SWECLIM
SWEDISH REGIONAL CLIMATE MODELLING PROGRAMME

SMHI

Reports Meteorology and Climatology

No 104, Dec 2003

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Final Report.

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RMK
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Report Summary / Rapportsammanfattning

Issuing Agency/Utgivare	Report number/Publikation
Swedish Meteorological and Hydrological Institute S-601 76 NORRKÖPING Sweden	RMK No 104 Report date/Utgivningsdatum December 2003

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Title (and Subtitle/Titel

The Swedish regional climate modeling program, SWECLIM, 1996-2003. Final report.

Abstract/Sammandrag

The Swedish Regional Climate Modeling Program (SWECLIM) was a 6.5-year national research effort with the aim of providing the Swedish society with more detailed regional climate scenarios than those available from international global climate model simulations.

SWECLIM built up a new scientific niche in Sweden, namely that of climate modeling, provided users with regionally detailed climate scenarios, expert advice and synthesis of climate change science. Regional climate modeling was a major activity, supported with studies of climate processes as well as on observed data on the Baltic Sea, regional hydrology and meteorology. The major impact study part was on hydrological modeling, to elaborate the potential impact of regional-scale climate change on hydropower, dam safety and water resources in general. Other types of impact studies were not performed by SWECLIM itself, but means were provided for outside experts to pursue such knowledge. This furthered the general understanding of climate change and created new insights into planning processes, especially in Sweden, but also on the Nordic, European and global arenas.

Examples of practical users of the results were experts and decision-makers within national, regional and local administration, organizations, businesses, politicians, as well as media and the general public. These Swedish efforts on climate science also contributed to international research and assessment networks, and to the quest for better knowledge base to act on in dealing with the climate problem.

This report provides the final reporting of the SWECLIM-program, building on earlier reports and complements the results published in scientific journals, as reports, presented in meetings and provided to the general public. The focus here is on the work undertaken during program phase 2, lasting from July 2000 to June 2003.

Key words/sök-, nyckelord

Climate change, climate modeling, climate scenario, regional climate, regional climate model, Mistra, SWECLIM

Supplementary notes/Tillägg	Number of pages/Antal sidor	Language/Språk
This work is a part of the SWECLIM program	47	English

ISSN and title/ISSN och titel

0347-2116 SMHI Reports Meteorology Climatology

Report available from/Rapporten kan köpas från:

SMHI
S-601 76 NORRKÖPING
Sweden

Contents

1 Introduction

The Swedish Regional Climate Modeling Program (SWECLIM) was a 6.5-year national research effort with the aim of providing the Swedish society with more detailed regional climate scenarios than those available from international global climate model simulations. The program activities started in earnest during the second half of 1997, and lasted until mid-2003. Counting also in the planning of the program, SWECLIM can be dated back to around 1995 (Swedish Climate Modelling Programme, 1995). The background was the increasing scientific and societal concern on the perceived enhancement of the greenhouse effect, due to manmade climate forcing and projected to lead to global warming, other changes in the climate system and thus impacts on natural and human systems in the decades to come. Especially the lack of coherent regional information on the plausible future conditions was recognized. To address this gap became the raison d'être for SWECLIM.

During the 6.5 years of research, SWECLIM built up a new scientific niche in Sweden, namely that of climate modeling, provided users with regionally detailed climate scenarios, expert advice and synthesis of climate change science. To meet the set goals required development and use of so-called regionalization techniques. Regional climate modeling was a major activity, although supported with other studies of the climate processes and available observed data on the Baltic Sea, regional hydrology and meteorology. SWECLIM performed also a considerable amount of hydrological modeling, to elaborate the potential impact of regional-scale climate change on hydropower, dam safety and water resources in general. Other types of impact studies were not performed by SWECLIM itself, but means were provided for outside experts to pursue such knowledge. Indeed, concretization of the potential impact of climate scenarios calculated by SWECLIM was done by a number of external groups with various branch-specific expertise. This furthered the general understanding of climate change and created new insights into planning processes, especially in Sweden, but also on the Nordic, European and global arenas.

Examples of practical users of the results were experts and decision-makers within national, regional and local administration, organizations, businesses, politicians, as well as media and the general public. These Swedish efforts on climate science also contributed to international research and assessment networks, and to the quest for better knowledge base to act on in dealing with the climate problem.

2 This report and its relation to other documents

The background of SWECLIM and the work undertaken during program phase 1 between 1997 and June 2000 was described by Rummukainen et al. 2001. In addition to reporting on Model development, Regional climate and water resources scenarios, Results from statistical downscaling and Basic process studies and data analyses, the interaction with users and media was discussed. The latter was thereafter reported to Mistra in April 2002 (SWECLIM 2002b).

The financial report to Mistra is provided separately.

The present report completes the earlier reporting on program phase 1 and the relatively recent report on User interaction and Communication, also mentioned above. Thus, the present report focuses on the more recent work during program phase 2 (July 2000 – June 2003), although where possible we refer to available material to avoid unnecessary duplication. Specific deliverables listed in the program plan are tabulated in Section 4, where also other aspects of the conductance of the program are treated. We provide some reflection on lessons learnt, in terms of the execution of the program in Section 5. A short outlook for the future activities building on SWECLIM is provided in Section 6. Acknowledgements for those who in one way or another have supported the activities are gratefully given in Section 7. For the detailed scientific findings, the reader is referred to the publications listed in Section 8.

3 Short summary of Phase 1: 1997-2000

In Phase 1 of SWECLIM, the program activities were organized in three subprograms: 1) Regional climatological interpretation, 2) Climate system processes – atmosphere/surface and 3) Climate system processes – ocean. This structure reflected the intensive modeling development during the first half of the program, covering meteorology, oceanography and hydrology. Each of the subprograms was characterized by collaboration between the participating university groups, the SMHI research department and the Rossby Centre established at SMHI. During the early part of Phase 1, the basic strategies on choosing model systems and model development philosophy were set in place. Contacts were established with international climate modeling centers and networks. The program grew in terms of expertise and reached its final volume by year 1999. The first Swedish regional climate scenario was calculated as early as 1998, based on the early version of the SWECLIM regional climate model, and an international global climate model simulation. The first SWECLIM scenario was soon followed by additional ones in 1999-2000 based on the successively improved regional climate modeling system and on additional global simulations. Already the first scenario was received with interest by the media and the society, a pattern that was to be repeated with each new major milestone of the program. The communication breakthrough really occurred in August 2000, when SWECLIM organized a climate conference in Stockholm, to mark the end of its Phase 1 activities.

More detailed reporting on Phase 1 is provided by SWECLIM (1999b) and Rummukainen et al. (2001). The reader is also referred to the relevant scientific publications listed in Section 8.

4 Program activities during Phase 2: 2000- 2003

In Phase 2, model development and scenario simulations were continued targeting coupled (atmosphere-land surface/hydrology-lakes-Baltic Sea-ice) regional climate system modeling. Increasing emphasis was put on the provision of climate scenarios and information to users. To reflect these priorities, the Phase 2 program organization was restructured into four subprograms:

1) Development of regional climate models
2) Computation of regional climate scenarios
3) User interaction and hydrological impacts
4) Theoretical and analytical studies of climate

The continuous investment in modeling development to the creation of the even internationally very advanced coupled atmosphere-ocean-hydrology regional climate model system, the RCAO, applied with Northern Europe in Focus. In 2002-2003, the improved modeling tools were applied to create a suite of regional scenarios covering different global climate models and emission scenarios. These scenarios were complemented by direct and statistical analysis of a wider range of global simulations, and they were put through hydrological modeling to create water resources scenarios. Towards the end of Phase 2, first attempts to put the scenarios into better perspective with the most recent climate conditions were made, with comparisons of how observed regional changes from the 1961-90 period to the 1990's related to the simulated regional changes during the 21st Century.

Phase 2 was also marked by increasing contributions to international networks, including non-funded co-operation and European and Nordic research projects. Contributions were also made in the context of the Intergovernmental Panel on Climate Change (IPCC) and national reporting to the United Nations Framework Convention on Climate Change (UNFCCC). Especially marked was the avalanche of societal demand for information on climate change and climate modeling (e.g. SWECLIM 2002b). This was recognized with a separate Communication Plan in the general program planning process (SWECLIM 2002c).

Much of the Phase 2 work was reported during the program execution (SWECLIM 2000b,c; 2001a,b; SWECLIM 2002a,b,c; SWECLIM 2003a). The reader is also referred to the relevant scientific publications listed in Section 8.

4.1 Communication

The program communication activities intensified during Phase 2. The intense activity was greatly facilitated by the fact that SWECLIM had a dedicated person to manage these aspects. By the end of the program, three experts had held the position. (It could be noted that the first – Johan Mattson – had a background in oceanography, the second – Rune Joelsson – in meteorology and the third – Gunn Persson – in hydrology. This was unintentional, but rather fitting.) The Subprogram Leaders and the Program Director contributed a lot as well.

In addition to the SWECLIM climate conference in Stockholm in August 2000, another stepping stone was a paper on regional climate change that SWECLIM published in *Forskning & Framsteg* the same year. During Phase 2, the number of presentations of SWECLIM at various meetings was of the order of 150 per year.

Organized internal communication featured the semi-regular SWECLIM Newsletter (see Section 8.4) and the annual All Staff–meetings. The latter were also a means for planning.

External communication took place on different arenas.

- Scientific communication was much focused on contributions to conferences and meetings (cf. Section 8.3, for a non-exhaustive list of activities) and published papers (cf. especially Sections 8.1-8.2 and 8.4). On the national scale, events like the Stockholm Water Symposium, Energitinget and Transportforum bear a special notice. Of interest is the initiative by SMHI, Mistra, the municipality of Norrköping and the county administration of Östergötland on the conference Miljöforum as an annual meeting point between researchers and decision makers. It was held for the first time in August 2002 and was followed by a second meeting in 2003. Climate and SWECLIM were very much in focus in these meetings. SWECLIM also organized several own scientific Workshops and Summer schools open to external participation and featuring national and international experts.

- Expert communication also gained momentum during Phase 2. Contributions were made to the IPCC process both directly, as well as via the national focal point at the Swedish Environmental Protection Agency, to the Arctic Climate Impact Assessment, ACIA, and to the national reporting to the UNFCCC. The program participants also contributed with expert advice and material to reports by national authorities ("remisser") relevant to the climate issue. Equally important were the relatively informal discussions with some of the more climate-sensitive sectors like the power industry, insurance companies, water supply, infrastructure and the environmental sector. Such dialogue certainly guided SWECLIM to focus on the very interesting issues for each sector.

- Popular communication occurred through interviews and other interaction with media, publishing (cf. Section 8.5, for a non-exhaustive account), lectures to a wide range of audience, the SWECLIM home page and direct interaction with interested individuals posing questions to SWECLIM via telephone, letters and electronic mail. A highlights was the publication of the issue No. 18 of Monitor both in English (*A warmer world*) and in Swedish (*En varmare värld*), produced in co-operation between the Swedish Environment Protection Agency and SWECLIM. It catered for a comprehensive review of the climate issue and contained recent results from SWECLIM presented in a very accessible manner. An archive of regional climate scenario results, in the form of drawn maps, has been available to the public, with updates in 2000 and 2003. Towards the end of Phase 2, a release of a public CD-ROM with SWECLIM data was also made.

The setting for the external communication activity can be described as a constant background demand, overlain by peaks caused by media coverage of new scientific results in Sweden or internationally, events in international negotiations and suchlike on climate, and, especially, the severe weather events. All these fed a growing public interest in climate change and variability. On the scale of Sweden the following events were especially noteworthy: the severe floods in 2000/2001 in Arvika and Lake Vänern, the extremely warm summers of 1997, 2002 and 2003, and the dry period that started in the summer of 2002. In Europe, the flooding disasters in River Odra in 1997 and in River Elbe in 2002, and the extremely dry and hot summer of 2003 in much of Europe, also touched many people.

The Phase 2 final SWECLIM scientific conference was held in Söderköping in June 2003, with participation of national and international experts, as well as stakeholders.

4.2 Subprogram 1: Development of regional climate modeling

Much of the major modifications and developments of the models used by SWECLIM took place during the first phase of SWECLIM. The activities during Phase 2 evolved around three main topics: 1) Refinement and further development of the atmospheric and land surface (RCA), ocean (RCO), lake (PROBE-lake) and hydrological (HBV) models, 2) Coupling of RCA and RCO and 3) Evaluation of the overall model system, as well as its various components.

After the intensive development during Phase 1, the main remaining problems in the RCA model were treatment of the surface energy and water balances and the description of radiation processes. The work on radiation managed some hurdles. Some important modifications were made in the existing code, which was in a number of tests found to perform unexpectedly well against more complicated schemes. Nevertheless, alternative schemes were still being considered by the end of Phase 1.

In the case of the surface energy and water balances, further improvements included a far better treatment of the effects of vegetation, and a soil-freezing algorithm to account for frozen ground. The new treatment featured different energy balances for the different surface types carried within a grid-square; for bare ground, few different vegetation and snow cover elements. An improved model for the treatment of snow was included, allowing some melted water to remain in the snow and to refreeze. A separate treatment of evaporation from the snow was also part of the improvement. Also included was a hydrological accounting for soil water transfer, based on the so-called HBV model at SMHI. A routing routine to transport local run-off generation in the region to the Baltic Sea was also developed.

In the ocean model, the suggested storm surge -model, to drive the water level variation in Kattegat and the water mass exchange between the North Sea and the Baltic Sea, was abandoned following successful work to statistically relate atmospheric pressure patterns to water-level variations in the Kattegat. New schemes for the vertical mixing in RCO were successfully tested and a simplified model for the White Sea was developed, to complement the regional representativeness of the SWECLIM model system.

The coupling of the models was a strategic goal. Indeed, since the very first regional climate scenario by SWECLIM, almost all of the scenarios have been coupled in some sense. In Phase 2, this work led to "full" coupling of RCA and RCO, complemented by the earlier mentioned large-scale routing of runoff. By this we mean that the fluxes between the atmosphere and the ocean are calculated only once and used by all the model components. (The earlier alternative was to pass so-called state variables, such as temperature, between the atmospheric calculation and the ocean calculation. Due to different development histories, the fluxes then calculated in the respective model in general differed. The physical process in the real system passes water, energy and momentum between the atmosphere and the underlying surface as fluxes.) Several evaluation integrations were carried out to fine-tune the system. Especially the atmospheric model was applied for a number of other regions, in part to test it in other climate regimes, in part to contribute to international model intercomparisons and to profit from the availability of observation data not available in the Nordic region. An important milestone was the initiation of transferring the model system into the Arctic region.

As a result, the SWECLIM model system was improved. The coupled model system RCAO was consequently available, and applied for improved regional climate scenario calculations in subprogram 2. Some problems remained but over-all the quality of the separate models, and of the coupled system, was very good by the end of SWECLIM, in terms of applications for Northern Europe. Towards the end of Phase 2, additional model development efforts were ongoing, to contribute to the future Swedish and international climate research activities.

Among the central SWECLIM Subprogram 1 publications were Meier et al. (2003), Döscher et al. (2002), Meier and Döscher (2002), Samuelsson et al. (2003) and Bringfelt et al. (2001).

4.3 Subprogram 2: Computation of regional climate scenarios

All in all, SWECLIM published 11 regional climate scenarios. About half of these were calculated during Phase 2. The scenarios were based on the successively improved regional climate modeling system, and a subset of available global simulations, these in turn covering a subset of plausible future emission scenarios. As the number of possible futures is large, the uncertainty aspect was much in focus throughout the work.

In terms of global mean warming, the calculations made by SWECLIM corresponded rather to typical projections on a 100-year time scale, meaning that the future might unfold with smaller, or even larger changes over this period of time. Another way of looking at the scenarios would be to take them as pessimistic examples on a 50-year scale, or optimistic ones on a 150-year scale. Nevertheless, the described regional changes in especially temperature and in many cases precipitation, were large compared to past natural climate variability over comparable time scales. Across the SWECLIM suite of scenarios, a number of the calculated changes were robust. For temperature, these included the magnitude of the warming, the regional warming being larger than the corresponding global mean, the seasonal contrast with the cold season affected more than the warm season and the non-linearity of changing temperature extremes. For precipitation, one robust feature was the mean increase especially in the north, and the tendency towards less precipitation in the southeast and south, especially in the summer. As the regional simulations, made as time slices towards the end of the 21st Century, grew longer, from the typical 10-year ones in Phase 1 to the 30-year ones in Phase 2, the emerging picture was that of somewhat increasing precipitation extremes, especially in summer. Towards the end of Phase 2, the analyses were proceeding more and more to how variability and extremes were projected to change due to global warming.

In case of the Baltic Sea, the scenario results for mean sea surface temperature changes, as well as those for sea ice, were rather robust across the different cases.

Salinity could not be handled well, due to both problems with the initialization of the future simulations, as well as the persistent positive precipitation bias in RCA and thus also in the coupled RCAO. (It can be noted that even though such a bias was found problematic in coupled modeling, in which the absolute values provided by one part of the model system fed into another part, it was not assessed to seriously impact the precipitation change scenarios, discussed earlier, taken as differences between two model calculations. A bias of the same origin and present in both calculations canceled out in practice). It was, however, shown that the uncertainty in treating salinity did not invalidate the simulation of water temperature, nor of sea ice. The whole Baltic Sea modeling activity was one of the major achievements of SWECLIM, considering that no such long calculations with such a detail had been performed earlier. Also, as typical global climate models lack a realistic Baltic Sea, there really was no alternative for own activity.

The various scenario results were widely distributed to external expert groups, and were used as forcing data for impact assessment on, especially, forest growth, windthrow, ecosystems, road maintenance, shipping conditions, soil-freezing, coastal planning and glacier development. The scenarios were used also by SWECLIM itself as input to water resources studies and, as Supplementary Projects, for air quality and eutrophication studies.

The regional climate scenarios computed by SWECLIM are of course only a small subset of plausible future developments. It is generally recognized that there is a genuine uncertainty on the future climate change. This uncertainty does not, however, concern so much whether or not mankind affects climate. It concerns the fact that it is not exactly known how sensitive the climate system is to emissions and the fact that it is not known how exactly these emissions will evolve. These aspects are studied by using different climate models, that provide alternative estimates of the climate system sensitivity constrained by physical considerations, and by using different emission scenarios. In Phase 2, SWECLIM based its regional scenario computations on two global climate models and two emission scenarios. The formers were the HadAM3H model of the Hadley Centre of the Meteorological Office and the ECHAM4/OPYC3 model of the Max-Planck-Institute for Meteorology in Hamburg, Germany. The latter were the so-called A2 and B2 emission scenarios of the IPCC SRES ones.

SWECLIM's studies confirmed that as on the global scale, even on the regional scale the computed changes grow with the accumulated emissions. The choice of the global model, even among models that project similar global mean changes, on the other hand was affirmed as very important in the Nordic region. This was especially true for variables such as precipitation and wind, and also experienced in the case of the problematic assessment for the Baltic Sea salinity mentioned earlier. An important underlying mechanism behind these differences was the response of the large-scale atmospheric circulation in the Atlantic and Arctic regions. How the circulation will respond to global warming is poorly understood, as exemplified by the very different responses of the global models mentioned above. One of them projected changes leading to intensified cold season westerlies towards the Nordic region, whereas the other project no mean change in the westerlies. (It can be noted that the importance and complexity of large-scale circulation in these parts of the world is well-recognized. SWECLIM has included a study of this within Subprogram 4).

Among central SWECLIM Subprogram 2 publications, during Phase 2, were Räisänen et al. (2003a, b), Bernes (2003), Palmer and Räisänen (2002), Meier and Kauker (2003b), Haapala et al. (2001), Christensen et al. (2001) and Rummukainen et al. (2003).

4.4 Subprogram 3: User interaction and hydrological impacts

Studies of hydrological impacts of regional climate change were very much in focus throughout SWECLIM. At the beginning of the program, it was already perceived that major user interaction would emerge on this topic. This also became true. However, as the societal demand of information grew, user communication was managed as an activity on its own towards the end of Phase 2 (see Section 4.1).

The hydrological studies covered impact analyses of water resources in terms of long-term means, as well as in terms of extreme conditions. Given the great spatial variability in the hydrological conditions in Sweden, initially six test basins were studied as examples. These were later supplemented by additional basins of particular interest such as Lake Vänern, Glafsfjorden and Lule River, either for actuality, given the recent flooding events, or in the case of Lule River, for its strategic importance. Finally, a nation-wide analysis of impacts on water resources with a countrywide hydrological modeling was realized as a SWECLIM Supplementary Project (see Section 4.6).

The river flow and extreme flow situation studies were complemented by focused studies on soil moisture, frozen ground and groundwater carried out for the Svartberget research area in the north of Sweden. Water quality aspects were also studied in River Rönneå in the south of Sweden, again as a SWECLIM Supplementary Project (see Section 4.6).

In order to put the water resources scenarios in perspective, studies on trends and variability of river flow and flood extremes based on long time series of measurements were carried out. These studies proved useful also in the debate on recent flooding and fluctuations in the hydropower production in Sweden. It is true that there are historical counterparts to the individual extremes in recent years, but that does not have to mean that the cause of the event would be the same now and in the past. Mere data-analysis of long time series does not as such provide information on the underlying physical mechanisms. It does emphasize fundamental flaws in our perception of variability and risk due to weather and climate.

Among central SWECLIM Subprogram 3 publications, during Phase 2, were Bergström et al. (2001), Gardelin et al. (2002a), Gardelin et al. (2002b) and Lindström (2002).

4.5 Subprogram 4: Theoretical and analytical studies of climate

Application of statistical downscaling to create additional regional scenarios and studies of key climate processes in the atmosphere and in the ocean, relevant in the regional climate system were in focus in this subprogram. Analyses were also made on selected long time series, especially of ocean variability. These studies aimed at putting the regional climate modeling into better perspective in terms of observed climate, at improving the regional model and at analyses of the sensibility of the regional climate to changing conditions.

Statistical downscaling

By the end of Phase I, statistical downscaling had been established as an activity to create alternative regional scenarios, a tool to evaluate climate models as well as a means for analysis of observations and for studies on how the large-scale appears to control our regional climate. In Phase I, it was found out that even though the atmospheric circulated expressed by sea level pressure patterns played a certain role in variations over the last 100 years, its role in the future climate change induced by emissions is likely limited. In Phase 2 the emphasis in statistical downscaling was on diagnostic studies and interpretations of the observed and modeled climate. Improved scenarios with estimated uncertainties were created and documented, thanks to the incorporation of the large-scale temperature and precipitation fields as drivers of the statistical downscaling in our region. Statistical downscaling was also found useful in studies of truly local-scale changes and on some climate variables such as sea ice and sea level. A systematic validation exercise of modeled precipitation, with non-standard data for Skåne, was also performed.

Studies of regional oceans (time series, processes)

The main objective was to study variations of the climate of the Baltic Sea itself, including long-term trends as well as variations on various timescales. During Phase 1 it was revealed that the variability on, say decadal timescales, was surprisingly large, indicating great sensitivity to variations in the meteorological conditions. The work during Phase 2 followed the same lines. More emphasize was given to mechanistic considerations along with extended studies of the historical records of data relevant for the Baltic Sea. Some of the studies were based on meteorological forcing derived from the RCA model. The finding of the state of the Baltic Sea, in terms of temperature, salinity and ice conditions, as very sensitive to changes in the forcing conditions was confirmed. This could mean that the response in the Baltic Sea to future climate change might be rather large. It also meant that improved regional modeling required proper interaction between ocean and atmosphere in view of the high sensitivity of the Baltic.

The study of the Thermohaline Circulation and the conditions of the Northern North Atlantic indicated that the interaction between ocean and atmosphere is important for the climate response in Scandinavia. A SWECLIM Supplementary Project (see Section 4.6) complemented this particular work.

Atmospheric circulation patterns

The response of the large-scale atmospheric circulation and the mid-latitude variability (travelling cyclones and persistent anticyclones) to an increasing greenhouse gas forcing was investigated. The focus was on investigating the response in large-scale atmospheric circulation and mid-latitude climate variability, through physical mechanisms, to changes in other parameters. So far, the changes in mid-latitude variability over the northern North Atlantic Ocean and Northern Europe were found small compared to the changes over e.g. the northern North Pacific. The strongest response was found in the Southern Hemisphere. This work continues as a PhD-project beyond Phase 2.

Among central SWECLIM Subprogram 4 publications, during Phase 2, were Rodhe and Winsor (2002, 2003), Nilsson et al. (2003a), Chen (2000), Hellström et al. (2001) and Busuioc et al. (2001a).

4.6 The supplementary projects

As Phase 2 of the program progressed and new results were gained, the need of additional studies became evident. Several factors contributed to the feasibility of such studies. Among these were earlier decisions by the Program Board to maintain a strategic funding reserve, success in external funding applications by the program participants and some staff changes. Towards the end of Phase 2, in 2002-2003, several small but rather innovative supplementary projects were created. These were proposed by the program itself, screened by the Management Group, and decided on by the Program Board.

Rather condensed reports are made here on each Supplementary Project. More detailed descriptions are submitted to SWECLIM. These can be requested from SMHI.

4.6.1 Detection

This was a joint activity by the research department of SMHI and the University of Göteborg. The basic question asked was: "Do we see a climate change signal, in accordance with the regional climate change scenarios produced in the SWECLIM program, in the last decades regional climate?" Starting from the hypothesis that not only the global but also the regional climate since the late 1980's years affected by global warming, this period was compared with the climate during the earlier decades of the 20th Century. In particular, it was looked for whether the types of signals that emerge in the future scenarios by SWECLIM could be located in the recent regional climate.

Datasets studied included Swedish precipitation, temperature and riverflow data. It became confirmed that during the recent period, air temperature and the studied Baltic Sea climate anomalies tended to exceed the past variations to the extent of historical data being available. The magnitude of the recent regional warming was found to be in line with the trends that correspond to the future scenarios. The recent excess of precipitation was found to be rather extreme compared to the few decades before. However, there were indications of similarly large amounts of precipitation in the 19th Century. Compared to the regional precipitation trends corresponding to the future scenarios, the documented change in Sweden mean precipitation in the 1990's from the few decades before tended to be larger. This meant that the future scenarios might describe too small changes, for a given amount of global warming, or that the latest observed period was more extreme than average, in terms of regional precipitation.

An interesting finding was that in terms of riverflow, the spatial distribution of the recent changes bore likeness to the modeled future changes. Consequently a tendency to less runoff generation in the southeast was noted, but increases especially in the north.

Detection is a first step in the study of relating ongoing changes to manmade climate change. It needs to be followed by attribution, i.e. unearthing of causality in the form of physical mechanisms, for a fuller answer to emerge. This is one of the challenges for the future activities.

4.6.2 Arctic simulations at MISU

The objectives were to improve models for Arctic conditions and to build up new meteorological databases using models/for use in models. The work focused regional model performance for an Arctic domain over recent periods for which enhanced observations are available. The US Navy COAMPS™ mesoscale non-hydrostatic model was used to simulate the full so-called SHEBA-year. This effort was also part of the international ARCMIP program for intercomparison of regional models for the Arctic region. SWECLIM's RCA model also participated in ARCMIP. Among the main findings were a significant winter warm bias and a slighter summer warm bias near the surface in COAMPS™. There was also an elevated cold bias slightly lower than 1 km in summer. Significant biases were found in the radiative fluxes. These various errors were believed to be interlinked.

The next step will be to analyze the results in some more detail before attempting to rectify the problems in the model. This post-SWECLIM work will be performed jointly within the ARCMIP project, and the results are submitted to JOSS – a joint database maintained at the University of Colorado, USA. A comparison of the larger scale dynamics is under way. In particular, the MISU will do a comparison of the boundary layer structure during autumn 2003. The work to improve model performance will likely be focused on the energy balance in the ice and the melt/freeze thermodynamics and on the cloud scheme. There are indications that the surface energy balance does not seem to account the latent heat of freezing/melting of neither sea ice nor snow in a proper way. Another likely problem stratus is an underestimation of drizzle.

4.6.3 The influence of changes in the Northern North Atlantic on the Nordic region

During Phase 1 and Phase 2 of SWECLIM, a modeling concept called PROBE was applied for the Baltic Sea, inland lake systems and the White Sea. During Phase 2, a formulation of PROBE also for the Northern North Atlantic (NNA) was done. Especially given the design of one of the global simulations used by SWECLIM in calculating the regional scenarios, it became desirable to look more into the response of the NNA to climate change as this affects the large-scale setting of regional climate. The globally simulated Atlantic sea surface temperatures (SST), used as boundary conditions in the SWECLIM regional modeling were studied, and the sensitivity of scenario responses to eventual errors in these boundary conditions, by means of additional simulations with the RCA model. Specifically, the relation between the SST in the NNA and the temperature in Scandinavia and also the relation between the heat flux to the NNA and the SST.

Results were indicative for that if the SST could adjust freely in the regional simulations instead of being prescribed as boundary conditions, then the SST would have been considerably higher and also the modeled temperature in Scandinavia. Thus, including appropriate interaction between NNA ocean and atmosphere may considerably amplify the climate response in Scandinavia.

4.6.4 Water resources for all of Sweden: A runoff mapping system for climate change scenario simulations in Sweden

The planned Phase 2 water resources scenarios, in the context of climate change was restricted to single catchment studies. The dialogue held with users pressed the need of results for areas in between these basins as well as on upscaling the results to entire river systems. A fine resolution HBV-model for the entire Sweden, with some modifications, was set up as a supplementary project to create water resource scenarios for the entire Sweden. The model setup consisted of 118 main basins divided into about 1000 subbasins. The model was recalibrated, tested, incremented with a system for automatic simulation and applied to produce water resources scenarios based on the latest SWECLIM regional climate scenarios, akin to the single catchment studies within Subprogram 3.

Extraction and summarization of the results was developed and the results saved as daily values for every subbasin. The output variables were temperature, precipitation, snow pack and cover, soilmoisture deficit, evapotranspiration, local runoff, total runoff, total inflow and groundwater.

The common signal for all impact simulations was that runoff increased in northern Sweden and especially in the westerly mountainous parts. The strongest scenario increases were as much as up to 40% for this region. The changes in seasonal distribution of runoff described an earlier spring flood by approximately one month in basins exhibiting a spring flood in the present climate case. In some rivers, the accumulated snowpack was no longer large enough to generate a spring flood in the scenario simulations. Instead, higher runoff during the whole winter was seen. Rivers south of and including Norrtäljeån showed a considerable decrease in runoff during the summer. The simulations confirmed the same general pattern of climate change impact on the water resources as found for the SWECLIM test basins. Spatial detail was, however, much improved. The common trends from the different scenarios were distinguished as increased fall and winter runoff, increased annual runoff volumes in northern Sweden and especially in the mountains, decreased annual runoff volumes in south-eastern Sweden and decreased summer runoff in southern Sweden. It was now possible to do more in-depth analyses. There were large differences in the results depending on the choice of scenario. The largest differences seemed to have to do with the choice of global climate model rather than with the choice of the available emission scenarios.

The fact that RCA output was averaged over six regions in Sweden before transfer to the hydrological model had a clear visual effect on the results, as jumps in the generated percentage change of runoff maps. Methods to deal with this were considered by the end of the project.

4.6.5 Transport of nitrogen: Expected changes in nitrogen transport and algal growth due to climate change

SWECLIM studied the regional climate and how it might change. Impact assessment for water resources, in terms of amount and extremes was also carried out. Based on the early results, and as improved model systems became available, it was feasible to launch additional studies. One of these was on the transport of nitrogen from land to lakes and the Baltic Sea, and water quality due to eutrophication. The connection to climate was the effect of the latter to atmospheric deposition, soil leaching, and biochemical removal processes in the fresh-water system of nitrogen. This project focused on the most important processes regulating the amount of nitrogen transported from land: arable-soil leaching, water discharge and nitrogen retention. The eutrophication problem with high algae concentrations was implicitly explored for one lake with respect to a future climate, with the help of the regional climate scenarios. The aim was to quantify the expected changes of nitrogen flow and algal growth in cooperation with the Mistra-funded research program VASTRA and for its pilot catchment Rönne å in southern Sweden. For nitrogen transport from land to sea, the same concept (i.e. TRK) was applied as in recent calculations on behalf of the Swedish Environment Protection Agency for the present climate, so that the respective results could be compared.

In the study, arable-soil leaching, water discharge and nitrogen retention was modeled with a process-based approach, starting from six RCA-modeled scenarios. These all gave similar impacts on water quality, even though one of the scenarios gave a different transport pattern due to less pronounced seasonal pattern of the hydrological load. The study indicated that in a future climate we may expect increased concentrations in the arable root zone (25%) and in the river (13%), as well as an increased annual load from land to sea as a result of the more pronounced winter high flow not sufficiently compensated by the increase in retention. It was also seen that such remote areas of the catchment that presently do not contribute to the load from land to sea might start to do so in the future. Radical changes in lake biochemistry were modeled, with increased concentrations of cyanobacteria (up to 350%), phosphorus and detritus, but decreased concentrations of phytoplankton (20-50%). The results showed that it might be of major importance to consider climate change effects when establishing water management plans.

4.6.6 Evaluation of inter-annual variability and trends in air quality and deposition using results from RCA2 coupled to MATCH

Already during Phase 1 of SWECLIM, an early attempt was made to study the possible impact of regional climate change on air quality, including transport and deposition of pollutants. Given the improved model performance and the appearance of longer climate simulations during Phase 2, an activity was launched on a more in-depth study. The object of the study during Phase 2 was to evaluate the combination of RCA and Multi-scale Atmospheric Transport and Chemistry model at SMHI, MATCH, for simulation of air quality and deposition for extended periods over Europe. The evaluation laid a foundation for continued work on the possible impact of climate change on air quality and deposition. The work was planned to continue within the framework of the EU-funded project Network for the support of European Policies on Air Pollution, NEPAP, and within the ASTA program supported by Mistra.

The study involved running MATCH for several years in the period 1985 to 2001 using meteorological data produced with RCA with boundary conditions from ECMWF meteorological analyses and relevant emission data from the EMEP database. Comparisons with observations were made across Europe. It was found that regional climate model simulations were more useful than operational forecasting fields, when variations on a monthly or longer time scale were in focus. For studies of short term variability meteorological fields based on assimilation were preferred. The discrepancies in model results versus EMEP observations on sulfur and nitrogen were not that much larger compared to using data from the operational HIRLAM model. For tropospheric ozone, the statistics for hourly data and daily maximum values are significantly better simulated using operational HIRLAM data. When looking at seasonal statistics the two approaches were of comparable quality.

4.6.7 Improved modeling of Stable Boundary Layers

SWECLIM's modeling exhibited problems in describing atmospheric and surface fluxes in Stable Boundary Layers (SBLs). This was the common problem to climate and forecast models of representing the observed intermittent turbulence in such situations. The problem was especially relevant in regions of frequent SBL occurrence, such as the wintertime Scandinavia and the Arctic. Some recent progress was recently made in the context of the regional forecast model HIRLAM-X. These revisions were to be tested in RCA and new techniques for representing surface fluxes developed in collaboration with Uppsala University to be implemented and tested.

Flux-calculation based on correction functions to the neutral drag and heat/mass transfer coefficients were further developed. Data from measurements of turbulent fluxes and mean profiles in stable stratification over different sites as well as evidence from climate and weather prediction modeling suggested that other mechanisms besides the traditionally-considered surface-layer stratification and, therefore, other arguments besides the bulk Richardson number should be considered. The new technique accounted for a generally essential difference between the roughness lengths for momentum and scalars and included a new effect of the static stability in the free atmosphere on the surface layer. Recommended correction functions depended besides bulk Richardson number, on one more stability parameter, involving the Brunt-Väisälä frequency in the free atmosphere, and on the roughness lengths. These correction functions were compared with two sets of data representing essentially different measurement sites located at high latitudes: Halley Bay in Antarctica and Sodankylä in Northern Finland. As a test for evaluation, the new flux-calculation technique was implemented in a 1-D version of HIRLAM and used to simulate the data and Large Eddy Simulation -results of the Beaufort Sea Arctic Stratus Experiment (BASE).

The results showed a significant improvement of simulated potential temperature in the cases of moderate and very stable stratification. There was improvement also for the vertical wind profile. The new technique was further implemented in a 3-D version of HIRLAM and a two-week experiment carried out. The verification scores obtained with the new parameterization demonstrated a significant improvement in comparison with the current parameterisation. The new parameterization was thereafter implemented as an option in RCA regional climate model system. Additional testing and evaluation will be carried out in the future work.

4.6.8 Statistical downscaling of daily climate information in Sweden

Extreme events was another aspect that gained increasing attention towards the end of the program. Many users wished more knowledge on extremes, so the problem of finite-resolution numerical models tending to smear out extremes remained to be tackled. Even as dealing with this was improved within the analysis of model simulations, an additional statistical downscaling method was attempted, as a supplementary project. A stochastic model was used to model daily variables in a statistical sense, related to statistics (e.g. frequency) of large-scale atmospheric circulation patterns. Such a stochastic formulation was felt to offer advantages in addressing uncertainties in future projections.

The data studied covered the period of 1961-2000 with daily precipitation totals for 366 stations. Considering the density of the station network the spatial scale of the 99th percentile was determined to be about 60-100 km. An index more related to specific events was the average annual daily maximum amount, with a corresponding spatial scale of 40-70 km. For regionalization of extreme precipitation, Maximum-Likelihood Factor Analysis was applied to data from 82 stations for days classified as extreme precipitation events. An extreme event was defined as a day with 40 mm or more of precipitation. A great majority of the heavy precipitation events occurred in summer. Based on weather type classification, the cyclonic weather type was connected with 63% of the extreme precipitation events (>50 mm) and the frontal type with 32% of the events. Measures of extreme precipitation were calculated for each station. They indicated higher extremes especially along the coast in middle Sweden as well as on the western side of the Swedish part of the Scandinavian mountain range.

The number and distribution of precipitation events was modeled based on a two-state Markov chain, involving two conditional probabilities: PWD, the probability of a wet day (W) following a dry day (D), and PDW, the probability of a dry day following a wet day. Monthly values of these probabilities were calculated and used to provide a transition from one season to another. Random sampling of the monthly distributions determined the occurrence of a wet day or a dry day. For each of the stations, a gamma distribution was fitted for the wet days. The extreme values based on the 90th, 95th and 99th percentiles were calculated. Using the estimated parameters of the gamma distribution and the transfer probabilities, 1000-year long simulations were made for the 366 stations.

The gamma distribution fitted to the daily precipitation data was found to be working fine. With the parameters estimated from the observed data, the daily precipitation statistics were reproduced rather well. The next step is to link the paratermers of the stochastic model to large-scale climate variables.

Another part of the study considered the concept of probability distribution, trying to see whether such a distribution of a climatic variable could be described as weighted sums of normal distributions resulting from different physical mechanisms/processes.

The hypothesis was that a probability distribution of a climatic variable was perhaps better described as a weighted sum of a number of normal distributions, which result from different physical mechanisms/processes, than as a single distribution. Indeed, many climatic elements do not comply with the normal distribution. A method to identify and characterize the multi modes was developed and described, and applied for daily surface air pressure and temperature in Stockholm, as a test example. The daily temperature in Stockholm was found to follow a two-mode model. The two modes could be interpreted as a winter and a summer mode, indicating that the transitional seasons were of limited importance.

The new model objectively characterized the temperature variation in more detail than the single distribution method, and opened for a new view on describing climate change, and quite possibly a new way to provide insight into the processes behind changes. For example, comparing the last 30 years (1971-2000) and the first 30 years (1761-1790) of Stockholm daily temperature data, the most interesting change is the increase in the weight of the summer mode. This means that the summer season has become longer and winter season shorter.

4.6.9 Estimate effects on nutrient leakage from alterations in Swedish regional agricultural production caused by climate change

Whereas the Supplementary Project on Transport of nitrogen addressed what happens to nitrogen after it enters the soil and waterways from its source, it did not address the sources themselves. This was studied as an additional project in co-operation with Linköping University, in terms of possible changes of nutrient leakage from agricultural land, looking into changes driven by climate change, but also to the effect of change of crops with corresponding cultivation practices. The aim of this study was to explore possible consequences of climate change on the environmental impacts from agricultural production in Sweden and highlight how this may influence implementation of the European Union Water Framework Directive.

Three main Swedish agricultural production areas were selected, and their future climate estimated based on SWECLIM scenarios. The indicated temperature and precipitation patterns were compared with present Europe. Data on environmental effects of different crops were obtained with a focus on nitrogen leakage. Based on a general strive for increased self-sufficiency for farmers and changed climatic conditions maize cultivation was selected for the study and compared with present day lea production. For the final discussion the results were related to the proposed structure for implementation of the water directive.

Among the main findings were that the simulated climate in the three selected Swedish agricultural areas resembled that of present day western France and that the simulated climate renders forage maize production possible in Sweden up to the

61°N latitude. An exchange of cultivation practices in fodder production from ley to maize was suggested to fivefold nitrogen leaching.

The results highlighted the possible effect a climate change will have on alterations in agricultural production and consequently on nutrient leaching patterns. The study was also an example of vulnerability analyses of potential impacts of future regional climate change on nutrient flows from agricultural land. Climate, of course, illustrated one of several factors subject to change that need to be considered.

4.7 Networks and research cooperation

Phase 2 of SWECLIM was characterized by its participants' increasing participation in research networks, as well as other types of research cooperation. The Rossby Centre joined a number of EU-funded research projects (cf. Section 7). These covered such aspects as European climate modeling infrastructure, high resolution regional climate modeling for Europe, climate modeling for the Arctic, impact of climate change on lakes and the parameterization of clouds and radiation in climate models. Nordic networks, both on the Arctic and on the interlinkage of climate and renewable energy production were also set up. Towards the end of Phase 2, yet new efforts were underway for projects, for example under the VI Framework Program of EU.

The development of the SWECLIM modeling system and the increasing availability of regional climate simulations led to data requests from different groups, both in Sweden, and in other countries. For SWECLIM this meant additional evaluation of the modeled results, as well as valuable further application of them. For Mistra and the society, this meant additional concretization of the implications of climate change in our region.

Contributions were made to the work and reporting by IPCC (e.g. Forty... 2001, Fifty-six... 2001) and to the national reporting to UNFCCC (cf. Chapter 5 of Ds 2001:71) as well as to the Arctic Climate Impact Assessment, ACIA (still ongoing in December 2003). Contributions were also made to international modeling intercomparison programs and projects CMIP2 (Coupled Modeling Intercomparison Program, Phase 2), PIRCS (Project to intercompare regional climate simulations), PILPS (Project for intercomparison of landsurface parameterization schemes) and ARC-MIP (the Arctic regional climate model intercomparison project). The international BALTEX and HIRLAM projects were additional cooperation fora.

Finally, SWECLIM had bilateral contacts and some activities with a number of other Mistra-programs. These included Mat-21, MARE, VASTRA, LUSTRA, SUFOR, Fjäll-Mistra and ASTA. In some cases joint workshops were managed, in other cases SWECLIM supplied commentary and data. In the case of VASTRA, a supplementary project was set up and executed (cf. Section 4.6.5). Another such a link was with ASTA (cf. Section 4.6.6).

5 Reflections on the program period

5.1 Program management

The daily management of SWECLIM, Phase 2, was at the hands of the Program Director – Markku Rummukainen – and the four Subprogram Leaders – Michael Tjernström, Lars Moen, Sten Bergström and Johan Rodhe. These five experts also formed the Management Group, supplemented later by the Program Communications Officer at that time, Gunn Persson. Lars Moen changed position in late 2002 and his duties within SWECLIM were taken over by Markku Rummukainen. The Management Group met at semi-regular intervals to discuss the progress within each Subprogram, coordination across the Subprograms, implementation of decisions by the Program Board (see below) and planning common activities, such as workshops, other meetings and the central program publications.

To the daily management of course also contributed the representatives of the Program Partners, i.e. the Rossby Centre and the Research Department of SMHI, the meteorology and oceanography groups and Stockholm University and the oceanography and natural geography groups at Göteborg University.

The Program Board consisted of representatives of major stakeholders: Hans Sandebring from SMHI, Leif Bernergård from the Swedish Environmental Protection Agency, Jan Fryk from Skogforsk (the Forestry Research Institute of Sweden, representing in a sense the forestry sector), Gunnar Hovsenius from Elforsk AB (an R&D broker for the Swedish electric utilities and power companies) and Erland Källén from Stockholm University (representing academia). A representative from Mistra was also present at the Board meetings. In the beginning of Phase, Mistra's representative was Kerstin Lövgren. Britt Marie Bertilsson later replaced her.

The Program Board met a few times a year, to allow the Board to monitor the progress of the overall program, decide on reporting, supplementary activities and dynamically steer the activities in concert with the developments in the Swedish society, international negotiations etc.

5.2 The functionality of the SWECLIM network

The SWECLIM network was characterized by a central resource – the Rossby Centre at SMHI – that was considerably larger than the other participating groups in terms of funding and personnel. This was a necessary arrangement, as the creation of a national regional climate modeling activity required broad expertise to cover the meteorological, oceanographic, hydrological and supercomputing aspects. The smallish share typical to some of the other participants meant that their SWECLIM commitment was very marginal compared to their other activities. This, of course was not the easiest state of affairs. Among other things it led to the smaller groups being vulnerable to staff changes. In practice, however, also considerable synergies were created. One example was that with small but targeted funding SWECLIM could introduce aspects of climate research and climate modeling to the curriculum of a number of PhD students.

It was also apparent, that the R&D cultures at SMHI and at the participating academia were different. SMHI seemed more used to the practices called for by Mistra.

The internal program interaction was supported by the composition of the Management group, which spanned the various scientific subject fields included in the program as well as the participating groups. The annual All Staff meetings and the SWECLIM Newsletter provided additional means of interaction within the program. Close interaction among participating scientists and students was overall observed to emerge rather automatically, whenever a need arouse.

5.3 Interaction with Mistra

As Mistra was present in the Board Meetings, there was a constant interaction between the program and Mistra. In addition, the Program Director was, as needed, in contact with the designated Mistra contact point, to discuss various practical matters, prepare for decisions etc. It was a bit unfortunate, that the designated contact point at Mistra changed during the course of the program. Another matter that created some confusion was the feeling of "directives in transition". The guidelines set down by Mistra changed from time to time, for example those on the structure of the program plan. A talking example is a point made by Mistra on the lack of a special Communication Plan, even though no such plan had been requested. Also the requirements in conjunction of the end of the program were rather broadly formulated. This, on the other hand, was also expressive of the much appreciated flexibility on Mistra's behalf to listen to the suggestions by SWECLIM on what which specific events and reporting were the most appropriate ones, considering the program progress and its dialogue with stakeholders.

The annual dialogue between the Chairman of the Program Board, the Program Director and Mistra was useful, as were the annual meetings with the other Mistra programs.

5.4 Communication and publishing

SWECLIM had a very successful communication activity. SWECLIM also had a rather impressive publication activity. This was a nice example of the fact that investing in scientific publishing does not exclude popular communication.

It was often the case, that one appearance in front of some audience led to additional requests. At times, this put on quite a pressure for the in practice limited resources. This was dealt with on a case-by-case basis. Overall, the interest from the society was very lively and spanned most areas and types of users. As copies of presentation material was often requested from SWECLIM, it was likely that the total volume of communication on climate change was larger than what could feasibly be documented.

It was observed, however, that during the program period itself, some of the program scientists were hesitant on the advisability and even the need of interaction with the broader public and the media. Also how questions from the public were met by the program spokespeople was discussed among the program participants, e.g. in conjunction of the All Staff meetings.

The approach taken by the program spokespersons was to present the subject in an objective manner, recognize that uncertainties remain, but that nevertheless a lot of knowledge is available. It was felt proper to inform on both Swedish and the international activities, and to encourage discussion among stakeholders for them to realize in what ways and how much climate change was an issue to them.

5.5 Funding

At the transition from Phase 1 to Phase 2 of SWECLIM, the annual volume of activities had stabilized to around 16 MSEK. The decision taken by the Mistra Board on Phase 2 funding meant that additional sources needed to be located, or the planned program activities to be reduced. SMHI took shortly thereafter a decision to cover an additional 3 MSEK of the overall Phase 2 costs. Together with a number of successful applications by the Rossby Centre to especially EU within the Framework Program V, this complemented the Mistra funding. The pursuit of external research funding also meant a certain inconvenience. Given that a typical EU-funded research program at that time was three years long, and that in the case of SMHI only partial funding could be acquired from EU, own financial commitments were created that were to last beyond the end of SWECLIM. This, however, was considered still in agreement with the long-term aims of climate modeling in Sweden, and within the strategic goals of the program participants.

All in all, the total amount of funds available during Phase 2 amounted to about 53-54 MSEK. Of these, about 70% were from Mistra (including some funds left from Phase 1), 14% were earmarked funding from SMHI, 7% from EU and the rest from various sources.

Towards the end of SWECLIM, additional externally funded research projects came about. In combination of staffing matters at especially Stockholm University, somewhat less of the earlier committed funds from Mistra were needed. This allowed SWECLIM to supplement the core program activities with value-adding projects (see Section 4.6).

5.6 Summary of practical lessons learnt

The establishment of a central resource, with a clear commitment to SWECLIM, was essential for a successful program. The involvement of academia was also most valuable for the overall program. In addition to the specific expertise from the involved groups, it made it more meaningful to pursue and contribute to research education in Sweden. On the other hand, small contributions were somewhat difficult to manage both on the participant level, and on the overall program level.

The management model worked well. The interaction between the day-to-day activities, the Program Director, the Management Group and the Program Board was both smooth, and efficient. The location of the operational management and the economic/administrative support at the same institute, SMHI, also contributed to efficient operations.

The program communication activity was very lively during Phase 2. This was not foreseen. Perhaps, in some sense, we ended up doing too much, as very few requests were turned down. Some activities, even though they fit within the budget, were certainly suboptimal. In some cases, SWECLIM could have been more aggressive in driving debate via media. Generally, however, we made the judgement that this would have undermined our role as an objective R&D broker on matter climate, climate modeling and climate change. Nevertheless, we recognize the value of interaction with the general public and media, in addition to the more established scientific and stakeholder dialogues. Our advice to new programs is to have a solid communication activity from the very beginning, management-level recognition of the relevance of communication and information and dedicated resources for the preparation and maintenance of material. Of course, it helps if one is successful in recruiting an able Communications Officer. Our belief is that such a person should have researcher training, and experience, in addition to communication skills. A further confirmation of the successful outreach of SWECLIM was the fact that the Programme Director was in 2003 ranked as No. 35 by Ny Teknik on a list of 50 influential Swedish scientists (*personerna med störst inflytande över svensk teknisk och naturvetenskaplig forskning,* www.nyteknik.se/pub/ipsart.asp?art_id=31189, read 2003-11-29).

The program framework set up by Mistra matured during the program period. In general, the additional requirements had a positive impact on the program management, even though living with guidelines-in-transition of course also meant additional work. We hope that our feedback to Mistra can be useful for the existing and future programs.

6 Outlook

One of the deliverables for SWECLIM was to report back to Mistra on the legacy of the program results and activities. As mentioned earlier, due to the fact that the program participants engaged in parallel external research projects, some of the active work by the end of Phase was continued within them. A continuous involvement in research networks, as well as communication, is pursued also beyond SWECLIM.

The major continuation of SWECLIM, however, involved securing a base for climate modeling in Sweden. The central resource of SWECLIM, the Rossby Centre at SMHI, was granted a temporary base funding of 9 MSEK/year from July 2003 to December 2005, with contributions from the Swedish Environmental Protection Agency (SEPA), SMHI, Mistra and the Swedish Energy Agency. This base funding covers about 65% of the current R&D/funding volume at the Rossby Centre. The remaining is covered by e.g. participation in EU-projects, and other additional activities. The Swedish Research Council for Environment, Agricultural Sciences and Spatial Planning, Formas, opened a 4-year research position at a Swedish university with the stated intention of this activity to cooperate with the Rossby Centre. The national agencies mentioned above form a Reference Group for the Rossby Centre in 2003-2005.

The matter of a permanent activity at the Rossby Centre is recommended to the government in the two recent reportings on national coordination of Swedish climate research, by a task force led by Formas. SMHI intends to continue this dialogue with the Ministry of the Environment, aiming for a permanent solution as the temporary base funding solution expires. We hope for a positive decision. Until then, the activities and investments will be managed assuming a long-term continuation of climate modeling in Sweden.

In this context, we also mention that SMHI, Stockholm University and the National Supercomputing Centre at Linköping University have applied for a dedicated supercomputing resource for climate modeling. This, again, would add on the base of long-term continuation of the activities started as SWECLIM.

The Rossby Centre aims to support and interact with academia on R&D on climate modeling and climate change. So far, a few joint applications have been prepared and sent to funding agencies.

We foresee a continuous societal need for expert advice on climate modeling and climate change, a Swedish research contribution of international class, and an R&D base for Swedish contributions to such international organizations as IPCC and UNFCCC. There are a number of research issues of particular interest for Sweden, including the Baltic Sea, the Arctic, Nordic mountain ecosystems, the marginal sea ice zone, the infrastructure, ecosystem and climate considerations of seasonal snow climate etc., that remain to be addressed. The activities built up during SWECLIM are a good base for future endeavors.

One missing activity that should be addressed in the future is to complement regional modeling by global modeling. This would offer operational, scientific and networking benefits. We also feel for exploring a more complete representation of the climate system, e.g. by complementing the SWECLIM modeling system with modules for ecosystems and vegetation. Regionally-varying forcing agents is another topic worth plunging into to, as is the interaction between natural sciences, technology research and social sciences.

7 Acknowledgements

SWECLIM was funded mainly by Mistra and by SMHI. Research supported by a number of other bodies also contributed to meeting the program aims: the European Union (Framework 5 research project contracts: EVK2-CT2001-00132 [PRUDENCE)], EVR1-CT2001-40012 [PRISM], EVK2-CT-1999-00007 [CLIWA-NET], EVK2-CT-1999-00051 [EUROCS], EVK1-2001-00297 [CLIME], EVK2-CT-2002-00164 [GLIMPSE], EVG1-CT-2001-00050 [ELDAS], C/2001/2023 [SEAREG]), the Nordic Energy Research and the Nordic Arctic Research Programme of the Nordic Council of Ministers Nordic Council of Ministers (within the CWE and RESMoNA projects, respectively), Elforsk AB, Svenska Kraftnät and the Swedish Rescue Services Agency (Statens Räddningsverk), as well as the Swedish National Space Board (Rymdstyrelsen).

The regional climate model simulations were performed on supercomputing platforms at the Swedish National Supercomputing Centre (NSC) in Linköping. The NSC staff is thanked for their expert advice and support.

The international HIRLAM project is thanked for the provision of the HIRLAM model, on which RCA builds on. We hope that our contributions match the help in kind. The international OCCAM project is thanked for the base on which RCO is

built on. CERFACS in France is thanked for their excellent coupling tool OASIS that facilitated the development of RCAO.

The provision of global simulations by the Hadley Centre of the Meteorological Office in the U.K., the Max-Planck-Institute for Meteorology (MPIfM) and the German Climate Computing Centre, DKRZ, both in Hamburg, Germany, and the Danish Climate Centre at the Danish Meteorological Institute (DMI) in Copenhagen, Denmark, is greatly acknowledged. For help with global model data we wish to thank especially Drs. Richard Jones, David Hassell, both at the Hadley Centre, Dr Erich Roeckner at MPIfM, and Drs. Jens Hesselbjerg Christensen and Ole Bøssing Christensen, both at DMI.

8 Lists of publications

Please note that those publications that are not published in international or national series are available upon request from the Rossby Centre, SMHI, SE-601 76 Norrköping, Sweden.

Please note also that articles in addition to those that are listed in the following sub-sections are in preparation. These works include 17 articles on the very recent work during Phase 2 of SWECLIM, submitted to the special SWECLIM-issue of Ambio, to appear in mid-2004. It is likely that 10-12 of the articles submitted to this special SWECLIM-issue will be accepted.

8.1 Peer-reviewed scientific articles

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8.4 SWECLIM Newsletters

SWECLIM published 14 issues of the approximately semiannual program Newsletter. The total number of pages amounted to 509. The first issue came out in May 1998, and the final on in May 2003. In addition to general overviews of various program activities and posted short news items, the most recent research results were presented. A number of external researches received the Newsletter free of charge. During Phase 2 the new issues of the Newsletter were made available, in full, also at www.smhi.se/sweclim.

8.5 Dissertations and Masters theses

SWECLIM contributed to the education of a number of doctoral students. They in turn contributed to the work done by SWECLIM. The theses so far prepared with major or minor support from SWECLIM are listed below. Additional few are expected to appear in 2004.

At the termination of SWECLIM as a Mistra-program, the onetime doctoral students continued their research. Anna Bratt was preparing to defend her thesis at Linköping University. Annica Ekman was about to return to Sweden (MISU) from a postdoc visit at MIT in USA on a Wallenberg stipend. Phil Graham was employed as a research hydrologist at the Rossby Centre of the SMHI. Cecilia Hellström pursued her research at Göteborg University. Måns Håkansson was employed by the Swedish energy production company Vattenfall. Anna Rutgersson did research at Uppsala University with funding from the Swedish Research Council (Vetenskapsrådet) in collaboration with the Rossby Centre. Robert Sigg worked for the Swedish defense research agency, FOI. Also Dance Zurovac-Jevtic was a Wallenberg postdoc stipendiary at MIT after working within SWECLIM. Presently she is continuing her research work at MISU.

The few postdoctoral researchers that SWECLIM employed during the program were likewise fully occupied afterwards. Patrick Samuelsson was affiliated at the Rossby Centre and Regine Hock obtained a "forskarassistent" position from the Swedish Research Council, and worked at Stockholm University.

Bratt, A.-L. 2003. *Managing agricultural nutrient leaching within the EC Water Framework Directive in Sweden.* Doctoral thesis, Department of Water and Environmental Studies, Linköping University. Linköping studies in arts and Science No. 284. UniTryck, Linköping, Sweden. ISBN 91-7373-788-7. 60 pp + 5 papers.

Ekman, A. M. L. 2001. *The atmospheric sulfur cycle and its impact on the European climate. A model study.* Doctoral thesis, Department of Meteorology, Stockholm University, Enheten för IT och Media, Stockholm University, Sweden. ISBN 91-7265-288-8, 35 pp + 4 papers.

Graham, L. P. 2000. *Large-Scale Hydrologic Modeling in the Baltic Basin.* Doctoral Thesis, Division of Hydraulic Engineering, Department of Civil and Environmental Engineering, Royal Institute of Technology, Stockholm. ISBN 91-7170-518-X, 55 pp. + 5 papers.

Green, M. 1999. *On the circulation and mixing in the Kattegatt and the Skagerrak.* Master thesis, Oceanography, Göteborg University. ISSN 1400-3821, 19 pp.

Hellström, C. 2003. *Regional precipitation in Sweden in relation to large-scale climate.* Doctoral thesis, Department of Physical Geography, ISSN 1400-3813, 34 pp. + 6 papers.

Håkansson, M. 2002. *Winds, shear and turbulence in atmospheric observations and models.* Doctoral thesis, Department of Meteorology, Stockholm University, Pitney Bowes Management Services, Stockholm, Sweden. ISBN 91-7265-497-X, 34 pp + 5 papers.

Rutgersson, A. 2000. *Water and Heat Exchange Processes over the Baltic Sea.* Doctoral Thesis, Comprehensive Summaries of Uppsala Dissertations from the Faculty of Science and Technology 530, Uppsala University, University Printers, Ekonomikum, Uppsala, Sweden. ISBN 91-554-4705-8, 36 pp. + 5 papers.

Sigg, R. 2000. *Studies of stratocumulus-topped boundary layers using a numerical weather prediction model.* Doctoral thesis, Department of Meteorology, Stockholm University, Academitryck AB, Edsbruk, Sweden. ISBN 91-7265-146-6, 30 pp + 4 papers.

Zurovac-Jevtic, D. 1999. *Dynamic modeling of cirrus cloud characteristics.* Doctoral thesis, Department of Meteorology, Stockholm University. ISBN 91-7153-905-0, 22 pp. + four papers.

8.6 Popular articles, external Newsletter contributions

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Bergström, S. 1999b. Konsekvenser av klimatförändringar (Föredrag vid VAV-dag i Säffle den 10 november 1999). *Meddelande VAV M111,* 13-17.

Bergström, S. 2000. Perspektiv på sommarens översvämningar. *Stadsbyggnad 5-2000,* 3-5.

Bernes, C. 2003. En varmare värld. Växthuseffekten och klimatets förändringar. *Monitor 18.* ISBN 91-620-1228-2. AB Danagårds Grafiska, Ödeshög. 168 s. (Also published in English as "A warmer world".)

Bringfelt, B. 1999. The land surface treatment used for the second regional climate simulation (RCA1) at the Rossby Centre. *HIRLAM Newsletter 34,* November 1999, 52-56.

Bringfelt, B. and Räisänen, J. 2000. Some developments of the HIRLAM land-surface treatment at the Rossby Centre. *HIRLAM Newsletter 35,* 143-148.

Bringfelt, B., Räisänen, J., Gollvik, S. and Ullerstig, A. 2000. A land-surface treatment at the Rossby Centre intended for RCA2. *HIRLAM Newsletter 36,* 32-41.

Döscher, R. and Meier, H. E. M. 2002. A new tool for coupled simulations of the BALTEX area: RCAO. *Baltex Newsletter, 4,* 1-3.

Joelsson, R. 1999a. Nordens klimat i förändring, även några kommentarer om globala klimatet. *Mekanisten 1999:2,* 15-20.

Joelsson, R. 1999b. Konsekvenser av klimatförändringar. *Meddelande VAV M111,* 8-11.

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