable and regular dialog with the user groups, such that the main results for the research can be prepared in a well thought out manner in relation to the needs of these groups. Since the results from *KlimaProg* will serve a basis for social science, natural science or technological effects studies, a strong coordination of *KlimaProg* with programmes covering such studies is particularly needed. This will ensure that the climate scenarios from *KlimaProg* are user oriented, and that they contain the central parameters requested by the effects studies. The coordination should occur both at the programme board level and with common meetings and workshops that ensure two-way communication between the researchers in the programmes.

- *KlimaProg shall ensure a good national division of labour such that the best national expertise in the various research areas is utilised.*

The programme shall be an instrument for ensuring optimal use of resources for natural science climate research. In addition to international cooperation, coordinated, cross-institutional projects on a national or regional level will be important for achieving this. As a starting point, about 60% the funding should go to such coordinated, cross-institutional projects. The total number of coordinated projects will depend on natural cooperation areas and funding (see Chapter 5).

- *KlimaProg shall ensure effective dissemination of results.*

Dissemination of research results shall be prioritised highly when many of the results of the research will have consequences for the people of Norway (and adjacent areas), Norway's management, marine and land-based economic activities, and ecosystems and biodiversity. In addition, it is completely vital for the Norwegian climate research that there is recruitment of researchers with a strong and broad scientific background. One means to ensure sufficient recruitment is to disseminate the research at the elementary school to university level, and thereby make the research areas associated with global climate changes and the need for climate research more visible. Research dissemination can occur through information on Internet web pages, through distribution of brochures or cassettes with information on the climate system and results from climate research, through popular scientific lectures and publications, and through close contact with the mass media.

- *KlimaProg shall ensure recruitment of talented climate researchers.*

In order to ensure recruitment of talented climate researchers, the programme shall provide scholarships to doctoral students and post-doctoral scholarships to particularly well-qualified candidates. It will be the programme board's task to distribute educational scholarships in conformity with the substance of the candidates and the need for new climate researchers.

Other strategic initiatives

In order to ensure high-quality projects in the programme, international scientific evaluations ("referees") will be used in the proposal handling process. The proposals will be ranked based on quality and relevance.

The criteria for success for the projects are: dissemination of results and knowledge within the outlined problem areas through publishing in international journals; making the results prepared for and made accessible for use in effects studies; and research dissemination to the general public.

The scientific prioritisation of the research is to be evaluated and, if desired and necessary, adjusted halfway through the programme. A comprehensive international evaluation of the programme is also suggested after about five years. The conclusion from this evaluation should be used in order to possibly strengthen the research over the remaining five years.

5. Prioritisation under various funding models

The prioritised research tasks described in Chapter 2 represent questions of great importance for the future development of society. They cover substantial research challenges, which require a comprehensive contribution of financial and intellectual resources over the long term.

In order to attain the highest governing objectives, ensure research at the highest international level and ensure efforts across the range of the central research challenges, it is necessary to have plan for step-by-step increases or escalation. One can point to the escalation that is occurring in other countries, for example the establishment of the Thyndall Centre and NERC's large contributions in the United Kingdom on, among other things, research on ocean circulation and its possibility for bringing about rapid changes, the establishment of the Rossby Centre in Sweden, and the comprehensive increase in investments that the NSF and NOAA are undertaking in the USA, with emphasis on the Arctic, among other things. One may also point to the *Cooperative Commission for Climate's* own recommendation, which stresses that it is necessary to double the funding of natural science climate research.

In the following, the scientific prioritisation that should be made assuming three different funding scenarios (*status quo, substantial increases, and reductions*) is outlined. The areas that should be maintained or strengthened are pointed out, and what the consequences of a reduced budget will have for climate research. The order of the activities listed under *status quo* and *substantial increases* is random and does not indicate prioritisation. As is evident from this, very substantial research results are lost with reductions. A complete achievement of the goals will be possible only with substantial increases. A plan for gradual escalation with 10-20% increases per year will be desired in order to ensure recruitment of the desired expertise. It should be noted that in all of the budget scenarios, it is assumed that an adequate infrastructure (supercomputing, etc.), which must be funded under other budgets, is at hand (see Chapter 6).

Status quo[3]

- Continue the work on targeted development of regional scenarios. This will address research problem areas 1 and 2 in Chapter 2.
- Continue efforts in studies of ocean circulation and climate changes. This will provide research on problem areas 3 and 5.
- Continue projects on natural climate variability/paleoclimate. This will provide research on problem areas 1 and 4.
- Continue projects that study physical and chemical processes in the atmosphere, emissions and radiative effects (direct and indirect). This will provide research on problem areas 8 and 9.
- Continue the present activity associated with the carbon cycle (including the ocean's uptake and emission of CO_2). This will provide a certain degree of continuity in research on problem area 7.
- Maintain efforts concerning the ozone layer and changes in UV radiation in the high northern latitudes.
- Maintain the activity associated with climate changes in the Arctic. This will provide research on problem area 6.

The majority of these problems are presently addressed in the national coordinated climate projects *COZUV*, *NOClim*, *NORPast* and *RegClim*.

With substantial increases[4]

- Begin a national effort on research on possible changes in marine and terrestrial sources and sinks of the most important greenhouse gases, including carbon dioxide, methane and nitrous oxide. This would lead to Norway having considerable research within problem area 7 and 8, and with the possibility of a new coordinated national project on problem area 7. At present, there is only limited research on the biogeochemical cycles. It is emphasised that in order to have a successful Norwegian effort here, it is necessary to have long-term funding for building up expertise, and a strong integration of this activity with the leading international expertise.
- The development of climate in the Arctic will be central for Norwegian interests. There is also an outstanding scientific basis for an effort here, and it is expected that Norway will assume an international responsibility. Large Norwegian efforts on research on central atmospheric and marine climate processes in the Arctic, including interactions between the ocean, ice, snow and atmosphere and within paleoclimate will provide a substantial contribution to arctic climate research. This will provide key research breakthroughs concerning, among other things, observations and understanding of human-induced changes, and on the development of the arctic sea ice cover (problem areas 1, 2, 3, 5, 6 and 8, and partially 7 and 9). A strong funding increase is a *prerequisite* for Norway to have research groups at a top international level within climate research regarding the Arctic, and for Norway to have research activities that fill out the increasing international activity.
- Reduce uncertainties associated with climate change on a global scale (including strengthened global climate modelling) and improve the degree of usefulness of the

[3]The basis for the *status quo* is that the programme's budget for 2001 (circa 26 mill kroner, excluding capital funds administered by the programme board of directors) is continued with adjustment for inflation.

[4]A contribution on the order of 5-10 mill kr is assumed, in order to carry out the research on one or more of the stated problem areas on a high enough level that the probability of obtaining notable and/or applicable results is large.

regional climate scenarios for Norway and adjacent area as defined above. This will ensure a high degree of goal-achievement for research on problem areas 1 and 2, and will strengthen problem areas 4, 6 and 8.

- Improve description of the hydrologic cycle in climate models, including development, testing, and validation descriptions of processes that affect albedo, water vapour, clouds, precipitation and runoff. This will strengthen particularly research areas 2, 6, and 8 and partially 3 and 4.
- Provide the necessary mass and volume to the research on possible changes in ocean circulation, including reducing existing uncertainties about the possible reduction of the North Atlantic drift-stream system depending on how the global warming continues. Given the substantial expertise in Norway within paleoclimate, oceanography and modelling, increasing funding will lead the Norwegian research environment in among the world's most central players on research on problems areas 3, 4, 5 and 6.

With reductions

Reductions (cutbacks) will mean that research efforts for problems 1 through 9 will be adversely affected, and that there cannot be research within many of the central problems in *COZUV*, *NOClim*, *NORPast* and *RegClim*. This will lead to undermining of activities where we presently have research groups that have an international presence. In particular, studies of regional climate changes, paleoclimate, atmospheric processes and changes in ocean circulation will be impacted. For example, research on the regional scenarios (problem 2) will suffer with reduced grants. This research is dependent on a continuous supply of new knowledge on processes and natural climate variability in the atmosphere just as much as in the ocean. Even though the prioritisation is largely on regional climate modelling, it will therefore be difficult to develop satisfactory products for effects research without a portfolio of observational and process-related projects.

Reductions will also mean that we will not carry out research with adequate depth regarding the possibilities for rapid and large climate changes that result from possible changes in ocean circulation in the North Atlantic, non-linear processes, or feedback processes (problem areas 3, 4, 5 and 6). Research on these sorts of processes that can cause large unexpected climate swings will suffer greatly.

Reductions will also mean that research on possible changes in the terrestrial and marine greenhouse gas budgets (problem area 7) will not be supported. There is also reason to assume that cutbacks will require comprehensive investments at a later time in order to quickly make up for lack of recruitment and knowledge on central problem areas and processes.

6. Assumptions and infrastructure

The natural science climate research is strongly dependent on a well-functioning infrastructure consisting of advanced instrumentation for field and laboratory studies; high quality measurements and observations; a number of long times series of climate observations, infrastructure for field observations, in particular sea- and ice-going research vessels; access to remote sensing systems; and prioritised access to substantial supercomputing resources. This underlying infrastructure, together with the technical support apparatus required in order to operate it, is perhaps the most important assumption for a sustained raising of the quality of climate research.

It is an underlying assumption for reaching the goals in *KlimaProg* that this infrastructure exists and is expanded. It is, however, not possible within the programme's own budget to finance the necessary infrastructure described in this chapter. *KlimaProg* assumes therefore that this will be given financial priority in the relevant management organisations and research institutions' budgets as well as in the other programmes in the Research Council.

Measurements/observations

The climate research will be dependent on a substantial underlying infrastructure that ensures continuation and enlargement of existing measurement programmes, and an instrument park on an international standard. It is particularly important to ensure long time series of central climate parameters. We have an international responsibility to ensure continuation of programmes within observations of variability in the ocean, changes in the sea-ice cover, heat transport in the ocean-atmosphere system, and glacier mass balances. Furthermore, it is important that there are platforms for acquiring essential paleoclimatic sample material both on land and in the ocean. For the atmospheric studies, systems for measurement of greenhouse gasses and aerosols must be ensured. The marine activities are generally dependent on substantial contributions from research vessels, among these the unique series from the weather ship *Polarfront* in the Norwegian Sea. It is important for the quality of Norwegian climate research that the researchers have access to modern research vessels. With an increase in Norwegian climate research in the Arctic, it would be advantageous to have a ship with ice-going capabilities. This is supplemented by the access to infrastructure that comes through international cooperation. For the paleoclimate activities, one of the most important challenges is to improve the chronological accuracy of the climatic time series with considerable access to dating resources. There is a particular need to strengthen the capacity for Norwegian AMS ^{14}C-measurements and to ensure implementation of new dating methods.

Supercomputing

The climate research is dependent on dedicated supercomputing capacity, the possibility for flexible access to supercomputing and comprehensive database, data storage and data processing systems. Realistic climate simulations on regional and global scales and the accomplishment of most of the stated research milestones (see Chapter 2) are completely at the mercy of access to supercomputing resources. The climate research is, and will continue to be, one the heaviest participants in the use of supercomputing in Norway. Depending on how the models' grid resolution increases and how new processes and parameterisations are included in the models, it will be necessary to allocate a significant portion of the national supercomputing resources to dedicated climate simulations. In addition to the supercomputing itself, it is necessary to have methods for storage and access to large amounts of data. In order to ensure that the climate research's requirements for supercomputing are taken care of, it is suggested that one of the programme board members either is a member of the national supercomputing commission, or has close and regular communication and contact with the committee. In 2000, the Service Centre for Norwegian Climate Research (*NoSerC*) was established with the task of assisting with data storage and data access.

Satellites and remote sensing

Remote sensing from satellites has the advantage in comparison to conventional observations in the atmosphere and the ocean in that the degree of coverage is on a nearly global scale, and the frequency of coverage is high. The disadvantage is that some sensors

are dependent on daylight and cloud-free conditions, and that sensors "see" only the ocean surface. There is increased potential for exploitation of satellite data through use of multisensor methods and calibration against long time series of conventional observations. Just the same, satellite measurements have already revolutionised the observation and coverage of key climate parameters such as sea surface temperature an currents, sea ice extent and concentration, glaciers, snow cover, mean air temperature and humidity, mapping of cloud cover and precipitation, the earth's thermal radiation, along with many atmospheric greenhouse gas and aerosol concentrations. For example, it is completely essential for the monitoring of the arctic sea ice cover that satellite passive microwave data exists. In order to study climate processes and the distribution of and changes in greenhouse gases in the atmosphere, as well as gases that affect the ozone layer, it is important to use satellite measurements. The total number of satellites and satellite sensors will increase over the coming decade, of which ESA's *Living Planet Programme is* one example. It is important and even essential that Norwegian climate research groups in the future take advantage of the information that is available from satellites in order to optimise the research outcome. The needs of the climate research ought to be incorporated into the newly established research programme on *Monitoring of Marine and Terrestrial Systems.*

Technology and innovation

Research breakthroughs are often associated with technological breakthroughs, where new methods bring new knowledge to the research. One weakness of Norwegian climate research is that it is characterised in too small degree by technological innovation and experimental activities. A long-term strengthening of this element will be important in order to reach the scientific objectives of *KlimaProg*. There are also good possibilities for industrial spin-off effects inasmuch as environmental monitoring is a growing international activity. The need is clearly indicated for systems for detailed process studies in the atmosphere-ice-ocean system.

General modelling improvements

Even though state-of-the-art climate models are capable of simulating several of the fundamental features of the observed climate development over the past 50-150 years, many challenges still remain. These are associated with, for example, improved description of non-linear processes (i.e., parameterisation), incorporating new processes in the models, use of more accurate and more efficient numeric, increased degree of parallellisation, etc. It is difficult to rank the requirements for model improvement, but more accurate description of the processes behind cloud formation, precipitation amounts and distribution, inclusion of active biogeochemical modules in ocean and atmosphere models, and improved description of the marine climate system in high latitudes are central. It is clearly advantageous if the Norwegian modelling environment has close connections to international groups, such that improvements and inclusion of new modules can benefit all parties. Such exchanges will also serve as a "seal of approval" of the Norwegian activities. This can occur by, among other things, primarily using models and model systems that are freely accessible internationally.

Appendix

Composition of the working group

The programme development group has had the following composition:

Eystein Jansen	Department of Geology, University of Bergen (leader)
Lennart Bengtsson	Max-Planck-Institute for Meteorology, Hamburg (member)
Hilary Birks	Department of Botany, University of Bergen (member)
Karin Borenäs	Swedish Meteorological and Hydrological Institute (member)
Ivar Isaksen	Department of Geophysics, University of Oslo (member)
Marit Viktoria Pettersen	State Pollution Authority, Oslo (member)
Jan-Gunnar Winther	Norwegian Polar Research Institute, Tromsø (member)
Helge Drange (secretary)	Nansen Environmental and Remote Sensing Center, Bergen

The group's work has been carried out in the period 20 September to 30 November 2000.

Mandate

The program development group received a mandate (short version):
"The programme working group is requested to formulate a proposal for the program plan for a continuation of the *Research Programme on Changes in Climate and the Ozone Layer*" for the ten-year period 2002-2011. It is used as a starting point that the program in continuation shall have about the same scientific and economic framework as today. The plan shall build upon and continue the current program note/action plan and be a concise (about 10 pages) strategy document that outlines the scientific basis for Norwegian climate and ozone research for the specified ten-year period by concretely defining the program's objectives, superior scientific priorities and content, as well as a superior governing plan for its execution."

Acronym list

ACSYS/CLIC	Arctic Climate System Study/Climate and Cryosphere Initiative (WCRP)
AMS	Accelerator Mass Spectrometry (for ^{14}C dating)
AO	Arctic Oscillation
CLIVAR	Climate Variability Study (WCRP)
COZUV	Coordinated Ozone and UV Project (Research Council of Norway)
ENSO	El Niño – Southern Oscillation
ESA	European Space Agency
IGAC	International Global Atmospheric Chemistry Study (IGBP)
IGBP	International Geosphere Biosphere Programme
IPCC	Intergovernmental Panel on Climate Change
JGOFS /	Joint Global Ocean Flux Study /
SOLAS	Surface Ocean Lower Atmosphere Study (IGBP)
NAO	North Atlantic Oscillation
NERC	National Environmental Research Council, UK
NOAA	National Atmosphere and Ocean Administration, USA
NSF	National Science Foundation, USA
NOClim	Norwegian Ocean Climate Project (Research Council of Norway)
NOAA	National Oceanic and Atmospheric Administration
NorPast	Past Climates of the Norwegian Region (Research Council of Norway)
NoSerC	National Climate Service Centre (Research Council of Norway)
NSF	National Science Foundation (USA)
OOPC	The Ocean Observations Panel for Climate (WCRP)
PAGES	Past Global Changes (IGBP)
RegClim	Regional Climate Development Under Global Warming (Research Council of Norway)
WCRP	World Climate Research Programme
WHO/UNEP	World Health Organisation/United Nations Environmental Programme