Sweden facing climate change

– threats and opportunities

Final report
from the Swedish Commission on
Climate and Vulnerability

Stockholm 2007

STATENS OFFENTLIGA
UTREDNINGAR

Swedish Government Official Reports
SOU 2007:60

This report is on sale in Stockholm at Fritzes Bookshop.

Address: Fritzes, Customer Service,
SE-106 47 STOCKHOLM
Sweden

Fax: 08 690 91 91 (national)
+46 8 690 91 91 (international)

Tel: 08 690 91 90 (national)
+46 8 690 91 91

E-mail: order.fritzes@nj.se

Internet: www.fritzes.se

Printed by Edita Sverige AB
Stockholm 2007

ISBN 978-91-38-22850-0
ISSN 0375-250X

Preface

The Commission on Climate and Vulnerability was appointed by the Swedish Government in June 2005 to assess regional and local impacts of global climate change on the Swedish society including costs. Bengt Holgersson Governor of the County Administrative Board in the region of Skåne was appointed head of the Commission. This report will be subject to a public review and will serve as one of the inputs to a forthcoming climate bill in 2008. The author have the sole responsibility for the content of the report and as such it can not be taken as the view of the Swedish Government.

This report was originally produced in Swedish. It has been translated into English and the English version corresponds with the Swedish one. However, one chapter with specific proposals for changes in Swedish legislation was not translated, nor were the appendices translated. Hence, these are only available in the Swedish original version.

Contents

1 Summary

Our most important conclusions and proposals

1. It is necessary to make a start on adapting to climate changes in Sweden. The principal features of the climate scenarios, despite uncertainties, are sufficiently robust to be used as a basis.
2. The risk of floods, landslides and erosion in many areas is increasing to such an extent that stronger initiatives for preventive measures are justified. A government climate adaptation appropriation should be established in support of large-scale costly initiatives.
3. The rate of forest growth will increase sharply, and conditions for agricultural production will improve. There is, however, a need for adaptation measures to minimise damage and preserve biodiversity.
4. There is a risk of dramatic changes in ecosystems in the Baltic Sea. Climate change will exacerbate the present-day situation, and efforts to reduce emissions should be intensified.
5. There will be an adverse impact on water quality in lakes and watercourses, which will make efforts to maintain good drinking-water quality necessary.
6. The mountains will largely turn to scrub, and the reindeer-herding industry and mountain tourism may be affected.
7. The warmer climate will affect health and lead to more deaths due to heat waves and increased spread of infection.
8. Sweden's energy balance will benefit as a result of reduced need for heating and increased hydropower potential.
9. The county administrative boards should be given a key role in climate adaptation efforts. A special climate adaptation panel should be established at each county administrative board, to provide enhanced support for the municipalities in particular.
10. We propose the establishment of a new institute for climate research and adaptation

Arrangement

This report is based on global climate change. The Commission has analysed how Sweden's climate may develop over the next hundred years. We have also analysed the consequences for a number of different sectors and areas. Important aspects that have been investigated are vulnerability to floods. landslides and storms. We propose various measures to reduce vulnerability and adapt society to long-term climate change and extreme weather events.

Sweden will become warmer and wetter

The UN's Intergovernmental Panel on Climate Change (IPCC) has concluded that global warming so far has been 0.7 degrees over the last 100 years. The rate of warming in the last 50 years has been almost double that in the whole 100-year period, and it is very likely that this has been largely caused by human activities. The mean global temperature will in all probability rise by a further 1.8–4.0 degrees by the end of the century compared with 1990. If sharp reductions in global emissions are made, it will be possible for temperature increases to be limited in the longer term. Some continued warming is, however, unavoidable.

Temperature will rise more in Sweden and Scandinavia than the global mean. The model scenarios we have used as a base point to average temperature in Sweden rising by 3–5 degrees by the 2080s in comparison with the period 1960–1990. Winter temperature may increase by 7 degrees in northern Sweden. The climate in the Mälardalen valley will resemble the climate in northern France today.

Precipitation patterns will also change. Precipitation will increase in most of the country during the autumn, winter and spring. In summer-time the climate will be warmer and drier, particularly in southern Sweden.

Sea levels are expected to rise by 0.2–0.6 metres globally over the next hundred years, then continue to rise for many hundreds of years. No melting of the ice caps in Greenland and Antarctica is included in the calculations. Sea levels are expected to rise by up to 0.2 metres in seas adjoining Sweden.

The results with regard to winds and storms in the future in Sweden are more uncertain. The trend in our model scenarios is for both average wind and maximum gusts to increase.

High flows, floods, landslides and erosion

The number of days of heavy precipitation will increase during the winter, spring and autumn in most parts of the country. There will be significant increases in the most intensive rains.

Runoff will increase in most parts of the country, mostly in the west. High flows with a return period averaging 100 years, known as 100-year flow, will increase sharply, particularly in western Götaland, south-western Svealand and north-western Norrland. In other parts of the country these high flows will decrease as warmer winters will result in less remaining snow cover, which will to a smaller spring flood. Local heavy rainfall, downpours, which mostly occur during the summer months, will increase in intensity throughout the country.

Floods will affect building construction and infrastructure

Several major floods have affected Sweden in recent years. The floods around Lake Vänern in 2000/2001 and Arvika in 2000 are two examples.

The increased risk of floods affects building construction, roads and railways in particular. Other infrastructure, industry and agriculture may also be at risk. There is a risk of the supply of drinking water being disrupted by the contamination of water sources or pipe fractures. Flooding of electricity substations may lead to prolonged power outages.

Increased interest in lakeside living has meant that homes have often been built in areas threatened by floods. In the present-day climate just over 6 million sq.m of floor area in buildings alongside watercourses is at risk of flooding on average once every 100 years. This area will probably increase.

Local downpours causing surface-water and sewer systems to flood are already a major problem today. This leads to basements being flooded and sewage being discharged. The problem will be even more serious in the future.

Landslides increase the risk to human life

In the last two years Sweden has suffered several landslides with consequences that could have been very serious. A local downpour in Ånn in Jämtland caused both a railway line and a road to slip. In Munkedal several hundred metres of the E6 motorway collapsed. Landslides have previously caused fatalities on a number of occasions in Sweden.

Heavy precipitation and increased flows in watercourses as well as raised and variable groundwater levels will increase the risk of landslides The increased risks will arise principally in areas where there is already a high risk today. This applies to the area around Lake Vänern, the valley of the Göta Älv river, eastern Svealand and almost the whole of the east coast. We have estimated that more than 200,000 buildings are located close to water in areas where the risk of landslides will increase. Local conditions dictate where the risks will be greatest.

Coastal erosion and rising sea levels – threats to building construction in low-lying areas

The rise in sea levels is under way and will continue for many hundreds of years. We have based our calculations on the IPCC's assessment from 2001, with a rise in sea levels of between 9 and 88 cm. The higher level roughly corresponds to the estimate made by the IPCC in its latest report if account is taken of the rise in sea levels being greater in adjoining sea areas. In the northern part of the country the rise in sea levels will be counteracted by land uplift. The southern parts of the country, Skåne, Blekinge, Halland and the West Coast, will be most exposed. Low-pressure movements and winds are also of great significance to sea levels and the risk of flooding and erosion along the coasts. With increased dominance of westerly winds, the maximum high-water levels in the Baltic Sea will rise substantially. The maximum high-water level in Karlskrona today is one metre above the present-day mean water level. At the end of the century it is estimated that it will be two metres above it. This will makes increased demands on the planning of new building construction and preventive measures.

Coastal erosion affects areas that consist of highly mobile soil or sand. The stretches of coast at greatest risk are in Skåne and

Blekinge and on the islands of Öland and Gotland. According to our calculations, around 150,000 buildings are located in an area susceptible to erosion in the case of a rise in sea level of 88 cm.

Hydropower production will increase sharply

The increase in water inflow, particularly in the northern parts of the country, will take place gradually. This creates very favourable conditions for increased hydropower production. Calculations indicate a possible increase in hydropower potential averaging 15–20 per cent by the end of the century. If it is to be possible for the whole of this potential to be exploited, however, there will be a need to expand power-plant capacity and reservoirs.

Dam safety should be reviewed

There are around 10,000 dams of varying size, type and age spread across Sweden. Most of the larger dams are hydropower dams, but there are also some large tailings dams to deal with mining waste. Two dams more than 15 metres high, the mine dam at Aitik and the Noppikoski Dam, have breached over the years. There were no injuries.

The largest dams, in risk category I, have been built to withstand very extreme flows. Climate change entails a risk of the flow for which these dams are designed increasing in parts of the country, but there is considerable uncertainty. The 100-year flow will increase substantially, particularly in western Götaland and south-western Svealand, with increased risks particularly for the smaller dams in risk category II. There will also be an increase in 100-year flow in the mountain regions, with the risk that this may propagate along whole watercourses down to the estuary. The present-day 100-year flows are expected to become less common in many other places.

The Swedish National Audit Office has reviewed government efforts in relation to hydropower dam safety. The National Audit Office considers there to be a need to improve and develop government efforts for dam safety and recommends that the Swedish Government takes the initiative for an overhaul. We agree on this.

Permits for water operations – review of old water rulings

In our sub-report on the risks of flooding in the area around Lake Vänern and other areas, we have seen that a modified regulating strategy can contribute towards reducing the risk of floods. We also consider that review or revision of a number of permits may be appropriate due to changed flows resulting from climate change, or in conjunction with the expansion of hydropower. This is, in many cases, a very extensive and complex process. We therefore consider that the legislation should be overhauled.

Increased aggregate income and increased costs of damage for floods, landslides, erosion and hydropower 2010–2100

	Revenue SEK billion	Costs SEK billion
State-owned, municipal and private roads		10–20
Flooding of buildings, lakes and watercourses		50–100
Flooding of buildings, coast		10–20
Landslides		10–15
Coastal erosion		20–90
Increased hydropower production	190–260	
Total	**190–260**	**100–240**

Measures and proposals

Physical planning should be adapted to the future risks. The government should also provide information and produce material in support of planning and preventive measures. Responsibility for measures should, as a matter of principle, be borne by the property owner and the municipality.

Information and training for staff in municipalities, for instance, are very important in order to improve awareness of climate change and adaptation measures.

We consider there to be certain deficiencies at present in insurance cover against natural disasters. These deficiencies do not, however, justify special government support for natural damage. The nature of the gaps that exist is judged to be such that they can be plugged by private insurance companies. Private insurance protection needs to be developed, however, with regard to damage due to natural disasters.

We propose the following to reduce vulnerability to flooding, landslides and erosion:

- The obligation of the municipalities to take account of the risks of floods and landslides in physical planning should become clearer in legislation and guidelines should be drawn up. The limitation period for the obligation of the municipalities to pay compensation should be increased from 10 to 20 years.
- There is a need for mapping, altitude data, geotechnical data etc. as well as warning systems required to reduce vulnerability to be prepared. The Swedish Geotechnical Institute (SGI) should take responsibility for scheduled duty activity for landslides.
- The county administrative board should be given a key role in adaptation, and a special climate adaptation panel should be established at the county administrative board.
- Adaptations of the transport infrastructure to a changed climate should be included in the objectives of transport policy. Funds should be earmarked for the climate adaptation of the transport infrastructure. The risks, particularly in the road and rail networks, should be mapped and measures implemented.
- A special climate adaptation appropriation should be created for greater investments aimed at reducing vulnerability to extreme weather events and long-term climate change. It should be possible for the appropriation to be used to contribute to financing major projects to prevent floods, landslides and erosion in particular. We estimate the annual need to be of the order of SEK 100–300 million for the next 10 years.
- A special negotiator should be appointed to share the costs between central government and other stakeholders in order to implement the proposals contained in our sub-report on measures to be taken in the areas of Lake Vänern and Lake Mälaren.
- The Swedish Rescue Services Agency appropriation for grants to the municipalities' preventive efforts should be retained at its present level of SEK 40 million per year. Erosion should be included in the grant. The grants should be reduced to a maximum of 60 per cent of the cost of measures.

- The impact of climate change on inflow conditions and how this can affect vulnerability and the risks of flooding in risk categories I and II dams should be analysed. An analysis of tailings dams should be carried out.
- A commission of inquiry should overhaul legislation on water operations in its entirety and analyse the need for reviews with respect to flood risks and drainage. The commission should also look at dams that do not have permits and owners, following an inventory by the county administrative board.
- The area of dam safety should be looked over to establish whether the current system of responsibility meets the safety requirements of modern-day society.

Land-based industries and terrestrial ecosystems

Large changes in temperature and changes in patterns of precipitation will lead to a substantial change in the natural conditions for agriculture and forestry, reindeer herding and winter tourism, as well as for natural terrestrial ecosystems. The distribution of species will generally be shifted northwards.

Increased production in forestry, but also increased damage

The generally warmer climate, a longer vegetation season and an increased carbon dioxide level in the atmosphere will result in greater growth. New tree species and different types may lead to even higher production

Calculations show that the rate of growth of pine, spruce and birch will gradually increase so that by the end of the century it is 20–40 per cent higher than today. In the south, drier summers will mean that spruce grows less well towards the end of the century. The proportion of deciduous trees might increase in forestry, but grazing wildlife are an obstacle to this.

Model calculations show that increasing rate of forest growth and taller trees will lead to a greater risk of wind-felling, even if the frequency of storms does not increase. Reduced ground frost and wetter conditions in winter-time will also contribute to an increased risk of storm-felling and make it more difficult to harvest trees, manoeuvre on forest tracks and bring out the timber.

The warmer climate will make the forests more prone to fire, fungal and insect attack, for example by spruce bark beetle.

Bigger crops in agriculture, but also more pests

The EU's Common Agricultural Policy has a strong bearing on the extent, orientation and profitability of agriculture, which makes it difficult to assess the impact of climate change on agricultural production.

Vegetation period and cultivation period will be considerably prolonged according to the climate scenarios. The improved cultivation conditions present opportunities for increased harvests throughout the country. Harvests will increase by around 20 per-cent in the valley of Lake Mälaren, for example, and by more than 50 per cent in Västerbotten if the same crops as today are grown. Yields of autumn-sown crops will increase, and new crops may be introduced. Conditions for livestock farming will be improved by a prolonged grazing season and increased harvests of forage crops. However, increased production requires increased use of fertilisers.

Problems with pests such as insects, fungi and viruses will increase in a warmer climate. The weed flora is expected to become more species-rich. If the use of pesticides were to rise to Danish levels, this would mean almost twice present levels.

Access to water in the future climate will look different than it does today. More precipitation in winter-time but less in summer-time will make new demands on both drainage and irrigation.

The increased temperatures in summer-time may pose problems for pig and poultry rearing in particular. A number of vector-borne infections will spread north. New diseases which may affect livestock are mostly zoonotic infections which are spread for instance by ticks and rodents, as well as viral diseases.

Changed conditions for the reindeer-herding industry

The conditions for reindeer herding in Sweden will be significantly affected by climate change. Vegetation period will be prolonged and plant production during summer grazing will increase. Insect harassment may be exacerbated. Areas of bare mountain are expected to decrease in extent, and pressure on coastal winter grazing may increase as snow conditions become more difficult inland and in the mountains, which may lead to more conflicts of interest with other sectors of industry. The most serious consequence will be a threat to Saami culture if conditions for reindeer herding worsen.

Worse for winter tourism, but perhaps better for summer tourism

The opportunities open to the rapidly expanding tourist industry may be further increased in a changed climate with warmer summers and higher bathing water temperatures. However, water resources and quality will remain a key issue. Winter tourism and outdoor leisure will be affected by winters with increasingly depleted levels of snow, particularly in the southern mountains, and adaptation measures will be required.

Terrestrial ecosystems will face great upheavals, and the loss of biodiversity may increase

Terrestrial ecosystems in Sweden face great upheavals, and the loss of biodiversity will increase as a result of climate change. The adaptation measures in themselves may also lead to an adverse impact on biodiversity, for example in agriculture and forestry. The adverse effects may, however, be limited.

The different types of nature which today are an important part of Sweden and represent an important cultural basis for a large proportion of the population will change. The natural forests we have today will be transformed both as a result of climate change in itself and due to changes in forestry.

The mountain environment is very delicate. The increase in temperature which is taking place is the main reason why the tree line has risen by 100–150 metres over the last 100 years. The future rise in temperature of up to 5–6 degrees over the next 100 years will lead to an invasion of scrub on large parts of the bare mountains.

Climate change will have a great impact on the possibility of attaining the environmental objectives of *A Rich Diversity of Plant* *and Animal Life, A Magnificent Mountain Landscape* and *Flourishing Wetlands.*

Increased aggregate revenue and increased costs of damage for agriculture, forestry and reindeer herding in Sweden 2010–2100

		Revenue SEK billion	Costs SEK billion
Forestry	increased growth	300–600	
	damage from storms, fires etc.		50–100
	other damage		50–190
Agriculture	increased yields	40–70	
	change in land use	40–70	
	use of pesticides		20–40
	increased irrigation		15–30
	more storms		0–5
Reindeer herding			1–3
Total		**380–740**	**135–370**

Measures and proposals

We propose the following to attain sustainable adaptation of the land-based industries and terrestrial ecosystems to a changed climate.

- The Forestry Act and associated regulations should be overhauled against the backdrop of climate change.
- Management and forms of support for the combination of biofuel production and nature conservation should be developed.
- Needs for future irrigation in agriculture should be mapped.
- An enhanced system for support to wetlands should be devised.
- Animal welfare rules and recommendations for livestock housing should be overhauled.
- The reporting of forest damage and damage to harvests in agriculture should be improved.
- Information campaigns targeted at forest owners, farmers and the tourist industry should be carried out.

- The development of infectious veterinary diseases should be monitored, and protective measures and further training of staff should be carried out.
- National interests in nature conservation, tourism, reindeer herding and outdoor leisure should be identified, as well as areas where competition for land may arise. A dialogue should also be developed between reindeer herding and tourism.
- Greater consideration should be shown in the reindeer-grazing area, and the Forestry Act should be amended so that the obligation of consultation before felling trees is extended to the whole reindeer-grazing area.
- Government agencies responsible for the environmental objectives should assess how the relevant environmental objectives are to be achieved, assess the effectiveness of present-day systems of protection and propose improvements.

Freshwater, seas and fisheries

According to hydrological calculations, annual runoff will increase over the greater part of the country, particularly in the mountain chain of Norrland and in western Götaland. Together with the rise in temperature and earlier ice break-up, this will have an impact on water quality in both inland waters and seas.

The freshwater environment – more difficult to attain environmental objectives

Climate change will increase the leaching of nutrients and humus. Higher humus levels will result in more brown-coloured water. The colour of the water will affect biological life and have an adverse effect on the quality of raw water for water treatment plants.

The increased supply of nutrients, such as nitrogen and phosphorus, will lead to increased eutrophication, and together with the rise in temperature will probably also lead to increased algal bloom in freshwater. Taken together, this will mean a deterioration in water quality, which will make it very difficult to attain the environmental objectives of *Zero Eutrophication* and *Flourishing Lakes and Streams.*

Drinking water may be adversely affected

Sweden has good access to water of good quality. Although there will be considerable consequences for the supply of drinking water, Sweden will be affected to a far lesser degree than many other countries.

The quality of the raw water in water sources will be adversely affected, with increased humus levels, increased algal bloom and increased contamination with microorganisms. Present-day treatment techniques will be inadequate, and new technology will have to be introduced, increasing the costs of drinking water treatment.

The Baltic a threatened sea

The temperature in the Baltic Sea will rise by several degrees and the extent of ice cover will decrease substantially. With increasing westerly winds and a substantial increase in precipitation, the salt level will be almost halved. If this happens, dramatic changes will occur in which almost all marine species will disappear.

Even if the effects on salt levels are more modest these, together with the rise in temperature and increased input of nutrients, will probably lead to large-scale consequences and an increased burden on an already polluted sea. Modelling calculations indicate that algal blooms will increase in the southern Baltic, while they may decrease elsewhere. There is great uncertainty on how the aggregate changes will affect biology.

The fishing industry – an industry under pressure

Great changes in ecosystems and fisheries await in a warmer climate. Cod may be completely eliminated from the Baltic and be replaced by freshwater species. Cod at present accounts for 25 per cent of the total value of catch for the Swedish fishing industry. Flatfish will also decrease in the Baltic Sea. Warm-water species such as perch, pike and pike-perch will increase and become established much further north. Climate change justifies further efforts against overfishing in the Baltic. Fisheries on the west coast will probably be favoured by climate change.

New species will gradually colonise Swedish waters and may seriously disrupt ecosystems. An example is the American comb jellyfish which is becoming established in the Baltic Sea. It has previously transformed ecosystems and destroyed fisheries in the Black Sea.

In freshwater, warm-water species will replace cold-water species. Catches of crayfish and pike-perch in the large lakes may increase by a value equivalent to SEK 15–20 million per year. Arctic char will decrease in the watercourses of Norrland, while salmon will be threatened in the watercourses of southern Sweden.

Increased aggregate revenue and increased costs of damage for drinking-water supply and fisheries in Sweden 2010–2100

	Revenue SEK billion	Costs SEK billion
Fishing industry		3–15
Drinking water supply		60–125
Total		**60–140**

Measures and proposals

We propose measures to adapt the supply of drinking water to a changed climate. We also propose EU measures to reduce the vulnerability of the Baltic Sea and inquiries on the future of fisheries.

- The National Food Administration should be given responsibility to coordinate drinking-water issues and overhaul protection and control routines for the preparation of drinking water, as well as providing information on risks and protective measures for individual wells.
- Sweden should press for measures at EU level that reduce the vulnerability of the Baltic Sea in a changed climate. There should be greater focus on the problem of nutrients and their impact on the Baltic Sea in future overhauls of EU agricultural policy.
- The effects on the Swedish fishing industry if cod disappears from the Baltic Sea should be studied and prioritised measures for the dispersal of fish in freshwater should be identified.

Effects on health and heating and cooling needs

Mean temperature in summer-time will rise by 2–4 degrees. There will be an increased number of days with extremely high temperatures. The number of tropical nights, that is to say 24-hour periods when the temperature never falls below 20 degrees, will increase substantially in southern and central parts of the country and along the Norrland coast. Towards the end of the century there may be as many such nights as there are at present in Southern Europe. There will be fewer really cold days.

More extreme heat waves will lead to increased mortality

When Europe was struck by a severe heat wave in August 2003, it is estimated that more than 33,000 people died as a direct consequence of the heat.

Elderly people and the sick in particular are greatly at risk in extreme heat. Sensitivity to heat varies in different areas, depending on how adapted the population is to high temperatures. The mortality rate in Stockholm is lowest at 11–12 degrees, while the optimum temperature in Athens is 25 degrees. A substantially increased mortality rate has been observed after 2 days of persistent heat.

Calculations for the Stockholm area show that a rise in mean temperature of 4 degrees increases mortality by just over 5 per cent. We estimate that the number of deaths per year in heat waves will have increased by just over 1 000 by the end of this century. The decrease in the number of really cold days results in reduced mortality, but this effect is smaller.

A hotter climate with increased precipitation results in increased spread of infection

The spread of infective agents will increase with rising levels of precipitation and higher temperatures. When floods and landslides occur, infective agents present in the soil and in the ground may pollute water sources, grazing land, bathing water in outdoor pools and irrigation water. Sewage may leak into drinking water sources and pipes.

Vibriosis is an example of a serious new problem for Sweden. The infective agents are present in Swedish waters but do not grow until water temperatures rise above 20 degrees. This disease, which was referred to as cholera in the media at the time of an outbreak in 2006, caused three deaths. The risk of an outbreak of vibriosis will increase in the Baltic right up to the Bay of Bothnia during this century.

A warmer climate during the summer months is expected to increase the number of cases of food poisoning. We will have a climate that will greater demands on food hygiene than we are accustomed to.

The shift in the seasons may have effects for several 'vector-borne' diseases where the infective agents in nature are transmitted by animals such as rodents, birds and foxes, by insects such as mosquitoes, blackfly etc., or by arachnids, particularly ticks. There are a number of examples of northerly spread as the climate becomes warmer, for example the spread of ticks, and with it diseases such as borrelia and TBE.

Risk of increased problems with mould in buildings

Climate change may seriously affect existing and future building structures. Increased air humidity and increased temperatures entail a greater risk of moisture and mould damage which can lead to increased health problems.

Overfull sewerage systems and flooding of basements will cause great damage. The external maintenance needs of buildings will also increase appreciably as a result of increased precipitation and higher temperature.

The future need for heating will decrease sharply while the need for cooling increases

Climate change will have a great impact on the need for heating and cooling. The need for heating will decrease sharply as a consequence of the rise in temperature, while the need for cooling will increase. The decrease in the need for heating entails large cost savings in the form of far lower energy costs. Energy use for heating will decrease by around 30 per cent or 23.5 TWh by the

2080s. The need for cooling, on the other hand, is expected to increase approximately 5 times, equivalent to an increase in electricity consumption of 8.5 TWh over the same period.

Increased aggregate revenue and costs of damage for effects on health, building structures, heating and cooling needs in Sweden 2010–2100

	Revenue SEK billion	Costs SEK billion
Heat-related deaths		500–660
Spread of infection		70–140
Building structures		50–100
Reduced heating need	600–690	
Increased cooling need		130–150
Total	**600–690**	**750–1 050**

Measures and proposals

We propose the following to reduce effects on health and adapt buildings to a changed climate.

- The guidelines for food handling should be overhauled and the public informed.
- A knowledge base for the emergency planning of municipalities and county councils to deal with heat waves should be established.
- The development of infectious diseases should be monitored and protective measures implemented. The public should be informed and further training should be provided for staff.
- Building regulations should be overhauled.

Wind and storms

The winter storm Gudrun

Sweden has been affected by a number of severe storms over the years. The winter storm Gudrun, which struck Sweden on 8–9 January 2005, has had the most severe consequences to date. The strongest gusts reached a speed of 42 metres per second. Småland, Halland and northern Skåne were worst affected. There was widespread damage to forests. Falling trees caused severe disruption and damage to the power supply, telecommunications networks, roads and railways. Seventeen people lost their lives, and the direct costs totalled SEK 21 billion.

Windier or not?

It has not been entirely clarified whether it will be winder or not. Different models produce partly inconsistent results. Most models show slightly increased average wind. The change in the very strongest gusts has only been calculated with one of the models we use. The results point to some increase in the southern part of the country. There is thus a risk of storms like Gudrun becoming worse.

Forestry most at risk

Regardless of whether storms become worse or not, storm-felling of forest will increase due to faster-growing trees, reduced ground frost and wetter soil in winter-time. If the storms additionally become more severe, the damage may be very substantial.

Local power and telecommunications networks will remain prone to storm damage – but susceptibility will diminish

Extensive burying of cables is taking place in the southern parts of the country to reduce the vulnerability of local power networks, and this will continue for several decades. Overhead power lines will, however, remain in the local networks, particularly in northern Sweden. The regional networks will continue to consist of overhead power lines. A change-over to wireless transmission is taking place in telecommunications networks. We anticipate that there will continue to be disruption as a consequence of storms that affect vital functions of society and the public, but that sensitivity in the networks will gradually diminish.

The national grid for the transmission of power and networks for radio and television distribution are designed for high wind speeds. These are not expected to be affected by increases in winds to any significant degree.

The overhead lines of the railway network are susceptible to strong winds and storm-felling of forest. Banverket, the Swedish Rail Administration, has given notice of measures to reduce vulnerability, for instance by overhauling the power line corridors along the railway track.

Wind power will benefit if average wind speeds increase. Production may already increase by 5–20 per cent by the 2020s.

Increased aggregate revenue and costs of damage for wind and storms in Sweden 2010–2100

	Revenue SEK billion	Costs SEK billion
Wind power	0–25	
Storm-felling of forest*		50–100
Storm damage in agriculture*		0–5
Costs to the municipalities of storms		0–2
Total	**0–25**	**50–110**

*Storm damage to forests and agriculture is also included in the table on land-based industries.

The consequences of a severe storm such as Gudrun are substantial. As well as the costs, there is a risk of vital functions of society and vulnerable groups such as elderly, the sick and the disabled being affected.

Measures and proposals

If vulnerability is to be reduced, it is important to improve the level of emergency planning in municipalities, business and government agencies.

We propose the following measures.

- The Swedish National Post and Telecom Agency should be given clearer responsibility for ensuring that telecommunications networks are robust. The vulnerability of the telecommunications sector to storms etc. should be analysed.
- The Energy Markets Inspectorate should be given clearer responsibility for ensuring that power networks are robust. The vulnerability of the energy sector to storms etc. should be analysed.

- Railway contact lines should be overhauled and measures to increase their ability to withstand strong winds should be implemented.

Responsibilities and organisation

Climate change will affect the underlying conditions in a large number of activities. Adaptation to a changed climate should therefore permeate virtually the whole of society. Practical efforts will be largely implemented at local level, by individuals, companies and municipalities. Here we mainly discuss responsibilities and organisation in the government sector.

Proposals for changed sharing of responsibility

Responsibility for adaptation to a changed climate is shared between individuals, municipalities and central government. We propose that the county administrative boards be given a leading role and the task of coordinating climate adaptation efforts in the county concerned. The Swedish Environmental Protection Agency should be given responsibility for monitoring adaptation efforts and reporting. The Swedish Meteorological and Hydrological Institute (SMH) should be given responsibility for the supply of knowledge on climate change. We also propose expanded responsibility for the Swedish Geotechnical Institute (SGI), the Swedish National Post and Telecom Agency, the Energy Markets Inspectorate and the National Food Administration. Finally we propose that a large number of sector authorities be given clearer responsibility for climate adaptation in their particular areas of responsibility.

- The county administrative boards should be given a key role in adaptation to climate change and coordinate the work in relation to municipalities, business and regional sector authorities. Regional analyses should be conducted in the counties as a basis for planning, for instance the long-term water supply should be analysed together with the water authorities. A special climate adaptation panel should be established in each county with the task of supporting the efforts of the municipalities, contributing to the supply of knowledge, summarising, providing, interpreting and forwarding information and coordinating, instigating and following up the work. The task includes initiating the formation and supporting the work of river groups.

- The Swedish Meteorological and Hydrological Institute should be given responsibility for the supply of knowledge on climate change and should create a reinforced information function in relation to different groups, in particular municipalities, sector authorities and county administrative boards.
- The Swedish Environmental Protection Agency should be given responsibility for collective national and international follow-up and reporting of climate adaptation efforts.
- All sector agencies concerned should be given clear responsibility for adaptation to a changed climate in their own areas of responsibility. The responsibility covers the risk of both extreme events and continuous climate change. The requirement that the agency will initiate, support and follow up work on adaptation to climate change in its own area of responsibility should be introduced into the instructions for each government agency. The Swedish Rescue Services Agency, the Swedish Meteorological and Hydrological Institute (SMHI), the Swedish Geotechnical Institute (SGI), the Swedish Geological Survey (SGU) and the National Board of Housing, Building and Planning should additionally be given explicit responsibility to assist the county administrative boards in their work on climate adaptation.

Research and development

The descriptions of future climate change are relatively imprecise. Knowledge on how climate change will affect different parts of society and what adaptation measures should be taken is still limited. The conclusions we draw on vulnerability, adaptation needs and costs in different parts of society in many cases rest on a relatively uncertain foundation. Build-up of knowledge and research are important in many of the areas studied by the commission.

Creation of a new institute for climate research and adaptation

In order to harness efforts on research for climate adaptation we propose that a new institute focused on climate research and climate adaptation be created and provided with new resources.

The approach of such an institute should be interdisciplinary, and its efforts should cover research on the climate as well as more applied research with elements of development efforts. These efforts should include:

- continued development of climate models,
- adaptation of the technical systems of society, focusing on high flows, floods, storms, landslides and erosion,
- soil ecosystems, water resources (freshwater and drinking water) and effects on land-based industries and the environment,
- ecosystems in seas, particularly the Baltic Sea, and effects on ecosystem services, tourism and fisheries,
- impact of climate and ecosystem change on the spread of infection.

The framework for an institute could be comprised of parts of existing research resources in the Swedish Geotechnical Institute (SGI), the Swedish Meteorological and Hydrological Institute (SMHI), IVL Swedish Environmental Research Institute Ltd, the Swedish Institute for Infectious Disease Control, the National Veterinary Institute (SVA) and the Swedish University of Agricultural Sciences (SLU).

The form which the institute takes should be investigated. One possibility is to create a ”network institute”. Another option is to take existing activities away from the agencies and institutions concerned completely in order to create a physically/geographically enitrely new organisation.

Climate change in Sweden and the rest of the world, socio-economic effects, adaptation measures and impact on the national economy

The effects of climate change in Sweden can be expected to be significant. On a global scale, however, the situation looks even more serious, with the risk of large agricultural areas being wiped out, flooding of coastal areas and migrations of populations. Climate change will also have direct effects and socio-economic effects in other countries, regions and sectors. These effects will have repercussions for development in Sweden and for the need for adaptation in the country.

We consider these issues to be crucial areas for research.
They relate closely to the research initiative recently taken by the Foundation for Strategic Environmental Research (Mistra), for instance with the creation of the Stockholm Resilience Centre and the research programme Swecia.

Proposals

- A new institute for climate research and adaptation should be established. The form which the institute takes should be studied more closely.
- SEK 100 million per year should be provided for the research brought together in the new institute.

2 The assignment and background

2.1 The assignment, scope and approach

2.1.1 Background

The climate issue has been high on the agenda both nationally and internationally since the early 1990s. The UN Intergovernmental Panel on Climate Change (IPCC) published its first report in 1990, clearly setting out the risk of large-scale changes across the globe, driven by the increasing emissions of greenhouse gases. Since that time, the focus of political efforts internationally and nationally has been on limiting these emissions. The UN Framework Convention on Climate Change was drawn up in 1992 and Sweden introduced a carbon dioxide tax at around the same time.

The pace of progress has been rapid since then. The field of climate research has seen developments in tools and knowledge, and in 2007, the IPCC produces its fourth report. The overall picture is largely the same as it was 15 years ago, but the conclusions are now considerably more reliable, and our understanding of the threat has been strengthened.

A great deal has also happened in the political arena, although a great deal remains to be done before we achieve a global consensus that is sufficiently strong. Internationally, the Kyoto Protocol was agreed in 1997. The protocol entered into force in 2005 and the first commitment period starts next year, in 2008. International climate work is now concentrating on getting the US, China, India and developing countries to adopt the emission limits. The EU is seeing the issue of climate change increasingly taking centre stage, and has itself adopted an objective of limiting global warming to no more than 2° Celsius above pre-industrial temperatures. Swedish climate work has also developed, with a national objective in force to cut emissions by 4 percent from 1990 levels to the average for the period 2008–2012.

Quite rightly, the main focus has been on limiting the increasing emissions. There is now a better understanding of the inertia in the climate system. Changes in climate over the next 30–40 years will be due in large part to historical emissions. Different future patterns of emissions will only have a minor impact on global warming over this period. However, emissions today and over the coming decades will determine the scale of climate change in the second half of this century.

This means that Sweden, like other countries, has to adapt to climate change that is already underway. We can now see that global anthropogenic warming has been happening since at least the mid-20th century and will become widespread and probably dramatic in the coming century. It is therefore natural for efforts to cut emissions to be supplemented with strategies for adapting society and reducing vulnerability to climate change.

As the long-term change in climate described above has continued, vulnerability to extreme weather events has become apparent. In recent years, a number of floods and storms have had a major impact on Sweden, see section 3.2. These weather events are not necessarily linked to climate change. Only in the future, once statistical material over a prolonged period is available, will it be possible to establish a link. However, climate scenarios do show an increase in extreme precipitation and high temperatures. A reduction in vulnerability to extreme weather events is therefore important in terms of the current situation and ongoing and future climate change.

2.1.2 The commission's terms of reference

The commission's terms of reference were decided on 30 June 2005, see Annex A 1. A summary of these terms of reference follows below.

Summary of the assignment

As a Special Investigator, the chairman of the commission is to examine Swedish society's vulnerability to global climate change and the regional and local consequences of these changes, and to assess the cost of any damage which climate change may cause. The chairman is *to propose measures to reduce society's vulnerability both to successive climate change and individual extreme weather events, and to report on whether there is a need for different information and improved preparedness within the relevant agencies. Of special interest is the impact of climate change on infrastructure, e.g. roads, railways, telecommunications, the built environment, energy production and electricity supply, agriculture, fishing and forestry, water supply and sewerage systems, and on human health and biodiversity. The need to adapt to the expected climate change and economic effects on society and various industries is to be reported based on possible scenarios.*

In order to access as broad a source of experience and expertise as possible, the chairman is to consult the relevant players, including agencies, municipalities, business, scientific institutions and individual organisations. The chairman shall also review the overall need for research with regard to society's vulnerability to and preparedness for climate change. Experience from other countries working on the vulnerability issue is to be taken into account.

A report on flood risk and drainage options for lakes Mälaren, Hjälmaren, Vänern and other areas where the consequences of flooding would be major is to be submitted to the government by 1 June 2006 (through supplementary terms of reference amended to 1 November 2006).

A final report is to be submitted by 1 October 2007.

2.1.3 Scope

The core assignment of the commission is to examine society's vulnerability to extreme weather events and long-term climate change, and to assess the need for various sectors of society to adapt to a changed climate. We have interpreted the assignment such that it applies to extreme weather events in our current climate, as well as changes to the intensity and frequency of these in a changed climate. In addition to this, we are to consider ongoing climate change as it may affect, for instance, conditions of ecosystems, agriculture, fishing and forestry or the spread of parasites and diseases. We have concentrated on the direct effects within the country. We only deal very generally with indirect effects of climate change in other countries, which may change conditions for production in various parts of the world, and the impact of this on Swedish industries such as agriculture, forestry and tourism, and more broadly on changed competitive conditions. Similarly, we have decided that the consequences of human migration and the potential increase in immigration pressure as a consequence of changed living conditions in other countries lie outside the remit of this commission. However, in section 4.7 we give an overview of the potential impact of indirect effects.

Under our terms of reference, we are to report on how preventive measures against natural disasters are handled. Specifically, we are to suggest how the system of government grants for preventive measures relating to flooding, landslides and erosion can be made more effective. We are also to survey the key players and, if necessary, propose organisational changes or clearer agency responsibility. In addition, we are to identify any organisational deficiencies in terms of responsibility for preparedness for extreme weather events and for adapting to a changed climate. It is our understanding of the commission's terms of reference that we are to examine organisation and responsibility with regard to preventive work. However, we will not be handling crisis management issues, such as organisation and management in an emergency situation.

In our work, we have focused on tasks for the public sector. This does not mean that industry and business have no need to take any measures as a consequence of a changed climate. Such measures will come about primarily through internal decisions within the private sector. The main task of society is to provide information in order to promote such measures, and to increase knowledge about climate change through research. The task of society is also to ensure that fundamental functions are maintained and that potential for development is identified. Collaboration between the private sector, municipalities and the state is vital. Measures in the private sector are needed to maintain public safety, for example where there is a risk of flooding and landslides.

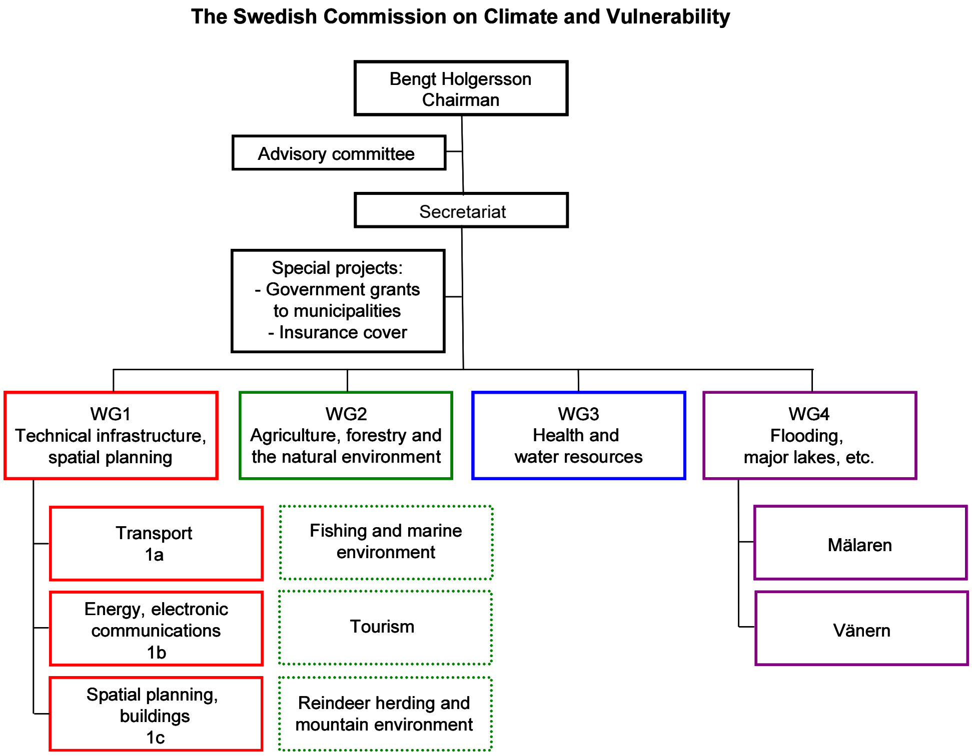
2.1.4 Approach and methodology

In line with our terms of reference, we have based our work on the assessment of global climate change made by the UN's climate change panel, the IPCC.

In order to highlight vulnerability in a future climate, we are using a number of global scenarios for climate change. These comprise two global climate models and two global emissions scenarios from the IPCC. Based on these four scenarios, the Rossby Centre at the Swedish Meteorological and Hydrological Institute (SMHI) has made calculations using its regional models. In consultation with the commission and various sectors, SMHI has developed around 40 specific climate indices as the foundation for assessing the future vulnerability of the sectors. A total of over 10,000 climate maps showing the development of the indices have been drawn up. The calculations have been made for various timeframes – 2020s, 2050s and 2080s. Data has also been produced for the trend over the past 15 years. We have constantly compared the future climate with the most recent complete reference period used in climatological contexts (1961–1990).

The point of departure for assessing vulnerability was the sector- or area-specific analyses. These were carried out within three main working groups, plus subgroups to these. The main working groups were: Technical infrastructure, spatial planning and buildings; Agriculture, forestry and the natural environment; Health and water resources. The working groups included participants with expert knowledge from central and regional agencies, municipalities, businesses and organisations as well as research institutions. In addition to the work of the working groups, areas such as increasing the effectiveness of government grants for preventive measures and assessing the need to strengthen insurance cover for specific groups were examined separately.

Figure 2.1 Organisational chart for the Swedish Commission on Climate and Vulnerability



A total of over 50 experts took part in the various working groups, with many also receiving support from their organisations and consultants. Many more took part in the various seminars held by the commission. A great deal of work went into compiling broad raw data from relevant sectors of society as the basis for the analyses. The work carried out by the working groups is, to a large extent, pioneering.

An advisory committee set up by the government provided its comments primarily on conclusions and proposals. The committee comprised representatives of central and regional agencies, municipalities, the business world, research institutions and several ministries. See Annex A 3.

Methodology

The work of the commission is based on vulnerability analyses, in part within sectors, and in part with a focus on specific consequences of climate change which affect multiple sectors. Vulnerability analysis comprises three parts: causes, systems/problem areas and consequences. Various input values and parameters have a major impact on the analysis. Once the vulnerability analysis is completed, assessments can be made of measures and costs.

The commission had four guiding input values set out in its terms of reference: long-term climate change and extreme weather events; regional climate scenarios from the Rossby Centre; timeframes of short, medium and long term plus a large number of social systems and the natural environment.

The first part of the vulnerability analysis, “causes”, comprises various important and guiding factors relevant to the problem, in our case the climatic factors which are considered important for the various sectors and problem areas. It was important to highlight the timeframe, and the intensity, duration, frequency, seasonal variations and monthly variations of the factors.

The second part, “systems/problem areas”, involves the vital, sensitive elements or characteristics which illustrate relevant systems/problem areas and which are crucial to their function. They constitute specific system types or correlations, possible facility level, geographical aspects, lifetime, development, setup time, redundancy and dependence on other systems/areas.

The third part, “consequences”, may be of a varied nature, direct for the system/problem area, indirect for society, positive, negative, acceptable or unacceptable. The seriousness of the consequences is important.

Vulnerability analyses can be carried out using various methods. The choice of method depends on factors such as the purpose, complexity and size of the problem. According to its terms of reference, the commission was to apply a scenario technique. We chose to carry out the analyses in partnership with representatives of a large number of sectors, in order to be able to assess vulnerability in a future climate with greater certainty. The scenario technique has also been supplemented with case studies, which have above all examined past extreme events.

In our work on the vulnerability analyses, we drew up a number of analysis questions which apply to the various systems/problem areas, see Annex A 4.

With the chosen methodology, the vulnerability analyses in each sector/problem area (see chapter 4) are largely presented in the following way:

- system/problem area description,
- vulnerability today, incl. consideration of past extreme weather events and sensitive climate factors,
- consequences of future climate change and extreme events, plus cost of damage,
- adaptation measures including costs and
- research needs.

The terms of reference place strong emphasis on assessing the cost. However, we wish to point out the methodological problems of making cost assessments regarding the impact of climate change in the long term. In order to assess future costs, an assessment first has to be made of what typical social and economic developments will take place in the coming century. This is problematic, since long-term economic analyses for Sweden lack such an extended perspective. The long-range assessments of the Swedish National Institute of Economic Research take us to 2030 at the most. An assessment of the costs that may be generated by climate change – for adaptation measures and the marginal benefit of any measures – requires a forecast of future effects deriving from a changed climate. In many cases, the effects and costs of damage, and of any adaptation measures, are difficult to quantify. This applies to effects arising from changes in society and ecosystems. We have also had difficulty compiling complete data for costs split into the short, medium and long term. We have therefore only made general assessments of costs in the short and medium-term.

The cost assessments we report here are therefore naturally uncertain and to some extent incomplete. They do however give an indication of magnitude from a long-term perspective.

2.2 International work

2.2.1 Global climate collaboration

The Climate Change Convention and the Kyoto Protocol

The UN Framework Convention on Climate Change (The Climate Change Convention) and the Kyoto Protocol together constitute an international response to the threat posed by climate change. The Climate Change Convention, which was opened for signature as part of the Rio Summit in 1992, forms the basis for international cooperation on climate change. By April 2007, 195 countries were signatories to the convention (UNFCCC, 2007).

The ultimate objective of the Climate Change Convention is to stabilise greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. The convention also sets out a number of key principles for international climate work. According to these, the Parties should protect the climate system for the benefit of present and future generations of humankind, on the basis of equity and in accordance with their common but differentiated responsibilities and respective capabilities. It falls on the industrialised countries to take the lead in this work. The convention does not contain any concrete and binding emission limits for individual countries.

The convention's first Conference of the Parties in Berlin in 1995 started a process to draw up a legally binding document with clear commitments from the industrialised countries. The extensive negotiations resulted in the Kyoto Protocol of 1997, which contains binding, quantifiable commitments from the industrialised countries listed in Annex 1 to the Climate Change Convention (the Annex 1 countries) to cut greenhouse gas emissions. Together, the industrial countries undertake to reduce their net emissions of the six most important greenhouse gases by just over five percent, as an average for the years 2008–2012, compared with levels in 1990.

The provisions of the Kyoto Protocol were made more precise and concrete in the agreements reached in Marrakech in 2001, and were adopted in Montreal in 2005. The Kyoto Protocol entered into force on 16 February 2005. Concrete negotiations on commitments beyond 2012 have yet to be carried out.

Activities within the Climate Change Convention concerning vulnerability and adaptation

The Climate Change Convention also contains principles and commitments on cooperation regarding the setup of work on adapting to climate change. According to Article 4.1, the parties to the convention are to take action and cooperate to facilitate adaptation to the impacts of climate change and as far as possible to integrate adaptation measures in the relevant policy areas. According to Article 4.4, the industrial countries (Annex 1 countries) shall also support the developing countries which are most vulnerable to the adverse effects of climate change.

During the first decade of the convention, work has continued on putting these principles into practice, with the focus primarily on supporting the developing countries. For example, the industrialised countries have supported the least developed countries (LDCs) in drawing up *National adaptation programmes of action* (*NAPAs*), based on the countries' own assessment of which activities in societies vulnerable to extreme weather and climate change need to be adapted in the first instance. So far, 13 countries have submitted their NAPAs. These documents are intended to form the basis for aid in this area.

In Marrakech in 2001, the industrialised countries agreed to finance four funds from which the developing countries can seek aid for their climate work. One of these specifically focuses on adaptation to climate change. The fund is financed through fees for CDM (Clean Development Mechanism) projects under the Kyoto Protocol, and it is thought that it will become the largest fund with secure finance. Work on making the fund operational has not yet been completed. Several of the other funds may also be used, to a certain extent, to fund adaptation measures.

Another significant initiative aimed at facilitating the work of assessing vulnerability and planning adaptation measures is the compilation of a handbook of methods and tools. The Climate Change Convention's secretariat published its first such handbook, *Compendium of Decision Tools to Evaluate Strategies for Adaptation to Climate Change*, in 1999. It is regularly updated.

The five-year programme of work

In 2005, the parties agreed a five-year programme of work on adaptation measures within the framework of the Climate Change Convention. The objective of the programme is to assist the parties to improve their understanding and assessment of the impacts of climate change and vulnerability, and to make informed decisions on practical adaptation measures. The programme of work has two thematic areas:

- Impacts and vulnerability
- Adaptation planning, measures and actions

The programme is designed to develop methodologies, increase understanding of and access to climate data, modelling results, and socio-economic information and to create and disseminate tools and information for planning and implementing adaptation measures. There is also a focus on facilitating research in the field and disseminating technology and knowledge relating to adaptation strategies and measures, including those aimed at diversifying vulnerable economies and sectors. The programme is to be implemented through work under the auspices of the convention, including special workshops, reports and web-based information. Implementation commenced in 2006 and in Nairobi in November 2006, the Conference of the Parties to the Climate Change Convention adopted the *Nairobi work programme on impacts, vulnerability and adaptation to climate change*, which provides a more detailed plan for the continued work on implementing the first thematic area of the programme. Discussions on the content of the second thematic area are due to begin in spring 2008.

Issues of adaptation are expected to be a key element in any agreement on a future climate regime. However, it is too early to say just what role they will play.

IPCC provides scientific basis

In 1988, the United Nations Environment Programme (UNEP) and the World Meteorological Organization (WMO) set up the UN's Intergovernmental Panel on Climate Change (IPCC). The role of the IPCC was to assess the scientific information available on climate change. The IPCC published its first assessment of the climate change issue in 1990. The report formed an important basis for the Climate Change Convention. The IPCC brings together several thousand researchers from around the world, and its most important task is to make regular assessments of where science stands on the issue of climate change. These assessments constitute a generally accepted scientific basis for the activities within the Climate Change Convention. The assessments are split into three parts, with the first addressing the science on the climate system, the second focusing on vulnerability and adaptation, and the third looking at possible measures for and methods of cutting emissions of greenhouse gases. The IPCC also produces summaries that are more accessible to the general public. The third assessment report was published in 2001 and the various sections of the fourth report have been – or will be – published in 2007, see also Section 3.3.

2.2.2 The EU's work

ECCP2

In autumn 2005, the European Commission launched the Second European Climate Change Programme (ECCP II). ECCP II is the Commission's main instrument for preparing and developing existing policies on climate, as well as investigating and developing new policy areas. Measures within ECCP II are intended to complement the member states' own packages of measures. ECCP II is split into a number of working groups, one of which focuses on adaptation. The working group is looking into the need for and possibility of drawing up a strategy for adaptation to climate change at EU level. In 2006, the working group held working meetings in ten different sectoral groups. The reports from these meetings formed the basis for the Green Paper on Adaptation that was presented in summer 2007.

The European Commission's Green Paper

The Green Paper *Adapting to climate change in Europe – options for EU action* was launched on 3 July 2007, and is intended to be followed by a White Paper some time in 2008. The Green Paper highlights Scandinavia as one of the most vulnerable areas, due to the expected increase in precipitation. Adaptation measures at EU level are motivated by the fact that climate change does not take into account national borders and therefore cross-border adaptation measures may be more effective than strictly national ones. The Green Paper suggests that, within the framework of the EU work, action should be considered in four areas:

1. Early action in the EU. In areas where sufficient knowledge already exists, adaptation strategies should be developed to ensure optimum allocation of resources.
   - Integrate adaptation when implementing and modifying existing and forthcoming legislation and policies (e.g. in conjunction with the review of the EU's agricultural policy in 2008).
   - Integrate adaptation into existing Community funding programmes (e.g. the Cohesion Fund, the Regional Development Fund, pre-accession instruments, the Trans-European Networks Programme and infrastructure measures under the Rural Development Fund, the European Social Fund, the Fisheries Structural Fund).
   - Develop new policy responses (e.g. an assessment of the risk structure of existing public and private natural disaster funds)

2. Integrating adaptation into EU external actions. The EU must focus on impacts and adaptations in the wider world and build new alliances with partners around the world, particularly in developing countries.
   - Adaptation to climate change is a cross-border phenomenon, which is why it has to be integrated into external relations, e.g. through EU Common Foreign and Security Policy (CFSP), strategies for poverty reduction (i.e. Poverty Reduction Strategy Paper, PRSP) and the European Neighbourhood Policy (ENP). The Green Paper suggests setting up a Global Climate Change Alliance to support the developing countries in their work on adapting to climate change. The Commission has earmarked a total of EUR 50 million over the period 2007–2010 for dialogue activities, and to support developing countries through targeted mitigation and adaptation measures.

3. Reducing uncertainty by expanding the knowledge base through integrated climate research. In areas where there remain gaps in knowledge, research within the EU and exchange of information and preparatory work are to help reduce uncertainties and increase the knowledge base. Work on integrating research results into policy and practical work is to be strengthened.
   - The Green Paper also states that although considerable progress has been made in understanding the earth's climate system, uncertainties remain particularly in relation to more accurate and detailed forecasts as to the impacts of climate change at regional and local levels, and the cost and benefits of adaptation measures for shorter timeframes such as 2020–2030. An integrated, cross-sectoral and holistic approach is to be promoted. The EU's 7th Framework Programme for Research (2007-2013) places a strong emphasis on climate change, both in terms of predictive capacity, modelling and adaptation strategies. Major EU-funded research projects within the 7th Framework Programme which focus on areas such as climate forecasting, impacts and adaptation include ADAM, CIRCLE, ENSEMBLES, PESETA and PRUDENCE. The first round of applications in the environmental field in the 7th Framework Programme are still being evaluated.

4. Involving Europe's society, business and public sector in the preparation of coordinated and comprehensive adaptation strategies.
   - As part of the European Climate Change Programme (ECCP) the Commission will consider the establishment of a European Advisory Group for Adaptation to Climate Change which should operate as a Commission's Expert Group and consist of representative policymakers, leading scientists and civil society organisations. It would comment on the work of a number of specific working groups over a period of 12 months starting in November 2007.

In autumn 2007, a number of regional workshops will be held around Europe in order to bring all the parties involved on board with regard to the Green Paper's proposals. The workshop for northern Europe, the Baltic and the Arctic will be held in Helsinki.

A public web-based consultation on the Green Paper is also ongoing, with interested parties able to make comments and submit suggestions.

The EU's report to the UN Framework Convention on Climate Change (UNFCCC)

Just as every individual country submits national reports (National Communications) in line with the United Nations Framework Convention on Climate Change (UNFCCC), the European Commission also submits a report for the EU as a whole. In its report to the UNFCCC, the European Commission points out that the European Environment Agency (EEA) published its report *Vulnerability and adaptation to climate change in Europe* in 2005 and the report *Impacts of Europe's changing climate* in 2004. These reports provide general analyses of how Europe may be affected by climate change, and what options exist for adapting to climate change.

The EU Floods Directive

On 25 April 2007, the European Parliament and the Council reached a compromise solution on the wording of the EU Directive on the assessment and management of flood risks and it is likely to be formally adopted by the Council in autumn 2007. The Floods Directive largely sets out a requirement that flood risks be surveyed and plans drawn up for measures in sensitive areas. The chosen level of protection is to be decided by the countries themselves. According to the Directive, the work is to be split into three stages. The first stage involves member states carrying out a general assessment of the flood risks in all river basin districts by 2011. The second stage involves mapping out the risk in sensitive areas by 2013. The preparation of flood risk maps is to include the likelihood of high flows and levels, and the potential consequences for selected return periods. In the third stage, flood risk management plans for the chosen level of protection are to be drawn up by 2015. The flood risk management plans are to minimise the risk of flooding and limit any damage. In the case of international river basin districts, the member states are to ensure that flooding problems are not simply passed on to other member states. The programmes are to be totally transparent and available to the public. The plans are to be reviewed every six years. In practice, a great deal of the work covered by the Directive is already underway in Sweden.

The EU Water Framework Directive

The EU Water Framework Directive entered into force in December 2000, with a view to creating a holistic approach to the water resources of Europe and the individual countries not just in theory, but also in everyday practical work. The purpose is to have all the different requirements for water status in one system, and gather together all the various motives for protecting water and water environments. As well as focusing on the quality of the water, the aim is also to ensure the good status of the water environment as a whole (e.g. water-dependent terrestrial ecosystems, wetlands, groundwater and highly productive coastal areas), as many living environments are dependent on a good supply of water and good water quality. Cohesive and wide-ranging water legislation which takes into account the whole picture, together with new ways of working and an organisation based around the river basin districts, is to lead to better coordination of the resources of the EU member states, and correct deficiencies in the management and protection of water. The Directive covers natural lakes and rivers and those heavily affected my man, surface water in estuaries and deltas, groundwater and coastal water. The only water not covered by the Directive is open seas and wetlands, unless these directly affect the surface water. However, the strategy for protecting and preserving the EU's seas is tied up with the work carried out within the framework of the Water Directive. The ultimate objective is good water status, the maintenance and improvement of water quality and no worsening of the situation, plus securing a long-term water supply. This is to have been implemented in all EU countries by December 2015, but under certain circumstances there is scope for different deadlines up to 12 years after that date.

The EU Solidarity Fund

To enable itself to respond in a rapid, efficient and flexible manner to urgent situations, the EU has established a Solidarity Fund. This will intervene mainly in cases of major natural disasters with serious repercussions on living conditions, the natural environment or the economy in one or more regions of a member state or a country applying for accession.

A natural disaster is considered as "major" if:

- in the case of a state, it results in damage estimated either at over EUR 3 billion (2002 prices), or at more than 0.6 percent of its gross national income
- in the case of a region, it results in damage inferior to this threshold, affecting the major part of its population, with serious and lasting repercussions on living conditions and the economic stability of the region

Assistance from the Fund takes the form of a single and global grant, with no necessary co-financing, complementing the public efforts of the beneficiary state. Urgent actions intended to alleviate non-insurable damage are eligible for support from the Fund. Restoration of infrastructure, temporary measures to provide accommodation and rescue services, protection of cultural heritage and cleaning up of disaster-stricken areas are examples of actions eligible for funding. According to Commission practice, a member state can receive a maximum grant equivalent to 2.5 percent of the total direct damage up to the threshold value (0.6 percent of GNI) and 6 percent of the amount that exceeds the threshold. Sweden applied to the Fund as a result of storm Gudrun. The Swedish application put the cost of total direct damage at SEK 20.8 billion or 0.86 percent of GNI. Damage to forests accounted for SEK 15.8 billion of that. On 23 March 2007, the Solidarity Fund paid out SEK 600 million to Sweden for the damage caused by storm Gudrun.

The EU's Community mechanism for assistance interventions

Under Council Decision No 2001/792/EC, the countries of the EU have undertaken to help each other in emergency situations, whether they are natural disasters such as storms and flooding or terrorist attacks. One element of that assistance is the Community mechanism, which is open to all member states of the EU, along with EEA and candidate countries for accession. Countries other than these may also request assistance. If an incident or disaster occurs that is of such magnitude that the affected country's resources are unable to cope, or if the incident risks having cross-border consequences, the affected country can apply for immediate help from other EU countries. The countries and the European Commission have set up special communication channels to make it quick and easy for a country to ask for help. In the event of assistance being provided, the affected country is liable for the costs, unless the assisting countries choose to waive payment. A range of resources and functions have been put in place to ensure that the Community mechanism can function:

- A Monitoring and Information Centre (MIC).
- A Common Emergency Communication and Information System (CECIS).
- A database of available teams, experts and other resources made available by the countries. These may be anything from chainsaws and firefighting aircraft to manpower.

Based in the European Commission, MIC is the operational heart of the mechanism, receiving information and requesting help from member states, expanding the request to other countries and informing the affected country of the help that is available. The Swedish Rescue Services Agency is Sweden's point of contact for the Community mechanism. In the event of a major incident or disaster in Sweden, this agency will request help from MIC, which in turn will get in touch with the contacts in the other countries.

For the first time in Sweden's history, a request for help was issued after storm Gudrun in January 2005. On the evening of 1 February, a request was sent to MIC, with Sweden seeking help in the form of residential electricity generating equipment, and by the following day several countries had offered assistance. Of the many countries able to provide help, Sweden chose to accept the Czech Republic and Germany's offer of generating equipment.

Early warning systems

The European Commission also manages two early warning systems for weather-related natural disasters: EFAS (European Flood Alert System) and EFFIS (European Forest Fire Information System), both of which were developed by the Joint Research Centre. EUMETNET, the Network of European Meteorological Services, which does not fall under EU control, has developed METEOALARM. The website *www.meteoalarm.eu* summarises and presents all the important weather warnings issued by the national meteorology services.

2.2.3 Adaptation work in other countries

According to its terms of reference, the Swedish Commission on Climate and Vulnerability is to examine equivalent work and describe how some of the countries which bear comparison with Sweden are handling the issue of society's vulnerability and preventive measures, plus the existence of any state aid for such measures.

Below is a broad summary of how other countries are tackling adaptation to climate change and preparedness for extreme weather events. Bearing in mind the enormous amount of material available, only adaptation measures of particular relevance to the commission's work are presented. For a more extensive report, see Annex B 35.

According to the OECD, two types of measures to adapt to climate change are discernable: 1) general, broad, institutional measures which lay the foundation for adaptation in a range of different decision-making and sectoral areas, 2) specific measures at a policy or project level (OECD, 2006).

Climate change adaptation strategies

Finland's national strategy for adapting to climate change was published in 2005 and aims to reduce the cost to society of global warming. The Finnish Ministry of Agriculture and Forestry (in partnership with other ministries and the research project FINADAPT) was the coordinating ministry in drawing up Finland's adaptation strategy. As there was no requirement to present an exact timetable for any proposed measures, or to suggest how proposed measures are to be financed, the term strategy is used, rather than programme. The strategy attempts to outline the future challenges up until 2080 using long-term climate scenarios, scenarios describing economic development and an overview of natural ecosystems. The objectives of the national strategy for adaptation to climate change are to strengthen and increase Finland's ability to adapt. The public administration has central control functions in terms of climate change preparedness and various administrative functions have started implementing the adaptation strategy. A large number of players and interest groups are working with the public administration to adapt Finnish society to climate change.

In **the UK**, Defra (the Department for Environment, Food and Rural Affairs) introduced a special programme called the UK Climate Impacts Programme (UKCIP) in 1997, aimed at coordinating research into the effects of climate change at a regional and national level. UKCIP is based at the University of Oxford and is funded by Defra. UKCIP works with the Met Office's Hadley Centre for Climate Prediction and Research, the UK's official centre for such work. UKCIP is intended to bridge the gap between researchers and decision-makers in government and private enterprise and to help organisations and companies to assess how they may be affected by climate change, so that they can prepare themselves in good time. Defra works with UKCIP to draw up national strategies for adapting to climate change – including capacity expansion, research, concrete tools and exchange of experience between different interested parties. The Hadley Centre analyses climate systems and develops models for predicting climate change. UKCIP packages this information and makes it of practical use to local and regional authorities in their adaptation work.

The various operational tools and data offered by UKCIP to help these authorities to develop adaptation strategies include:

- Socio-economic scenarios that allow local authorities to assess and analyse how climate change will affect their regions. The scenarios are tailored to the various regions of the UK.
- A methodology for estimating the cost to society of climate change. A method has been developed to work out the costs of climate change impacts on an organisation, an event or an area.

- A database of all the adaptation work in the UK. The database contains information showing how organisations and sectors in the UK are adapting to climate change.
- Guidance on the identification and selection of adaptation options that can be used to reduce vulnerability to climate risks.

The British government has chosen not to prescribe detailed measures, as the needs shift between different regions and over time. The government sees its main role as encouraging early assessment of the risks of climate change at a local and regional level. The subsidiarity principle is considered to apply, i.e. the work should be carried out at the most suitable level. A large part of the climate change adaptation work is carried out in Regional Climate Change Partnerships, which involve a number of different participants. Their task includes increasing awareness at regional and local level. They are funded in part by the UK's Environment Agency.

At the end of 2007, the British government intends to present the *Adaptation Policy Framework, APF,* outlining measures for a sustainable adaptation policy. The following measures are expected to be proposed:

- Cross-sectoral work within the Cabinet Office to enable joint decisions to be taken on how state property and buildings are to be adapted and protected (not least within the Ministry of Defence, which has a considerable land and property portfolio).
- Protection of key infrastructure, incl. an overhaul of the rail network, which is susceptible to higher temperatures.
- Increase preparedness for flooding and landslides, incl. an overhaul of the rail network.
- Protection and better use of natural resources. The functions of the ecosystem, e.g. water absorption, could be better exploited.

France is currently drawing up a national adaptation strategy (*Plan national d'adaptation au changement climatique*) aimed at reducing vulnerability and preparing society for the consequences of climate change. The strategy is based on a comprehensive investigation by the French commission/expert group ONERC (*l'Observatoire national sur les effets du réchauffement climatique*) from 2006. The strategy appears as an annex to the assessment of the Climate Plan 2004–2012, which was published at the end of last year. An operational adaptation plan was to have been drawn up by summer

2007, but it has been delayed. The objective of the strategy is to protect people and property, integrate the social aspects of the climate change issue, limit the cost to society and safeguard natural resources. Society is to be adapted to climate change through research, observation, information and education. Information campaigns targeting citizens and elected representatives will be carried out in the future. The French government is keen to integrate the local and regional level in the plan as that is where the best knowledge lies regarding infrastructure and buildings, for example. The local level is being tackled through improved dialogue on the impacts/risks of climate change, costs that may arise locally, vulnerability, etc.

The adaptation plan will focus on:

- Agriculture: Adaptation of land, crops and water resources is necessary to cope with climate change.
- Energy and industry: Increased temperatures and lower precipitation are predicted to increase demand for electricity (for air conditioning). Availability of hydroelectric power is forecast to fall due to lower quantities of meltwater from snow.
- Transport, housing: Flooding may affect road and ferry traffic in the future. The cost of road maintenance is expected to increase. The vulnerability of the major cities to climate change will be investigated in more detail. Disasters due to heatwaves must be avoided
- Tourism: The French tourism regions must adapt what they offer due to climate change.
- Banks and insurance companies: Better collaboration between banks and insurance companies is desirable.
- The non-European territories (Guadeloupe, Guyana, Martinique, Réunion) are to be prepared for extreme weather conditions and the impacts of climate change.

From 2008, the French government will include in its budget a report on the measures being carried out by government and its ministries in the climate change field (*document de politique transversale*). The plan, which is primarily aimed at Parliament and the Senate, is a way to make climate change policy more visible and transparent, and is intended to help improve consensus across the political board and make for more efficient use of public resources.

The French government's spending on climate change issues is estimated at over EUR 2 billion per year.

The Netherlands is working on its national programme *Adaptation, Spatial Planning and Climate* (ARK). The programme under development will help to create a consensus on the effects of climate change and propose concrete adaptation measures.

The work will be made up of three pillars, in three phases:

1. raising national awareness, forming networks, developing a strategy.
2. increasing knowledge and developing a consensus on the risks and division of responsibility.
3. developing instruments and regulations, stimulating innovation in the short and long term.

A *National Adaptation Strategy* and a *National Agenda* are to be drawn up in the first phase. This phase is a case of defining what has to be done and when, and will involve working on the three pillars in parallel. Seminars with regional and local authorities, business and NGOs will be held with a view to raising the general level of knowledge surrounding the problem. The second pillar involves identifying the Netherlands' climate development today and identifying the gaps in knowledge that need filling. Alternatives for action in the short term (up to 10 years), medium term (10–20 years) and long term (after 2025) are to be identified and analysed. The third pillar covers analysis of necessary investment decisions, the longer economic perspective and administrative issues. The work is to be led by a steering committee comprising representatives at the level of director from the agriculture, transport, water, economic affairs and environment ministries. These will also work with various organisations, companies, interest groups, etc. Above all, the "planning agencies" (institutions which are publicly funded but politically independent and which carry out analysis work in a range of specialist areas) are to be involved. As well as the steering committee, a programme team will be set up, comprising 6–8 staff from each relevant ministry, the unions, the social insurance office, and a group called "Routeplanner". Routeplanner is a group of scientists who have studied climate change. The whole organisation is led by the Ministry of Housing, Spatial Planning and the Environment. The first phase of ARK (2006 – to early 2007) has a budget of EUR 800,000.

EUR 800,000 has also been earmarked for phase two, to be started in 2007. No funding has yet been allocated for the third phase (2008–2014).

The expected effects of climate change on Danish society have been investigated and assessed a number of times since 1988, most recently in the *Danish EPA report of 2004: Adapting to Climate Change.* The general conclusion is that **Denmark** will not be particularly badly affected by climate change, based on the more moderate climate scenarios, and that suitable ad hoc measures are sufficient to protect society. In October 2005, the Danish government initiated preparations to tackle the primary effects of climate change. The aim is, based on three possible future climate scenarios, to catalogue predicted consequences and how to deal with them. Since 2005, the Danish Emergency management Agency has been publishing its *National Vulnerability Report,* which aims to promote a culture of preparedness in the public and private arenas. The report presents the most significant incidents of the previous year and what measures have been taken.

In the view of the Ministry of the Environment in **Norway**, there is no coordinated responsibility for what measures should be taken to adapt society to ongoing climate change. Coordination work led by the Ministry of the Environment and the Ministry of Justice is, however, expected to commence once the government has given the official go-ahead. The Norwegian government intends to set up a steering committee to deal with the issue in spring 2007. The middle of 2006 saw the publication of a written follow-up to the seminar *Report on vulnerability and adaptation to climate change in sectors in Norway,* in which a large number of ministries took part. This can be considered the first step towards a national adaptation strategy. All the participating ministries were urged to make an assessment of their own sectors' vulnerability to climate change. The report stresses the importance of better coordination and a flow of information that works both horizontally and vertically.

Protection against extreme weather events

A key political area in **the Netherlands** is water management, and perhaps above all protection against flooding. Major floods have occurred several times in the history of the Netherlands, although now the country is effectively protected against the threat from the sea due to massive sluices. The floods suffered by the Netherlands in the 1990s were, almost without exception, related to abnormally high flows in the many rivers. Climate change is expected to increase the risk of flooding in the future. In 2003, a national management agreement on water (NBW) was drawn up between the state, the provinces, the municipalities and the water boards, producing a joint plan for future water management, primarily to combat the effects of climate change. In the first instance, the NBW covers the period until 2015, but it also focuses as far into the future as 2050. It is estimated that the total cost of expansion and maintenance during the period 2003–2050 will amount to around EUR 16 billion. Work is currently underway to replace eight legislative acts relating mainly to water management with one single Water Act (*Waterwet*). The act is to bring about a clearer focus on the central objectives, improve cooperation between the relevant public agencies and reduce the administrative burden for those who use water. The idea is that water issues are not to be treated as a number of independent issues, but as a whole, while at the same time integrating them into environmental policy and spatial planning, for example. The basic political stance on flood prevention has changed in recent years. A new policy has been developed, called "More Room for Water". The idea is that water has to be able to take back part of the land that has been reclaimed, at least temporarily during periods of high flood risk. Creating areas which can be submerged under water reduces the risk of dams bursting in other places. There will also be "disaster zones" which can be allowed to be flooded under extreme conditions. Another example of how to give water more room is the widening of the river beds. Dutch knowledge of water, and in particular flood prevention, is increasingly being considered a product for export. The industry body Netherlands Water Partnership (NWP) has been created by private and public players to promote this Dutch export, as well as international collaboration. The most prominent example in this area is the contact which the Dutch have had with Louisiana since the flooding of New Orleans.

In **Italy**, the Department of Civil Protection (*Dipartimento di Protezione Civile*) has noted an increase in extreme weather situations, primarily in the form of: heatwaves, drought, flooding and forest fires. Since 2003, a national network has been in place to protect the population against the negative health effects of heat waves. Protezione Civile coordinates and allocates resources using a central database, monitoring, forecasts and observation stations, and work is underway to draw up action plans tailored to specific regions and cities. Every day in Rome, during the summer, a temperature bulletin is compiled. If three days of extreme heat occur, a raft of measures from regions and municipalities is set in motion. These may include issuing warnings to the public, increasing the number of hospital beds and admitting old people to care facilities as a preventive measure. A higher frequency of dry periods is a phenomenon already well established. The economic damage to agriculture, particularly in the Po valley with its extensive irrigation, may become considerable. Legal instruments for water rationing already exist and can be put into action at short notice, as happened during the heatwave of 2003. Alongside the increasingly common dry periods, there has been an increased frequency of flooding. This also occurs much more quickly in the Mediterranean than in northern Europe ("Fast floods"). It is estimated that 60 percent of the country is at risk of flooding. Recently, EUR 150 million was allocated at national level for preventive investment (plus 50 million for maintenance of existing protection). Major funding has also been put into increasing the capacity to combat forest fires. For example, Italy has Europe's largest fleet of aircraft and helicopters, and has on several occasions loaned out its planes to France and Spain. The high level of preparedness requires significant resources, but has shown good results: the year 2000 saw 6,600 fires destroy 58,000 hectares of forest, while almost the same number of fires in 2006 only destroyed 16,000 hectares. Protezione Civile considers itself to have a successful organisation with a high level of preparedness and great capacity to handle the effects of climate change. Adaptations to the higher temperatures have already been introduced. There is therefore no reason to expect any organisational changes due to climate change.

In **France**, the Ministry for the Environment is responsible for preventing natural disasters and reducing society's vulnerability. Policy focuses on improving citizens' knowledge of the risks, organising monitoring and adopting regulations and crisis management plans. The prevention of risks is largely a question of information measures to which French citizens are entitled under a law from 1987. Since 1995, the *départements* (the 96 counties of France) and the municipalities in vulnerable areas have been responsible, by law, for drawing up regional crisis management plans (*Plans de prévision des risques naturelles, PPR*) aimed at protecting society against extreme weather conditions (flooding, avalanches, forest fires, etc.). The objective of this system is to gain greater knowledge of the phenomena, set up some form of monitoring, inform citizens of the risks and how they can protect themselves, etc. The crisis management plans are partly funded by the state, which in the past 10 years is said to have contributed over EUR 800 million for this purpose. The heatwave of 2003, which resulted in a large number of deaths in France, led to the French Ministry for Health, Youth and Sport drawing up a national plan to prepare against heatwaves. The plan is to be implemented at local level and in a number of cities, and is based on four information/warning levels (from increased forecasting to active measures). Hospitals and old people's homes are to be equipped with air-conditioned sections and to have higher staffing levels, corresponding to 13,200 new posts by 2007.

The UK has developed, and is continuing to develop, a Flood Risk Management Plan looking at how the Thames Barrier flood defences may be adapted to account for a changed climate. UKCIP's scenarios and HadCM2 modelling suggest that a 20 percent increase in peak flows is likely in the future. A clause on consideration for climate change has been introduced into the UK's Building Regulations, and Planning Policy Guidance has been drawn up to provide guidelines for building in areas susceptible to flooding.

Germany has had a national warning system for heatwaves in place since 2005, managed by Germany's National Meteorological Service (*Deutscher Wetterdienst, DWD*). The warning system reacts when certain thresholds, depending on the region, are exceeded, issuing warnings to the public, the public sector and the health service. The federal state of Hessen has worked with DWD to develop its own local weather warning system. A rise in sea level of 25–30 cm is taken into account in the state of Mecklenburg-Vorpommern when building coastal defences, while in Lower Saxony the figure is 60 cm. Following studies of climate scenarios showing that the risk of flooding will increase by 2050, the states of Bavaria and Baden-Württemberg have stated that, when building new flood defences, peak flows 15–40 percent higher than today are to be taken into account.

The city of Toronto in **Canada** has implemented warning systems for heatwaves and for cold spells (the Health Alert and

Emergency Response System and the Cold Weather Alert System). The warning systems are intended to warn the city's most vulnerable population groups (children, the elderly, the sick and the poor) of impending danger through: warnings in the media, distribution of water in the summer, distribution of hot food in the winter and the issuing of public transport tokens to those who need to make their way to air-conditioned centres. 2007 will see publication of the study *National Climate Change and Health Vulnerability*, which maps out how Canada's public health will be affected by climate change.

Finland is trying to avoid flood damage by taking account of flood risks at the planning stage of new developments. Interested parties can contact the West Finland Regional Environment Centre for an opinion on the lowest recommended height for building.

Many countries with territory in the Alps have drawn up programmes for preventing natural disasters and extreme weather events, e.g. PLANAT (Switzerland), FeWIS (Germany) and Mapping of Hazard Zones (Austria). There is also a cross-border framework for cooperation, the Alpine Convention Framework. The countries of the alpine region have been working on measures aimed at reducing the damage from torrential rain, flash flooding, avalanches and similar events for over a hundred years. **Austria**, which was hard hit by flooding in 2002 and 2005, has launched the project *FLOODRISK,* which studies the consequences of flooding and proposes preventive measures for reducing vulnerability. An *Action plan for flood defences – water development until 2015*, which proposes action programmes in the medium term, and a priority list for the successful control of flooding have been drawn up. The Forest Engineering Service in Torrent and Avalanche Control works to protect the population, society and cultural areas from torrential flooding, avalanches and erosion. The agency applies biological and technical solutions and approaches. Forests provide natural protection against torrential flooding, avalanches and erosion, and around 20 percent of all the forest in Austria has some form or protective function. In 2002, the *Austrian Protection Forest Strategy* was published, setting out the future of the forest and its protective function, and how to keep any beneficial properties intact through forestry. Already, 75 percent of all the municipalities in Austria are in the risk zone for landslides and erosion, flooding and/or avalanches, and the risks will increase with climate change. The Forest Engineering Service in Torrent and Avalanche

Control is therefore working to prepare and assess the production of “hazard zone maps”, with almost the whole of Austria now mapped. Although they are not legally obliged to follow these maps, they are used by the *Länder* (regions) and the construction sector, as the basis for drawing up outline and detailed plans. In 2005, Austria spent a total of EUR 122 million on preventive measures against torrential flooding, avalanches and erosion, with the federal government providing EUR 69 million of that.

Insurance against natural disasters (property insurance)

Table 2.1 Compensation in the event of a natural disaster

Countries without state insurance provision	Countries with state guarantees	Countries where systems are under development
Austria	Denmark	Finland
Germany	France	
Greece	Norway	
Italy	Spain	
Netherlands	Switzerland	
Sweden		
Turkey		
UK		

Source: European Insurance and Reinsurance Federation (CEA), 2005.

In **Norway**, there is a twofold financial compensation system for natural disasters, split between the private and public sectors. The body responsible for meeting losses depends on whether the damage was insurable. Losses due to a natural disaster are generally paid for through the Norwegian Natural Perils Pool, an association of Norwegian insurance companies. Under the Norwegian Act on Natural Damage Insurance, buildings and belongings covered by fire insurance are also covered against losses due to natural disasters. The Natural Perils Pool is organised as a distribution pool, which means that each insurance company is responsible for its own customers, with the pool then redistributing the member companies’ costs across all pool members in proportion to how many fire insurance policies each insurance company has issued. Property that cannot be insured on the private insurance market may be covered through the state's natural damage fund via the Norwegian National Fund for Natural Disaster Assistance, the public body for covering losses due to natural disasters. In an average year, the Natural Perils Pool pays out between NOK 100 million and NOK 200 million in compensation for losses due to natural disasters. Pay-outs from the Norwegian National Fund for Natural Disaster Assistance are considerably lower, at a few million Norwegian *kroner* per year.

The UK has a market-based system with no state involvement. It is standard for property insurance, private and commercial, to provide cover against storms, hail, snow damage, avalanches, flooding, earthquakes and frost. Protection against subsidence is not as common. The insurance companies have come to an agreement with the government that they will continue to insure all areas, on the understanding that the government will take certain preventive measures, for example building flood defences. On the question of consequences of major climate-related events, e.g. flooding, Defra has suggested that compensation could be made available via a crisis fund. However, the role of the government is considered, first and foremost, to be one of encouraging adaptation measures and carrying out risk prevention work at local and regional level. The insurance industry is working on trying to manage the new risks of climate change by integrating its insurance products with the capital market to a greater extent. Due to its sheer size – the value of the global financial market currently lies at around USD 120,000 billion – the global capital market offers enormous opportunities for risk diversification. New insurance products currently being developed include weather derivatives and catastrophe bonds. However, the transaction costs are likely to be high, as investors are not used to these new insurance products.

In **France** all policyholders, private individuals and commercial enterprises, who take out fire insurance are also insured against losses caused by storms. Losses due to hail storms, lying snow, lightning and water plus damage to sewage and water pipes caused by freezing are covered, depending on the policy. Losses arising from natural disasters other than those mentioned above are insured against through the *Catastrophes Naturelles* (CatNat) programme, introduced in 1982 as a response to that year's serious flooding in southern France. Policyholders who have insured their property, private or commercial, are also insured against natural disasters. There is no legal definition of what a natural disaster is.

Instead, the government issues a decree declaring whether an event is to be considered a natural disaster. Insurance against natural disasters is funded by the insurance companies taking out a statutory and uniform supplementary premium of 12 percent of the cost of the property insurance. The excess payable in the case of natural disasters is also prescribed by law. The insurance companies can then reinsure themselves on the private reinsurance market or through the state *Caisse Centrale de Réassurance* (CCR). CCR offers unlimited reinsurance protection, which is guaranteed by the French government, in the event that CCR should use up all its funds. To receive this state guarantee, an insurance company must place half of its natural disaster reinsurance with CCR. This has had the effect that most insurance companies reinsure themselves with CCR. Since the programme started in 1982, 110,000 events have been declared natural disasters and around EUR 6.4 billion has been paid out in compensation. In recent years, the excess has been raised for municipalities which have not drawn up PPR risk prevention plans. Since 1982, there has also been a fund, the Barnier Fund, for the prevention of natural disasters. The fund is used to finance state expropriation of private property which is considered to be exposed to a foreseeable risk of torrential flooding. Since 2003, the Barnier Fund's obligations have been expanded to also part-finance preventive measures which are deemed necessary once PPR surveys have been carried out.

Germany also has a market-based system, with no state involvement. Only since 1991 has it been possible for private enterprises to take out increased cover to protect against flooding, earthquakes, landslides, subsidence, avalanches, snow, volcanic activity and water damage. There are essentially two categories of property insurance: 1) commercial insurance, for companies who choose to customise their own insurance cover based on their own requirements and risk aversion, 2) private insurance, for private individuals and small businesses who are offered an insurance package, where cover against natural disasters is an optional extra, over and above the normal property insurance. In Germany, it is permitted to build close to the waterline on the bank of a river, but the owner is informed during the process of obtaining planning permission that it will not be possible to obtain insurance against flood damage for the property. The insurance industry in Germany has developed a risk assessment system which places properties in different zones, depending on the risk of flooding, torrential rain and a sewage backwater build-up. The system is used by insurance companies when offering customers flood insurance. So far, demand for this flood insurance has been relatively low. There have been discussions on making it compulsory to take out flood insurance, with a view to encouraging risk aversion among the general public.

Sector-specific measures

Denmark has prioritised coastal protection as a problem for society, and has developed a national strategy for dealing with it. A special agency, the Danish Coastal Authority, is responsible for coastal protection. The national strategy is based on certain stretches of coastline being protected, by establishing a target/limit for how many metres the shoreline is allowed to retreat. Along certain stretches, the shoreline is not allowed to retreat at all, while natural erosion is permitted at other sites. A total of 1,800 km of coastline is currently protected by groynes or other fixed installations. However, attempts are being made to move away from this method and make more use of coastal nourishment, a method where sand is pumped close to the shore to compensate for erosion. The Danish Board of Technology is working to find more technical solutions to the problem, and it is hoped that methods can be developed which follow the natural development of the coast to as great an extent as possible. A particular problem arises when trying to protect coastal settlements close to river mouths from flooding. Building groynes is no long-term solution, as this only shifts the flooding problem. One solution under discussion is recreating natural flood plains upstream inland, which would relieve the pressure on the river mouths.

In developing the residential area of Örestad in **Denmark**, an expected rise in sea levels of 50 cm was taken into account when building the metro stations.

When building the Confederation Bridge, which is expected to have a lifetime of a hundred years, in **Canada** in 1997 a future rise in sea levels of one metre was assumed when calculating the height it needed to be for vessels to pass beneath it. Forecasts were also compiled regarding future winter conditions and how much ice could be expected to pass through the Northumberland Strait, which the bridge crosses, so that the piers could be made to the right dimensions.

In 2003, **Italy** launched the Moses Project, aimed at protecting Venice from today's high tides and future rises in sea level. The project involves 79 gigantic steel barriers fixed to the seabed at the entrance to the Venice lagoon. The Moses Project is due to be completed by 2010, at an estimated cost of at least around EUR 3.5 billion.

In **Finland**, the Ministry of Transport and Communications has used case studies to examine the challenges that the Finnish Road Administration will face as a consequence of climate change. The results of the studies are then to be followed up by the Road Administration's Regions.

In **Germany**, the Federal Nature Conservation Act 2002 requires each state to establish an interconnected network of biotopes corresponding to 10 percent of the total area of the state. The aim is to preserve biodiversity and protect the existing ecosystem against climate change.

Denmark developed a National Forest Programme, one result of which was a revised Forest Act, aimed at making the forestry sector more robust and better adapted to climate change. The national objective is to increase the amount of forest to 25 percent of the country's land within one tree generation (80–100 years).

The storms of 1999 and the drought caused by the heatwave of 2003 have led to the forestry sector in **France** working to increase the robustness of the forests. The approaches include increasing biodiversity and planting species which are better adapted to local conditions in today's climate and in a future climate. Attempts are also being made to thin forests out at an early stage, in order to reduce the risk of storm damage.

2.3 Earlier examinations of the issues

National climate policy in global cooperation (Bill 2005/06:172)

In June 2006, the Riksdag adopted the Government Bill *National climate policy in global cooperation* (2005/06:172), which states that the national climate objective adopted for the climate policy of 2002 remains. This climate bill focuses primarily on how to limit Sweden's emissions of greenhouse gases, although it does also deal with adapting to climate change. It is considered clear that climate change is a reality already, and that even with strong and immediate measures, the climate will change. How vulnerable society is to these changes in climate depends in part on their scale. However, vulnerability can also be mitigated through planning and taking into account the expected climate change. Vulnerability also depends on how well society is prepared for the expected changes. This is particularly relevant when considering that extreme weather events such as storms and major precipitation can be expected to become more common in the future. Building up a good level of readiness for adaptation measures requires knowledge about the expected climate change. It is on the basis of the above that the government decided to appoint the Commission on Climate and Vulnerability.

The Commission on Vulnerability and Security (SOU 2001:41)

In June 1999, the government decided to appoint a Special Investigator to head a commission of inquiry with a mandate to analyse and submit proposals for principles concerning a more integrated approach to civil defence and emergency preparedness planning in peacetime. The assignment also involved assessing which organisational and structural division of functions should be in place and what objectives there should be regarding society's ability to cope with a heightened level of preparedness and with major societal emergencies in peacetime. The commission published its report *Vulnerability and Security in a New Era* (SOU 2001:41) in May 2001. In the report, the commission proposed a new planning system for civil actions during crisis management. It also outlined a new system for managing and coordinating the handling of major emergencies in society. As regards the various phases of a crisis, it was the commission's view that public bodies must assume responsibility for leadership, coordination and prioritisation in connection with responses to acute crises. The report presented a basic framework for the organisation of these activities. It was also the view of the commission that the necessary process of change in this field should be based on the principles of responsibility, parity and proximity: i) Under the principle of responsibility, whoever is responsible for an activity in normal conditions should assume corresponding responsibility in crisis or war situations. ii) The principle of parity means that during a crisis or war, authorities should as far as possible be organised and located as in peacetime.

iii) The principle of proximity means that crises should be dealt with at the lowest possible level. The commission reported that there should be a body at every level which has ultimate responsibility for crisis management. At national level, it was proposed that this responsibility should be exercised by the government with the assistance of a national crisis management agency. The agency should be located in the Government Offices and primarily have coordinating functions. The Commission on Vulnerability and Security also stated that society has become highly dependent on IT and that information is one of today's most valuable assets. The commission therefore felt that IT should be regarded as a separate, albeit cross-sectoral, area that requires special attention in all aspects of crisis management.

Society's security and preparedness (Bill 2001/02:158)

In its Bill *Society's security and preparedness* (2001/02:158), the government sets out an overall goal of maintaining a high level of information security throughout society, which means that it is to be possible to prevent or deal with disruptions in important public activities. In principle, whoever is responsible for information processing systems should also be responsible for ensuring that the system has the security necessary to keep the system operating satisfactorily. A key role of the state was therefore to meet society's need for information security and to take measures which could not reasonably be made the responsibility of the individual system owner. The government also decided that the proposals from the Commission on Vulnerability and Security should be implemented, and put forward its own proposal for strengthening society's structures for crisis management. An action plan was also published, covering a number of activities within the Government Offices regarding issues such as information preparedness, telecommunications and IT support and security of electricity supply. In addition, the intention was expressed to place particular emphasis on developing training activities and exercises, which would be made much more frequent and which would particularly target key figures in the Government Offices. The bill also announced the name of the new agency tasked with coordinating the work to develop the preparedness of Swedish society to manage serious crises – the Swedish Emergency Management Agency

(SEMA). As a consequence of the policy stance in the bill, the government produced the Ordinance (2002:472) on measures for the handling of crises and increased preparedness in time of peace. The ordinance requires state agencies to analyse whether there are any vulnerabilities and risks within their area of responsibility which may seriously disrupt their ability to function. Selected agencies also have a particular responsibility to take action in the form of planning and preparations.

The Swedish Defence Commission's report 2006

At the government's request, the Defence Commission drew up the proposal *A strategy for Sweden's security* (Ds 2006:1). In its report, the Defence Commission stated that the ongoing work on security at the Government Offices should be more coordinated, and that the division of responsibilities between ministries should be reviewed. The commission also stated that a development in Sweden in which security issues are dealt with in a more concerted manner would be in line with the latest directions within the EU. It proposed the following objectives for the security of society:

- to protect our ability to maintain our basic values such as democracy, the rule of law and human rights
- to protect the lives and health of the population
- to protect the functions of society

Furthermore, in the view of the commission, the department set up at the Government Offices with the task of supporting the government's crisis management efforts should be developed. In situations that can result in extremely serious cross-sectoral consequences, the commission felt that a designated crisis management function at agency level should be established in order to conduct intelligence work and analysis. The report believes that climate change may, in the long term, affect water flows and create the risk of flooding or cause other natural disasters. The vulnerability of society can be reduced by making our systems more robust and taking various security and control measures.

Cooperation in crisis – for a more secure society (Bill 2005/06:133)

In its Bill *Cooperation in crisis – for a more secure society* (2005/06:133), the government agreed with the proposals submitted by the Defence Commission regarding national crisis management capabilities. However, the government decided that the proposed crisis management function at central agency level would have the task of handling operational crisis management, and comprise two components. One related to the government's ability to appoint an emergency management agency. The second was that there should be a function at agency level which was able to identify serious crises and furnish players at national, regional and local level with a national status report and cross-sectoral analysis. The government also decided that in order to meet its needs, the Government Offices should be able to produce their own overall status reports and cross-sectoral analyses. The geographical area of responsibility at national level was thereby developed, i.e. the government's responsibility to ensure cross-sectoral coordination, cooperation and prioritisation during crises. Furthermore, the government stated that the proposal that coordination of and decisions on central operational activities be delegated to agency level did not change the government's ultimate responsibility at national level. Instead this was to be seen as a way of clarifying the importance of having crisis management led by people with great expertise regarding operational activities. The Bill describes the government's view on a more developed strategy for information assurance and a national programme for security research. The Bill also describes the need to broaden the use of the radio communications system Rakel to support work on order, security and crisis preparedness in society. The Bill proposes a change to the Swedish Electronic Communications Act (2003:389), which would mean that the requirement for invitation procedures before a decision on issuing permission to use a radio transmitter in the event of a lack of bandwidth would not apply to the kind of radio use needed for activities aimed at maintaining public order, security or health. The Bill also proposes a new law on the measures taken by municipalities and county councils prior to and during exceptional events in peacetime and in times of heightened preparedness. The purpose of the provisions in the act is to ensure that the municipalities and county councils reduce the vulnerability in their activities and are well able to handle emergency situations in peacetime. This would also ensure a basic capability for civil defence. The new act replaces the Swedish Act (2002:833) on exceptional circumstances in peacetime in municipalities and county councils and parts of the Swedish Act (1994:1720) on civil defence, which are to be repealed. The provisions on facilities protection, home protection, blackouts and warnings in the latter act are to be completely abolished. Certain changes are also proposed for the Swedish Secrecy Act (1980:100) and the Swedish Planning and Building Act (1987:10), as well as a number of other laws, as a consequence of the proposed new laws.

Be prepared! A new agency for accidents and emergencies (2007:31)

On 29 June 2006, the government decided to appoint a Special Investigator to head a commission of inquiry with a mandate to review the activities of the Swedish Rescue Services Agency, the Swedish Emergency Management Agency and the Swedish National Board of Psychological Defence, with the aim of submitting proposals for a detailed allocation of information, responsibility and resources. A fundamental point of departure for the commission's proposals is the need to strengthen and clarify responsibility for crisis preparedness work in society, above all at state level. The commission proposes the development and simplification of the crisis preparedness work, in part through a stricter application of the principle of responsibility and clearer cross-sectoral coordination. It also proposes streamlining the planning process, refining the crisis preparedness grant *7:5 Krisberedskap* and developing the system of risk and vulnerability analyses. The commission's proposal for a new agency for protection against accidents, crisis preparedness and civil defence will be implemented from 1 July 2008. The current agencies, the Swedish Rescue Services Agency, the Swedish Emergency Management Agency and the Swedish National Board of Psychological Defence, will cease to operate once the new agency has been established.

Bibliography

CEA, (2007). *Reducing the Social and Economic Impacts of Climate Change and Natural Catastrophes.* Report.

CEA, (2005). *The Insurance of Natural Events on European Markets.* Report.

Council of Ministers and European Parliament, (2006). *On the assessment and management of flood risks.* Common Position (EC) No 33/2006.

Council of Ministers, (2002). *Establishing the European Union Solidarity Fund.* Council Regulation (EC) No 2012/2002.

Council of Ministers, (2001). *Establishing a Community mechanism to facilitate reinforced cooperation in civil protection assistance interventions.* Council Decision 2001/792/EC, Euratom.

Ds 2006:1. *A strategy for Sweden's security.* Defence Commission report 2006.

EEA, (2006). *Vulnerability and Adaptation to Climate Change in Europe.* EEA Report no 7/2005.

EEA, (2005). *Vulnerability and Adaptation to Climate Change in Europe.* EEA Technical Report No 7/2005.

EEA, (2004). *Impacts of Europe's Changing Climate.* EEA Report No 2/2004.

European Commission, (2007). *Adapting to climate change in Europe – options for EU action.* Green Paper.

European Commission, (2006). *Fourth National Communication from the European Community under the UN Framework Convention on Climate Change.* COM 2006:40.

European Commission, (2000). *Establishing a framework for the Community action in the field of water policy.* EU Water Framework Directive.

OECD, (2006). *Progress on Adaptation to Climate Change in Developed Countries.* Paper.

SOU 2001:41. *The Commission on Vulnerability and Security.*

SOU 2007:31. *Be prepared! A new agency for accidents and emergencies.*

Swedish Government Bill 2001/02:158. *Society's security and preparedness.*

Swedish Government Bill 2005/06:133. *Cooperation in crisis – for a more secure society.*

Swedish Government Bill 2005/06:172. *National climate policy in global cooperation.*

UNFCCC, (2007). *www.unfccc.org, http://unfccc.int/essential_background/convention/status_of_ratification/items/2631.php)*

3 The climate – past, present and future

3.1 The regional development of the climate to the present day

3.1.1 Typical features of the Swedish climate

Sweden's proximity to the North Atlantic and the predominantly south-westerly to westerly winds give it a relatively mild climate during the winter, given its latitude. The prevailing winds drive in relatively warm and moist air in conjunction with low pressure areas and weather fronts that sweep across the country following the North Atlantic Polar Front.

Variable, with precipitation all year round

The shifting low pressure areas give variable weather conditions from day to day and from year to year. The climate is categorised as temperate moist – in the coastal areas of the south warm temperate and in the majority of the country cold temperate, with lasting snow cover generally occurring during the winter. The low pressure areas make the climate quite rich in precipitation, with precipitation occurring all year round. The most precipitation falls in the west of the country. However, long periods of dry weather can occur when a high-pressure area pushes the low pressure areas north and/or south of Sweden. The highest-lying mountain areas have a polar climate. Small areas in southern Sweden, e.g. southern Öland, have drier, so-called semi-arid, climatic conditions, i.e. precipitation is more or less equal to evapotranspiration.

Maritime climate with quite small differences between summer and winter

Proximity to the sea makes for relatively small differences in temperature between summer and winter, particularly in western Götaland and across a small belt along the east coast, as well as in western parts of the mountain ridge. Areas with a localised continental climate and large temperature differences during the year occur in the inner parts of northern Norrland, western Värmland, Dalarna and Härjedalen in the lee of the Norwegian mountains and in the interior of southern Sweden's highlands.

3.1.2 The climate since the Ice Age

Oscillation between warm and cold since the Ice Age

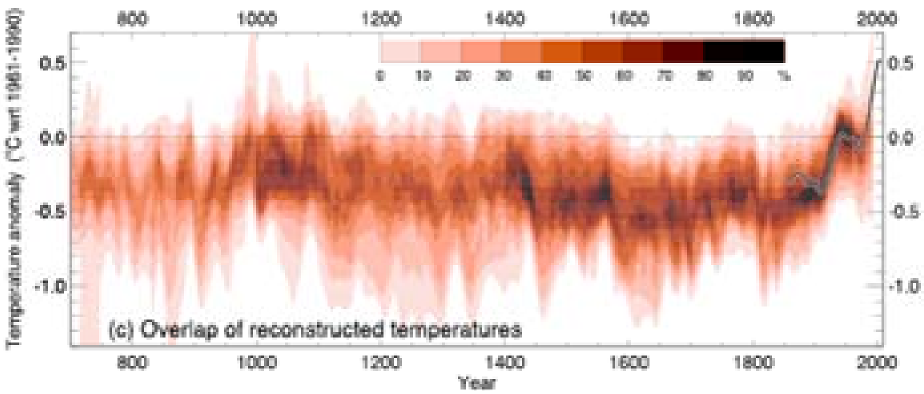
The oscillation between cold glacials (ice ages) and relatively short and warm interglacials started around 2.5 million years ago. The interglacial period we are currently living in has lasted around 10,000 years. Earlier interglacials have lasted varying lengths of time, from a few thousand to almost 30,000 years. The geographical and seasonal variations in the amount of solar radiation reaching the earth are cyclical in nature, with regularities associated with the planet's orbit of the sun. These regularities can also be calculated into the future. A change in solar radiation such as those that marked the end of earlier interglacials is not expected for around another 30,000 years (IPCC, 2007).

Paleoclimatological studies show that the earth's climate has also varied somewhat during the current interglacial. The variations can be seen to a certain extent on a global scale, but are more apparent regionally. The period 5,000–8,000 years ago was relatively warm, while a relatively cold period, known as the *Fimbul winter,* peaked around 2,500 years ago. It became relatively warm again during the Viking Age around the year 1000. A few hundred years later, a relatively cold period started in the northern hemisphere, and is often called *the Little Ice Age*.

Significant variations during historical times

The climate also varied within the Little Ice Age, which is considered to have drawn to an end during the 19th century. With the help of tree rings and sediment, researchers have been able to map out temperature variations before the advent of modern measurements. The results for the northern hemisphere, for which the most data is available, are shown in figure 3.1.

Figure 3.1 Reconstruction of the temperature over the past 1,300 years in the northern hemisphere, anomaly from the period 1961–90. The colour scale describes the reliability of the data. The more studies showing the same results, the darker the colour



Source: IPCC, 2007.

The variations in earlier temperatures in Sweden are likely to have been similar to those for the northern hemisphere in general. Examples of extreme weather events during the past millennium and the effects of these primarily in Sweden are given in the table below.

Table 3.1 Weather and climate in Sweden and the immediate vicinity over the past 1,000 years

Year	Event
1007	In Sweden, the spring is so wet that Lake Mälaren experiences serious flooding
1186 and 1290	Very mild winters
1300	The Little Ice Age starts, and continues for 600 years. The climate becomes increasingly harsh and Viking settlements in Greenland and Iceland disappear in the 14th and 15th century
1306 and 1323	Very harsh winters
1400 and 1402	Östergötland suffers extreme spring flooding
1544	One of the worst floods ever of the Dalälven river
1566	On 29 July, 4,000 Danish sailors perish in a northerly storm in the Baltic Sea just off Visby. Possibly the worst weather-related disaster ever within Sweden's current borders
1598	Major flooding of the Dalälven river
1658	On the "March across the Belts" in Denmark, the Swedish army crosses the ice from Jutland to Funen and on to Zealand on 5-6 February.
1659, 1661	Another two major floods of the Dalälven river
1700	A period with a better climate starts. The 1730s in particular are thought to have been warm, with mild winters similar to those during the 1930s and in recent years
1789	Record heat in Scandinavia followed by torrential rain leads to landslides claiming over 60 victims in south-east Norway. Ten people lose their lives in a lightning strike on a church in Dalsland, Sweden
1630–1890	One of the coldest periods of the millennium. Several poor harvests, including in 1867-1868, and many Swedes emigrate to America
1850	Over 100 people lose their lives in snowstorms across Södermanland and Östergötland
1867	In May, it snows for eight days in Skara, and in Umeå the ice on the Umeälven river remains until Midsummer on 24 June
1868	One of Sweden's warmest and driest summers ever. Crops are devastated and Sweden suffers its second year of famine in a row

Source: SMHI (2001).

The posited global warming between the 19th century and the early 20th century still remains in line with the warmest phases of the past millennium. However, the warming over the past 50 years deviates from earlier variations.

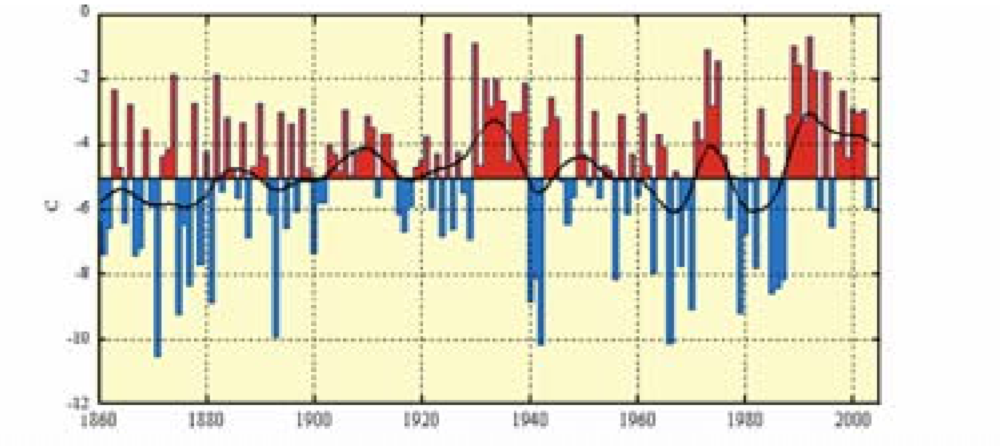
3.1.3 The climate during the 20th century

Warm period in the 1930s and at the end of the century

The climate in Sweden has been relatively warm over the past 75 years, particularly in the 1930s and since 1987. From the end of the 19th century, the temperature rose considerably up until the 1930s. The winter temperature in northern Sweden saw a particularly large rise of around 2.5°C. From the 1930s to the 1980s, the average annual temperature fell back by a round 0.8°C in the north and half as much in southern Sweden. Series of extremely cold winters also occurred during the 20th century, including the winters of 1940–42 and 1985–87. Since the late 1980s, there has been significant warming.

Figure 3.2 Winter temperature (December-February) in Sweden 1860–2003, the black line shows running ten-year averages

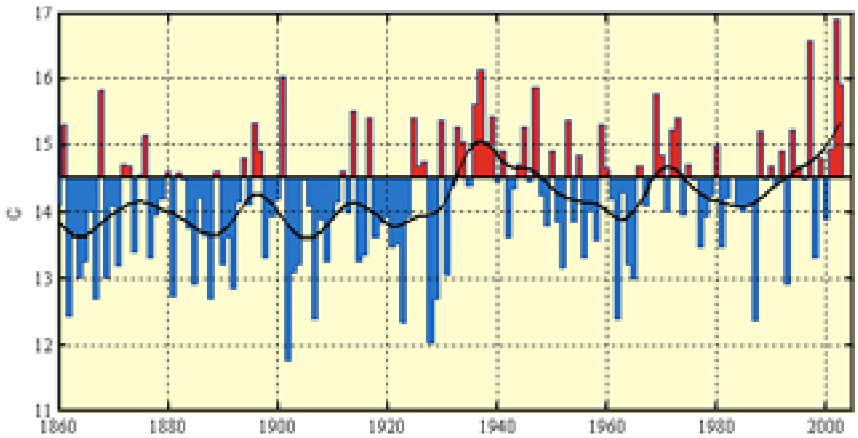
Source: SMHI.



The past 15–20 years have been distinctly warm. For example, the average temperature for Sweden in the winter has been over 1°C higher than a hundred years ago. Even within a shorter timeframe, the change has been great. The difference in winter temperature between 1991–2005 and 1961–90 is around 2°C, see section 3.1.4.

Compared with the winter, temperatures in the summer generally vary less over the years. However, the peak in the 1930s and the temperature rises at the end of the century can still clearly be seen, even in the summer, see Figure 3.3.

Figure 3.3 Summer temperature in Sweden 1860–2003 (June–August), the black line shows running ten-year averages

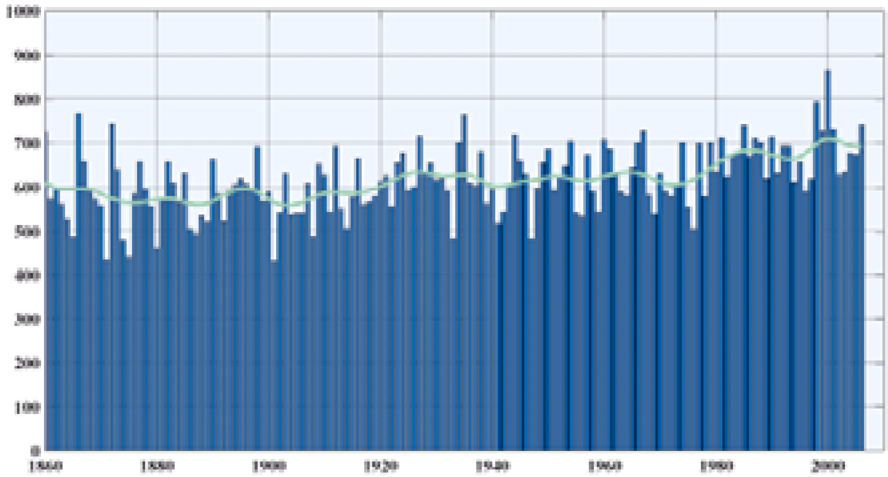


Source: SMHI.

Increasing precipitation

Although precipitation is not easy to summarise as an average for the whole country, it is clear that precipitation increased significantly in Sweden as a whole during the 20th century. The lower levels of precipitation before 1920 may be due to the fact that precipitation gauges were different then, and their location was often more exposed to the wind. However, the upswing after the 1970s is indisputable. The increase is also supported by other indicators such as mild autumns, winters and springs, which have been common in recent times, giving more precipitation than cold ones. During the summer, however, the reverse is generally true.

Figure 3.4 Annual precipitation, Sweden 1860–2006 in millimetres, the green line shows running ten-year averages



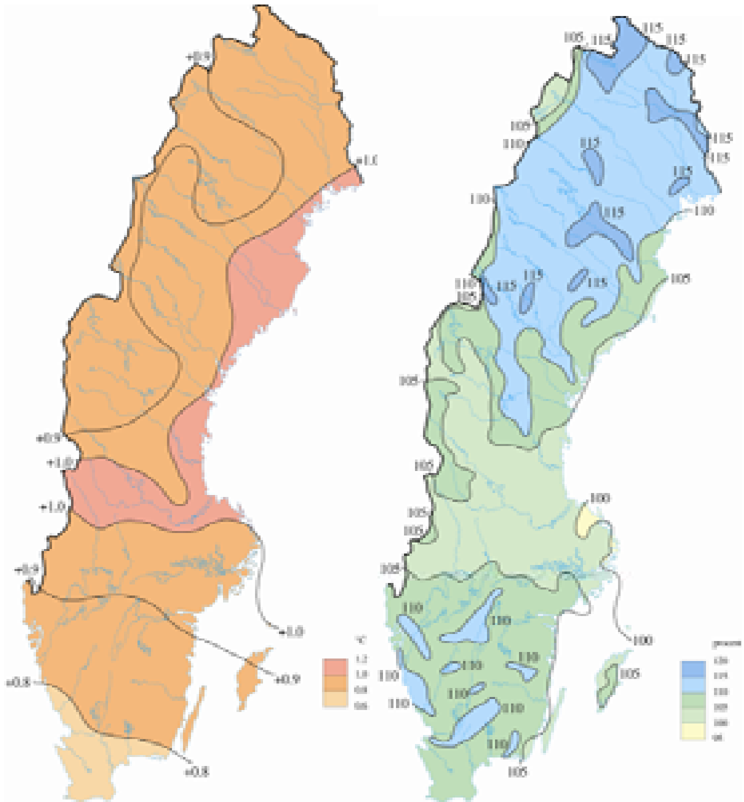
Source: SMHI.

3.1.4 The climate over the past few decades

Manifest warming over the past few decades and even more precipitation

During the years 1991–2005, the average annual temperature was generally over 1°C higher than in the period 1961–1990, see Figure 3.5. The increase was at its clearest in the winter, at over 2°C in central and northern parts of the country, and was least obvious during the autumn with, locally, almost unchanged temperatures primarily in south-west Sweden. Precipitation also increased across all the seasons except autumn, in some areas by 15–20 percent.

Figure 3.5 Change in average annual temperature and annual precipitation in 1991–2005 compared with the period 1961–1990



Source: www.smhi.se (klimat/sveriges klimat).

per cent

No clear trend for strong winds

We rarely see really severe storms. Over the 20th century, major storms hit Sweden in 1902, 1943, 1954, 1967, 1969 and 1999. With so few cases, it is extremely difficult to identify any trends. However, a violent storm (Gudrun) occurred on 8–9 January 2005, with hurricane winds gusting across southern Sweden, causing by far the most extensive storm-felling of trees in at least a hundred years. Storm Per in January 2007 also caused significant damage.

2006 and the start of 2007 – examples of what we can expect?

Although Sweden's climate has always varied, the rise in temperatures and precipitation over the past 15 years has been unusually large, from a 100-year perspective. 2006 was also a warm year in Sweden, despite the cold start, with March being a particularly cold month across the country. For each of the six months July–December, record highs recorded at least somewhere in the country in terms of average monthly temperature. July saw record temperatures in many places in southern Götaland, August more locally along the coast of Västerbotten, September in large parts of southern and central Sweden, October along the coast of Götaland, November locally along the west coast and finally in December across large parts of the country. Several absolute temperature records were also beaten. In the early part of 2007, even more records for high monthly average temperature were beaten (January, March and April). In January, the country suffered several major storms, of which the most serious was storm Per (SMHI, 2007).

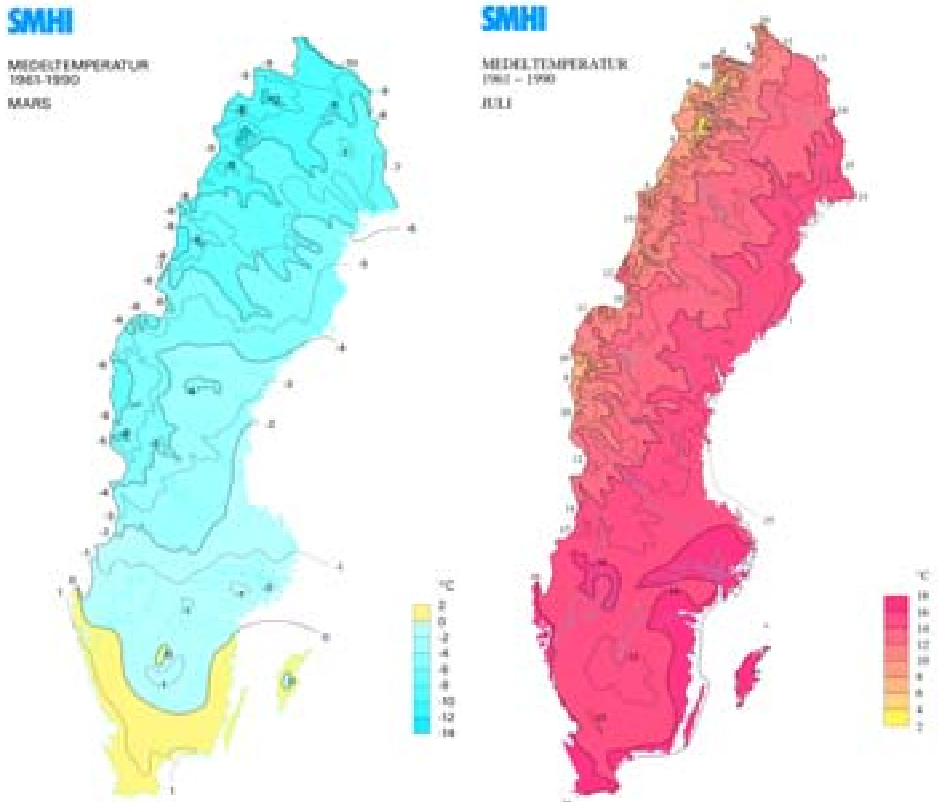
3.1.5 The climate for the different seasons over the reference period 1961-1990

Since there are major variations from year to year, studies are required over longer time periods in order to be able to draw relatively reliable comparisons. The Swedish Meteorological and Hydrological Institute (SMHI), like other meteorological institutes, uses the period 1961–1990 as a reference period for its comparisons. In our work, we have also chosen to compare the scenarios for a future climate with this period.

Spring during the reference period

Spring (average temperature per 24 hours is above zero but below 10°C) normally comes to the southernmost parts of Skåne at the end of February and normally reaches southern Värmland and southern Dalarna at the end of March. Spring spreads to most of Sweden during April and the average temperature is still below 0°C in May only in parts of the mountain regions. The average precipitation during the spring months is low at around 30–40 mm per month in large parts of the country. However, higher levels are experienced by western parts, particularly in the mountains.

Figure 3.6 Average temperature in March and July during the period 1961–1990



AVERAGE TEMPERATURE
1961–1990
MARCH

AVERAGE TEMPERATURE
1961–1990
JULY

Source: www.smhi.se (klimat/klimatindikatorer och observationer/klimatkartor/temperatur).

Summer during the reference period

Generally speaking, summer (average temperature per 24 hours is above 10°C) comes to the southern half of the country in late May. By June, summer has reached everywhere except the mountains. The average temperature in June usually stands at just under 15°C in large parts of Götaland and Svealand. The temperature is somewhat lower in eastern Norrland and only just under 10°C in the mountain regions, with the highest-lying areas even lower. In July, which as a rule is the warmest month, the average is just under 17°C in south-east Sweden. In eastern Norrland it is around 15°C, see Figure 3.6. The lowest average temperatures for July are to be found high up in the Lapland mountains, with Tarfala in the Kebnekaise area recording the lowest temperatures of SMHI's stations at around 7°C. In August, temperatures start to drop slightly, mostly in the northern parts of the country. The average precipitation for June lies between 40 and 50 mm in eastern parts of the country, with up to 70–80 mm in parts of the west. In large parts of the country, July and August tend to be the months with the heaviest precipitation. The average precipitation varies during this time from 50–60 mm per month in eastern Sweden to over 100 mm locally in western Götaland and the mountain regions.

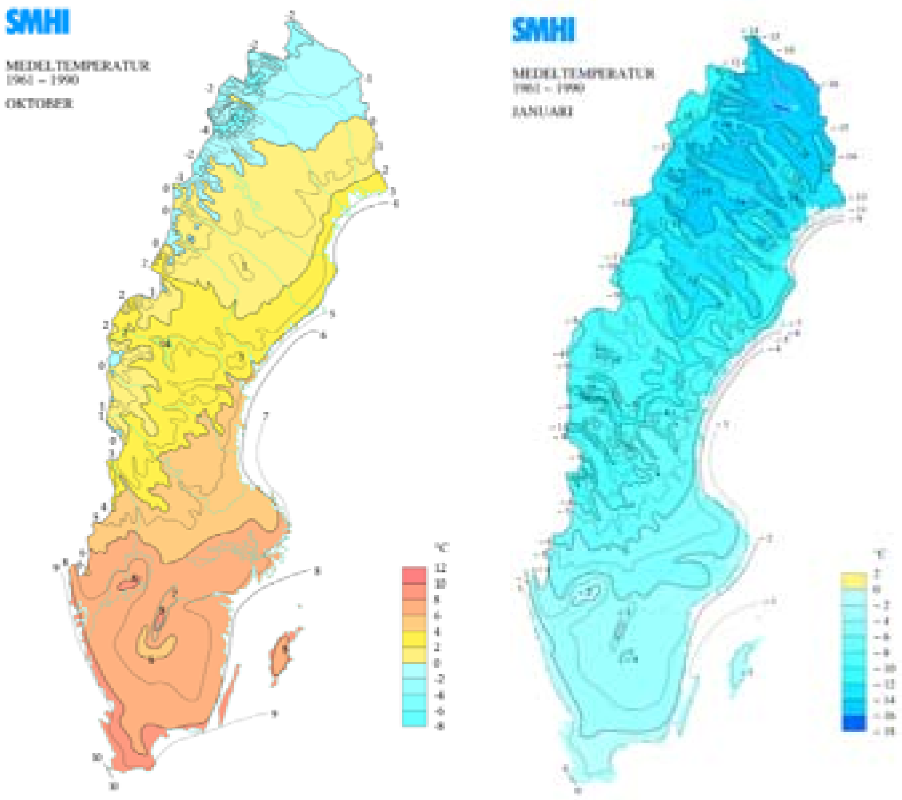
Autumn during the reference period

The average temperature in September ranges from around 12°C around the coast of Götaland and Svealand to around 10°C along the Norrland coast and down to around 5°C in the mountains. By early September, autumn (average temperature per 24 hours is between zero and 10°C) has arrived in the mountains and across a large part of the interior of Norrland. In both September and October, precipitation amounts to 50–60 mm per month in eastern Sweden, but as much as 100 and more in western Götaland and in parts of the mountains. In September, autumn continues to push south and by the start of October only the coastal areas of Götaland enjoy summer temperatures, on average. At this time, winter is moving into the mountain areas of Norrland. By mid-November, winter has also generally reached Svealand. The autumn months experience quite a large amount of precipitation. Many places have the same amount of precipitation as or even more than during the summer months.

Winter during the reference period

On average, by the end of December, winter (average temperature per 24 hours is below 0°C) has gripped the whole country, except the coastal areas of Götaland. The average temperature for December is a few degrees above freezing along the Götaland coast and around 0°C on the Svealand coast, a few degrees below freezing in inland Götaland and Svealand and along the coast of southern Norrland, and between -5°C and -10°C in large parts of inland Norrland. The coldest average temperatures of almost -15°C occur in the valleys in parts of inland northern Norrland. In January and February, the south coast of Skåne hardly has winter temperatures, while the coldest valleys of inner Lapland can be -16°C to -17°C. Winter precipitation is quite evenly spread across the country. Large areas receive an average of 40–60 mm in December and January, but less in February. Western parts of southern Sweden's highlands and the western mountains receive an average of almost 100 mm per month in December and January (locally even more in the mountains), but here too the figure is less in February

Figure 3.7 Average temperature in October and January during the period 1961–1990



AVERAGE TEMPERATURE
1961–1990
OKTOBER

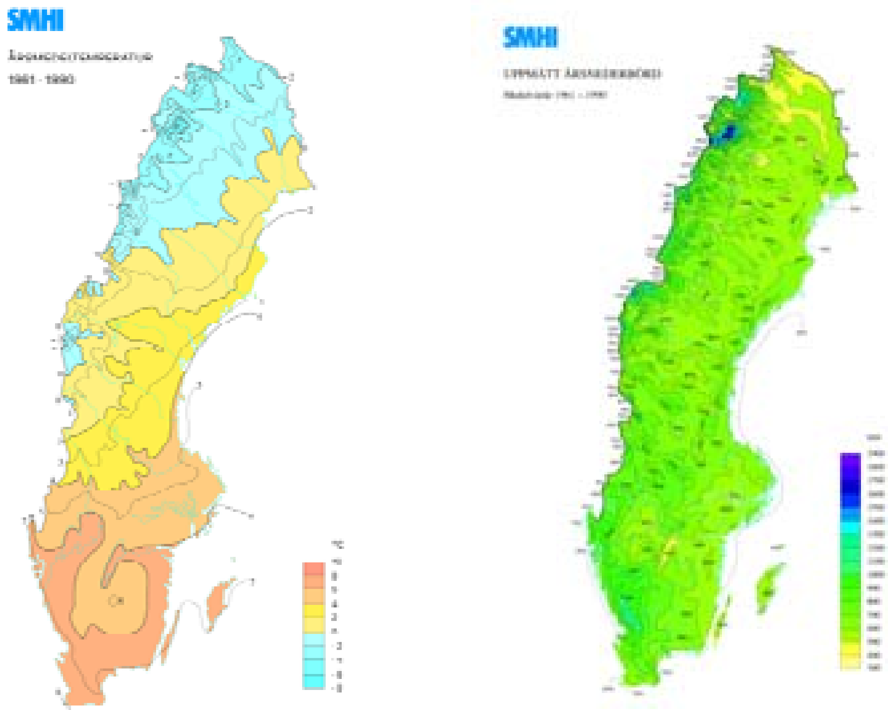
AVERAGE TEMPERATURE
1961–1990
JANUARY

Source: www.smhi.se (klimat/klimatindikatorer och observationer/klimatkartor/temperatur).

Annual temperatures and precipitation during the reference period 1961–1990

The pattern from most of the individual months is reflected in the spread of average temperatures and precipitation across the year. The warmest areas are along the west coast and in southern Götaland, but the differences in average temperature are quite small up as far as Mälardalen. Norrland, particularly inland and in the mountains, has a significantly colder climate than the rest of Sweden. Precipitation shows a clear gradient from west to east, with the largest amounts in western Götaland and parts of the mountain region.

Figure 3.8 Average annual temperature and annual average precipitation 1961–1990



AVERAGE ANNUAL TEMPERATURE
1961–1990

RECORDED ANNUAL PRECIPITATION
Average 1961–1990

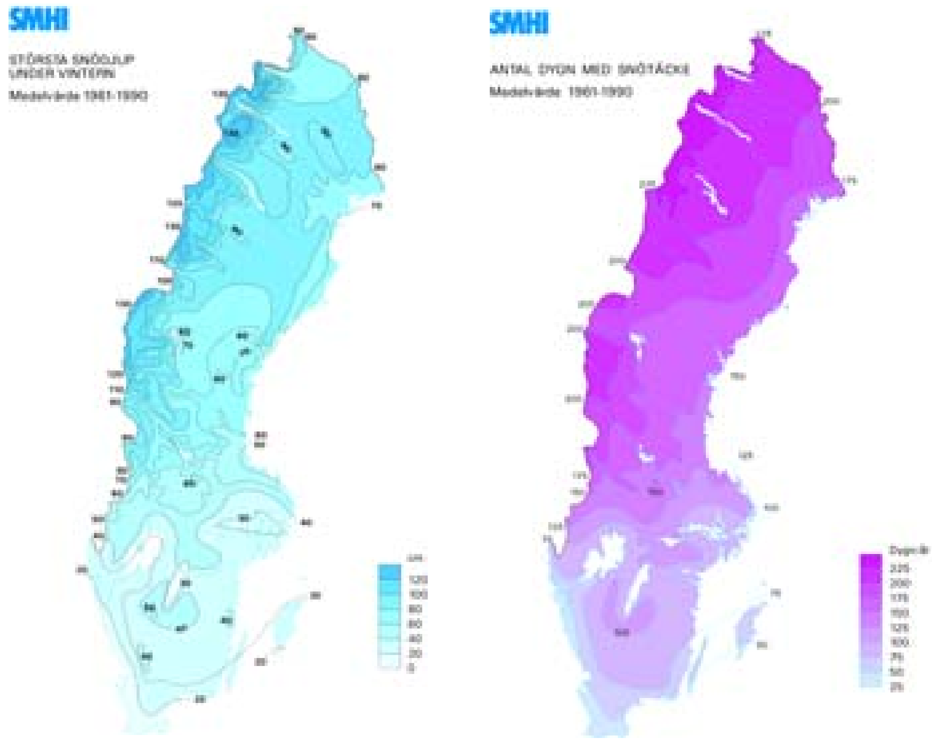
Source: www.smhi.se (klimat/klimatindikatorer och observationer/klimatkartor).

The average precipitation across the country is around 600–700 mm per year. The borderlands between Halland and Småland see around 1,100 mm and locally the western parts of the mountain chain have 1,500–2,000 mm. The lowest amounts of precipitation fall in the southern parts of Öland and in northernmost Norrland, around 400–500 mm per year.

Snow cover during the reference period 1961–1990

The inland areas of Norrland have the deepest snow in the country, usually during late winter/early spring, with an average of 80–100 cm, and even more in the mountains. In southern Sweden, the deepest snow cover averages 20–40 cm. The snow cover lasts around 230 days in the Lapland mountains, falling to around 100 days in southern Svealand and inland Götaland, and less along the Götaland coast. The snow first settles in October in the Lapland mountains. By early November, large parts of Norrland and northernmost Svealand are generally covered with snow. By early December, only the coastal areas of Götaland are usually snow-free. The snow that does arrive here is gone by the end of March, and leaves other parts of Götaland by mid-April. By 1 May, Svealand and much of the Norrland coast are free from snow, while the mountain areas of northern Norrland retain their snow cover until the start of June.

Figure 3.9 Average deepest snow cover and no. of days with snow cover during the period 1961–1990



DEEPEST SNOW COVER
Average 1961–1990

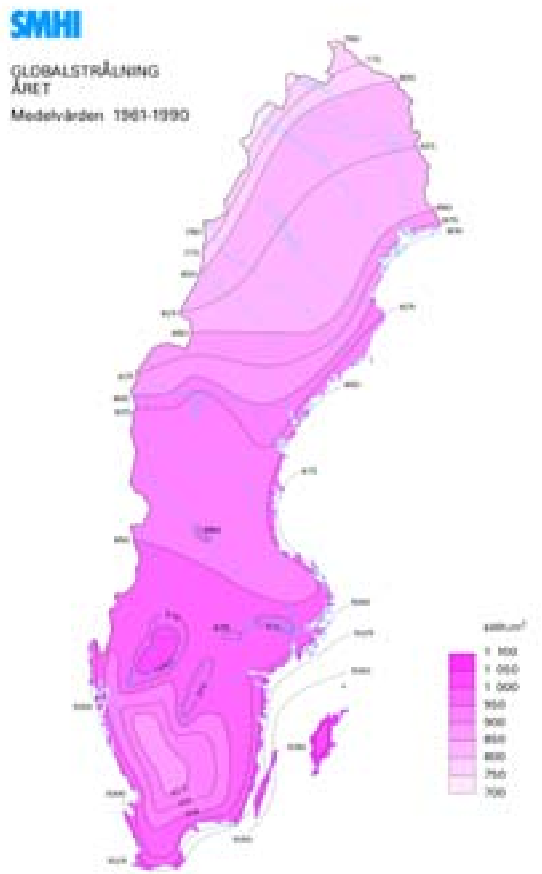
NO. OF DAYS WITH SNOW COVER days/year
Average 1961–1990

Source: www.smhi.se (klimat/klimatindikatorer och observationer/klimatkartor).

Solar radiation during the reference period

Solar radiation varies naturally with the seasons and due to cloud cover. Figure 3.10 shows global solar irradiance, i.e. the amount of solar radiation striking a horizontal surface. In general, the solar irradiance is greatest along the coasts and by the large lakes, as this is where we find least cloud. Since solar irradiance is highly dependent on how high the sun is in the sky, the incidence of cloud in the summer is the main factor determining variations in solar irradiance. Inland Götaland and north-west Norrland have the least global irradiance.

Figure 3.10 Average solar irradiance 1961–1990



ANNUAL GLOBAL IRRADIANCE
Average 1961–1990

Source: www.smhi.se (klimat/klimatindikatorer och observationer/klimatkartor).

3.2 Extreme weather events in recent years

Changes in climate can have major effects on the functions of society and on the natural environment, which can put major strains on society. Society's vulnerability to climate change depends in part on how large the changes are, and on how we plan our preparedness and take account of these expected changes today. Our preparedness today is also of great importance in dealing with extreme weather situations such as storms, heavy precipitation landslides in the current climate and that of future. These extremes are expected to become more common.

3.2.1 Storms

Over the years, Sweden has been affected by a number of major storms. Storm Gudrun, which had the most serious consequences so far, struck the country on the night of 8 January 2005. The storm claimed 17 lives, some during the cleanup work and reinstatement of power lines. At its peak, the wind was recorded at speeds of 42 m/s on Hanö. Winds almost as strong were recorded at several locations along the west coast and on Gotland. Remarkably strong gusts were also recorded inland, e.g. 33 m/s in Ljungby and Växjö, and it was here that the damage was worst. Kronoberg County and neighbouring parts of other counties were hit particularly hard.

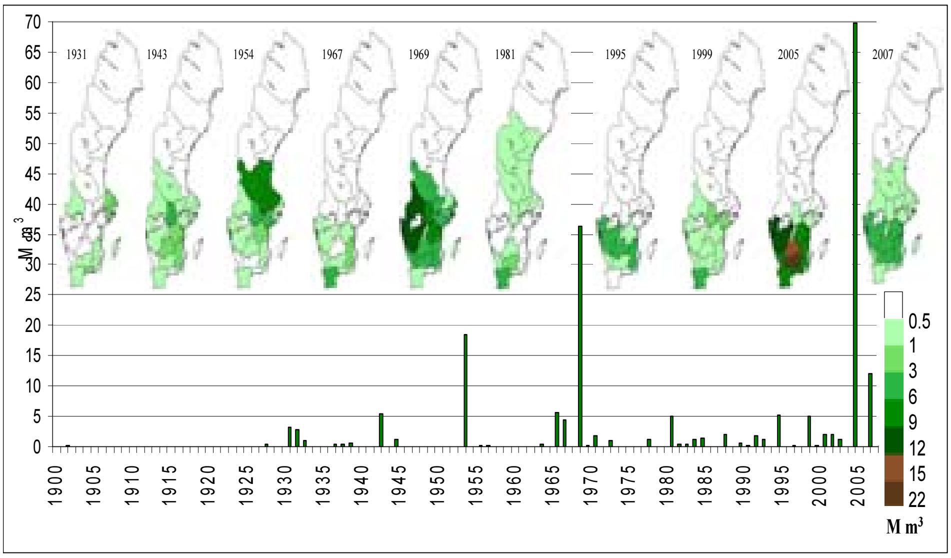
The strong winds of storm Gudrun, falling trees and pieces of timber flying around caused major disruption and damage to the infrastructure for electricity, electronic communications, roads and railways. The indirect consequences were serious, due to society's huge dependence on electricity and telecommunications. Various functions were affected, including water supply, care of the elderly, heating and transport.

The impact of storm Gudrun on the forests

The volume of storm-felled timber amounted to around 10 years of normal felling in some forest districts. The storm felled a total of around 75 million m^3 of timber, i.e. more than twice as much as during the severe storms of 1969 and equivalent to almost an entire year of felling for the whole country. The mild weather and a lack of ground frost made the forests more vulnerable to the strong winds, resulting in more trees falling. Another reason for the large volumes of storm-felled timber is the fact that we expanded the forests in Sweden in the 20th century, and the condition and composition of the forests has changed. It was mainly the spruce trees that were felled, with deciduous forests suffering relatively little damage. The direct cost of the storm is estimated at almost SEK 21 billion (Ministry of Enterprise, Energy and Communications, 2005).

Prior to storm Gudrun, severe storms occurred in September 1969, when 25 million m^3 of forest fell in Svealand and northern Götaland. Before that, you have to go back to winter 1954, when 18 million m^3 of forest was destroyed, primarily in Uppland and southern Norrland.

Figure 3.11 Annual volume of storm-damaged forest, million cubic metres per year. Data before 1930 is largely non-existent. The maps show the extent of major storm damage by county



Source: Study by C. Nilsson (based on Nilsson, C et al, 2004).

The impact of storm Gudrun on electricity distribution and power stations

Storm Gudrun had a major impact primarily on the local electricity network. Over 660,000 households were without electricity and almost 30,000 km of power lines were damaged, with around 2,700 km needing to be completely rebuilt. Many households still had no electricity after a week, with some rural households without power for up to 45 days.

Both insulated and uninsulated overhead power lines were taken out by the storm. So many trees fell in some areas that they damaged insulation, brought down pylons and broke lines. Despite the regional network largely comprising uninsulated power lines, damage to these was relatively minor, as the network primarily runs along broad, cleared routes. Overall, energy companies with a greater proportion of power lines underground had a lower proportion of customers affected. (Swedish Energy Agency, 2005; Swedish Energy Agency, 2005b).

The coordination body for dealing with major disruptions to electrical supply, *Elsamverkansorganisationen för storstörningar*, swung into action. Preparedness was quickly raised and resources from other, unaffected areas were diverted to the affected areas. In addition to this body and the companies' own resources, international help was also received. The clearance and reconstruction work was delayed primarily due to the absence of telecommunications and a lack of road clearance. The rate of investment in more secure supplies to urban and rural areas has intensified since the storm. The large power lines of the national grid were spared during Gudrun. None of its pylons were damaged. The early stages of the storm caused a build-up of salt, which resulted in short circuits in switchyards and caused the nuclear power plants on the west coast to be shut down. Earlier storms have brought down some pylons before, although this did not cause any major disruption to the electricity grid as there was built-in redundancy. (Svenska Kraftnät, 2006).

Storm Gudrun caused problems for many hydroelectric power stations within the affected areas. A number of these were tripped due to damage to the existing network. Problems arose with communications between stations and personnel in the field. Disaster protection systems for the dams worked and no dams were breached.

The impact of storm Gudrun on heating

Storm Gudrun struck during an unusually mild winter, which meant that demand for heating was less than normal for the time of year. Some electrically-heated homes in rural areas and small towns with small district heating systems, which were dependent on electricity from power lines at mid-voltage level, had problems. However, it was possible to partly mitigate these difficulties through alternative heating options or mobile generators.

The impact of storm Gudrun on electronic communications

The availability of fixed and mobile telephony, as well as the Internet, was seriously affected during storm Gudrun. Local networks were knocked out to a large extent across southern Sweden and over a quarter of a million subscribers were unable to make telephone calls immediately after the storm. The causes of the system collapse were the dependency of the telecommunications network on electricity, the backup power being insufficient and the storm destroying telecom equipment such as circuit boards, telegraph poles and telephone lines. Within a few days, the majority of subscribers were able to communicate electronically, primarily by mobile telephone, but for subscribers in rural areas primarily with fixed telephony, the disruption in service lasted a month or more.

The Swedish National Post and Telecom Agency (PTS) opened up all operators' networks (known as roaming) in the most serious phase, so that certain functions in society were able to use their mobile networks, irrespective of operator. A national telecom coordination group was formed, and remained in place even after the worst was over. (PTS, 2005).

There was only a minor impact on radio and TV broadcasting. Slave stations that lacked backup power stopped and some local radio/TV equipment was shifted off target due to the storm. The broadcasts were managed by increasing power, so that full coverage could be achieved.

Blocked roads were a problem, preventing the transport of mobile generators and fuel for backup generators. Communication and coordination of efforts was made much more difficult by the lack of fixed or mobile telephony.

The impact of storm Gudrun on the transport sector

The impact of storm Gudrun varied depending on the transport system. The rail network was closed down primarily in the southern and western rail regions, and to some extent also in central and eastern areas. The material damage essentially comprised fallen overhead lines and damaged or destroyed pylons. Extensive clearing work was required due to fallen trees. During the reconstruction phase, priority was given to industrial freight. Dependence on telecommunications and electricity was a limiting factor in the reconstruction work. In the southern track region, which was hardest hit, the service interruption lasted over a month (Swedish Rail Administration, 2005).

The road network in southern parts of the country was equally badly affected by fallen trees. National roads were made useable within 24 hours. However, it took up to a week before other public roads were passable. Major costs have arisen since the storm, due to heavy loads on roads with poor load capacity during the clearing work. The road and rail sectors both had problems with the robustness of materials, personnel and information.

Air transport was only slightly affected. Gothenburg's Landvetter Airport was forced to close, but not Stockholm's Arlanda Airport.

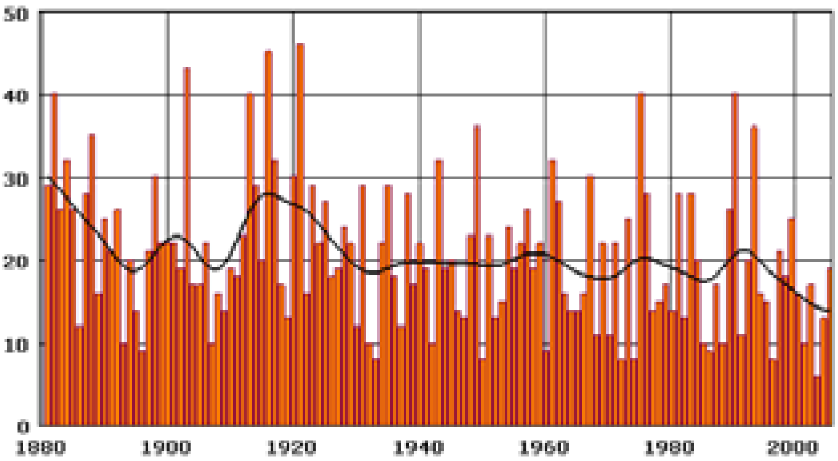
The coastal radio network for maritime traffic showed certain shortcomings. The emergency radio system AIS (Automatic Identification System) is used by all vessels over 300 gross tonnes. Since the storm, the Swedish Maritime Administration has started building a supplementary radio communications system into Teracom masts.

Despite Gudrun and Per, no long-term trend towards more storms – yet

Storm Per hit Sweden in January 2007. The damage was not as extensive as during storm Gudrun, but around 16 million m^3 of forest is thought to have been lost. The damage to the forests affected a geographically larger area of Götaland and southern Svealand and was also more widespread. Once again with storm Per, electricity distribution and telecommunications in particular were affected, but not to the same extent as during Gudrun.

It is impossible to determine at this stage whether or not the severe storms of recent times are the start of an increasing trend. Looking over past data, it is difficult to discern any clear trend, at least from a longer perspective, see Figure 3.11.

Figure 3.12 No. of cases of calculated wind speeds exceeding 25 m/s in southern Sweden, 1881–2005. The calculations are based on air pressure measurements taken in Gothenburg, Falsterbo and Visby. The black line shows running ten-year averages



Source: SMHI.

3.2.2 Floods and high flows

Floods and high flows occur regularly. Short intensive rain causes high flows mainly in small watercourses, with resultant flooding. Such rain can also cause flooding in built-up areas due to overloading of the drainage system. More prolonged periods of rain increase the flows in large watercourses and lakes. The expansion of settlements and infrastructure nearer watercourses, lakes and coasts is leading to an increased risk of flooding, with major consequences.

Numerous floods since 2000

A number of floods have affected many areas of the country since 2000. Värmland, Dalsland and Västra Götaland were hit in autumn 2000/winter 2001 by prolonged periods of rain which had widespread consequences. Other examples include the protracted rain that affected southern Norrland in summer 2000, Orust in summer 2002 and Småland in summer 2003 and 2004. Persistent rain affected western Götaland in late autumn 2006 and parts of Småland, Västergötland, Östergötland and Skåne in summer 2007.

The floods in autumn and winter 2000/2001

During the severe flooding of autumn 2000/winter 2001 in Värmland and Västra Götaland, it was estimated that river flows were at their highest in 200 years. Arvika was hit hard. The County Administrative Board temporarily took over responsibility for water discharge from Lake Vänern, with the support of the Swedish Rescue Services Act, and instructed water company Vattenfall to increase discharge to more than was allowed in the water decree. The flooding caused significant damage. The severe floods of 2000/2001 also affected Lakes Mälaren and Hjälmaren, although not as dramatically as in Dalsland and Värmland. In December 2000, Lake Mälaren saw its highest water level since regulation began. The situation showed that there are security problems which could come to affect central Stockholm. In Lake Hjälmaren, several embankments were breached and a number of others were close to breaching (SOU 2006:94).

The impact of recent flooding on transport

The road sector has been hit hard in recent years by serious water flows and flooding. In many cases, the high flows have been at levels expected to occur every 100 years, although even higher flows have occurred, for example in summer 2004 in Värmland and in Småland. The Western Region of the Swedish Road Administration (SRA), which largely covers Västra Götaland, has suffered the most damage, while its Central Region has incurred the most costs, primarily in 2000–2001. In 1994–2001, around

200 major incidences of damage were caused by high flows. (SRA, 2002).

The high water flows in 2000 around Arvika, the Lake Vänern area and central Norrland, in autumn 2001 in the Sundsvall area and in summer 2004 in Småland caused widespread damage to the railways, including eroded rail embankments, lower load capacity and flooding of tracks. This led to train cancellations and reductions in speed. The Swedish Rail Administration's inventory of damage between 2000 and autumn 2001 showed a total of 200 incidences of damage (Swedish Rail Administration, 2001).

The high flows and water levels in 2000 in the Göta Älv river also caused problems for shipping, as the flows increased to a level which vessels with low engine power could not handle.

The heavy rains in the area around Sundsvall in summer 2004 caused flooding and erosion problems that affected Midlanda Airport (Sundsvall/Härnösand).

The impact of recent flooding on dams

In the mid-1980s, several high flows and floods took place in various locations across the country. During a high flow in autumn 1985, a dam structure collapsed at the Noppiskoski power station in Dalarna. Other dam damage occurred in Sysslebäck in 1973 and Aitik in 2000. The damage was due to a combination of heavy precipitation, overflowing and technical problems.

No major damage occurred to dam structures during the high flows (estimated as flows with a return period of 100 years) in southern Norrland in July 2000, but around 50 incidents involving dam structures were reported. In almost half of them, the flows were greater than the maximum discharge capacity from the spillways which can be used without extraordinary measures being taken. The July flows of 2000 in Norrland were exceeded several times in the 20th century in the affected areas. The likelihood of them being repeated in the near future is judged to be great (SMHI, 2001).

The intensive and persistent rain in the Sundsvall area in August/September in 2001 resulted in a minor dam breach that caused the flooding of minor roads. Other dams in risk class 2 (see section 4.2.2) or lower also ran the risk of overcapacity.

3.2.3 Landslides, erosion

Precipitation affects soil moisture properties such as pore pressure and groundwater levels which, together with the type of soil, have a major impact on the soil's solidity and stability. Rapid, short-term changes, such as intensive rain, fluctuating water levels and erosion, have a major negative impact on stability. Human influence and external loads have a further effect on the situation. Rockslides, landslides and mudslides are sudden and fast processes which can have disastrous consequences.

Erosion in running water requires loose soil and a flow speed that is sufficiently high to dislodge and transport that soil. Erosion from waves may be caused by wind waves, waves generated by discharge from dams or dam breaches and swell from boats.

Landslides with major consequences

Over 55 large landslides, with a spread of at least one hectare, have occurred in Sweden over the past 100 years. The most likely soils to suffer landslides are marine clays which, due to rising land levels, have risen above sea level (quick clay). Particularly susceptible areas include the Göta Älv valley and other valleys in western Sweden. The topography of the land along the Göta Älv today has largely been formed through a number of major landslides. Clays inclined towards landslide can also be found in the Stockholm area, along the Norrland coast and in many other locations around the country. Slides on sand and silt slopes are common in the valleys of the large Norrland rivers.

Major landslides include the Surte landslide in 1950, the Göta landslide in 1957 and the Tuve landslide in 1977, plus the slide in Vagnhärad in 1997. The Surte, Göta and Tuve slides all claimed lives. The landslides caused immense damage primarily to buildings, but also to infrastructure. In the Göta Älv valley, shipping is often affected by underwater slides. More detailed descriptions of landslides in the Göta Älv valley can be found in the commission's interim report (SOU 2006:94).

In December 2006, a major landslide occurred south of Munkedal. The slide covered a stretch measuring 550 metres long and 250 metres wide in a valley along which the E6 road and the Bohus rail line run. The soil in the valley, which contains quick clay, shifted around 20 metres sidewards and 7 metres downwards at its peak. Several cars were caught up in the landslide and some people were injured. A train was stopped around 1 km from the location of the incident (Swedish Rail Administration, 2006). The landslide caused serious damage to the road and railway, as well as telephone cables embedded in the banks. Full repairs took almost two months.

In summer 2006, a road and rail embankment was washed away at Ånn in Jämtland, see picture 3.1, after intensive rain upstream, resulting in a high flow and erosion. The watercourse was usually just a small stream, but the heavy rainfall turned it into a torrent that swept along everything in its path. A train had just passed the site of the incident moments before. Reconstruction took a couple of weeks.

Picture 3.1 The rockslide in Ånn in summer 2006

Source: Swedish Road Administration, 2006.

Erosion along the coast and watercourses

Coastal erosion occurs largely in Halland and Skåne and on Öland and Gotland. The most widespread coastal erosion occurs along the south coast of Skåne. The municipality of Ystad has seen erosion since the 19th century, and both natural habitats and buildings have been affected. In the past 30 years, the shoreline has shifted over 150 m inland at Löderup beach (Rankka and Rydell, 2005).

During high flows, erosion and landslides can occur along watercourses. For instance, a number of landslides occurred in 1995, causing several farm buildings in Västra Tandö to slide down into the Västerdalälven river (Swedish Geotechnical Institute – SGI, 2005).

3.2.4 Extreme temperatures

Europe experienced a prolonged heatwave for two weeks in August 2003. Studies have shown that over 33,000 people died as a direct consequence of the heat in France, England, Wales, the Netherlands, Spain, Italy and Portugal. Deaths due to other causes have not been included. France alone recorded over 14,800 deaths, mainly of elderly people. The same maximum temperatures had different effects in different cities and regions of France. The cause of this may be differences in city size, the "urban heat island" effect, population age, ground-level ozone, cultural differences and adaptations to high temperatures (air conditioning, human behaviour, etc.). For the whole of summer 2003, the number of heat-related deaths in Western Europe is believed to amount to over 44,000.

3.2.5 Ice formation

As well as causing problems for shipping, ice formation impacts on systems which have overhead cables and masts. Pylon damage has occurred in the national electricity grid on five occasions due to extreme formation of ice combined with only moderate winds. This has occurred as a local phenomenon in northern Sweden down towards northern Dalsland and primarily in high-lying areas. Two cases saw the loss of six and eight pylons respectively.

3.2.6 Heavy snowstorms

Heavy snowstorms which affected infrastructure occurred in 1995 in Gothenburg, in 1998 in Gävle and in 2001 in Stockholm. In addition to the snowstorm in Gävle, incidences of heavy snow causing damage to buildings occurred in winter 1976–77 and in 1985 in eastern Småland, in 1987–88 along the Norrland coast and in 1992–93 in Örnsköldsvik.

The snowstorm in Gävle and its surrounding area involved heavy snowfall for several days. The maximum depth of snow measured almost 140 cm (new snow). All routes past and through central Gävle were closed. Passage was only possible for vehicles with caterpillar tracks. Several roads were only passable after almost a week. As well as the road network, the extreme snowstorm also hit the railway. Buildings were mainly affected by rooftop snowslides due to the huge loads of snow (SMHI, 1998).

A common contributory factor in heavy and often wet snowfall is proximity to an open and relatively warm sea. This is particularly the case with onshore winds from the Gulf of Bothnia and the Baltic Sea, when they are not iced over. This means that the temperature during snowfalls or hazardous situations is often around 0°C.

3.3 Global changes in climate

3.3.1 Increased certainty about the causes of global warming observed to date

Increased concentrations of greenhouses gases and warming of over 0.7°C in the past 100 years

The global average temperature has increased by an average of 0.74°C over the past 100 years (1906–2005). The most important greenhouse gas from human activity is carbon dioxide. Emissions of carbon dioxide derive mainly from the combustion of fossil fuels such as coal, oil and natural gas. Since the mid-19th century, carbon dioxide concentrations in the atmosphere have increased from around 280 ppm in 1850 to 379 ppm in 2005. Concentrations of methane and nitrous oxide have also increased as a result of human activity. In its latest assessment from 2007 (Assessment report 4, *AR4*), the IPCC states that

Most of the observed increase in temperature since 1950 is very likely due to the increasing greenhouse gas concentration (IPCC 2007).

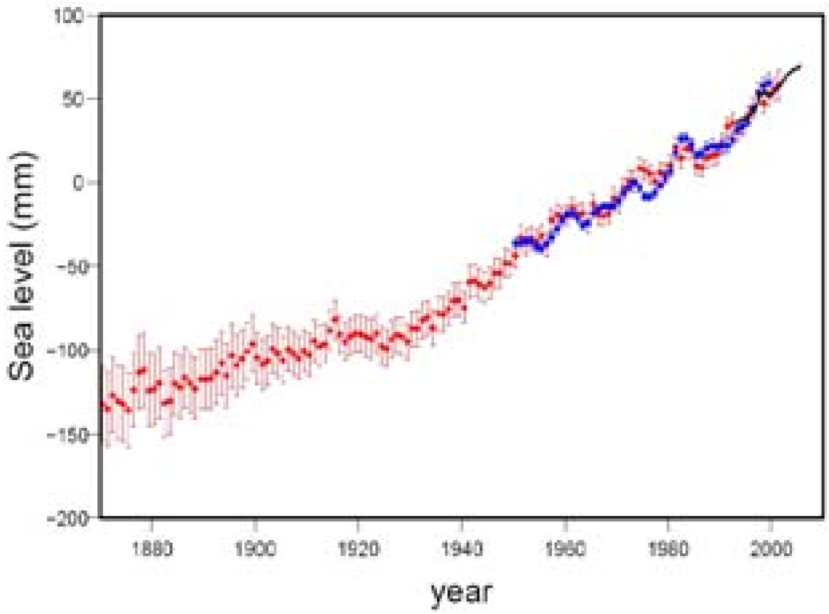
Particles slow warming

The levels of particles in the atmosphere have also increased, in part due to emissions of sulphur and soot during combustion. The increasing particle levels have a primarily cooling effect on the temperature of the earth's surface and are therefore likely to suppress some of the warming which would otherwise have taken place.

Rising sea levels

Over the period 1961–2003, global sea levels rose by just under 8 cm. This rise can be explained in part by an expansion of the seawater in conjunction with the warming of the oceans and in part by the melting of glaciers. The rise was around twice as fast during the period 1993–2003 as it was over the past 40 years. The increase in the rate of the rise is due primarily to the increasing expansion of the seawater due to global warming.

Figure 3.13 Sea level rise over the past 100+ years. (The 0 level is the average for the period 1961–1990)



Source: IPCC, 2007.

Certain extreme weather events more common

Some extreme weather events have become more common, and others less common. The number of cold winter nights and frosty days on land has fallen, while the number of very warm summer days and warm summer nights has increased. Both these trends are likely to be due to an increased greenhouse effect. The number of intense tropical cyclones has increased over the past 35 years, particularly across the Atlantic, and it is quite likely that this may be linked to global warming.

Better understanding of the interaction between the earth's surface and the atmosphere

Warming has occurred both at ground level and in the troposphere (the bottom 10 km of the atmosphere). Observations had not produced such a clear consensus at the time of the previous IPCC report (IPCC, 2001: Third Assessment Report, TAR). The level of water vapour in the atmosphere has increased in line with the warming of the atmosphere and in line with climate models.

3.3.2 Increasing concentrations of greenhouse gases lead to continued warming

Different scenarios for emissions suggest different levels of warming in the future

The scenarios for greenhouse gas emissions as used by the IPCC contain everything from extremely high increases in greenhouse gas concentrations in scenario A1FI to limited increases in scenario B1, with a range of scenarios in between. The higher scenarios assume a continued increase in the use of fossil fuels and so the continued rapid increase in carbon dioxide concentrations. Around the year 2100, carbon dioxide concentrations stand at almost three times the pre-industrial level in scenario A1FI. Scenario B1 assumes a technological and social development which enables the reduced use of fossil fuels. In this case, the increase in carbon dioxide concentrations is calculated to continue, until it stabilises at around twice the pre-industrial level. None of the IPCC's scenarios contain suppositions about international agreements to limit emissions.

A whole range of different climate models from research institutes around the world have been used to calculate the climate change which may be caused by increasing concentrations of greenhouse gases. Compared with the previous IPCC assessment, IPCC 2001:TAR, considerably more simulations have been carried out with a larger number of models. There is therefore now a much broader range of modelling data on which to base assessments. The climate simulations have been conducted for the timeframe 1990–2095. The B1 scenario projects an increase in the global average temperature of 1.8°C, with an interval of uncertainty of between 1.1°C and 2.9°C. The highest emissions scenario (A1F1) projects a global temperature rise of 4.0°C, with an interval of uncertainty of between 2.4°C and 6.4°C. The total interval of uncertainty of 1.1°C–6.4°C is not directly comparable with figures given in TAR, as a different methodology was used to calculate the uncertainty. The new methodology has been able to be used above all because so many different simulations have been available. The new scenario results correlate well with the results presented in TAR. Overall, this gives a high level of certainty to the conclusion that:

> Continued greenhouse gas emissions at or above current rates would cause further warming and induce many changes in the global climate system during the 21st century that would very likely be larger than those observed during the 20th century (IPCC, 2007).

Continued rise in sea levels

The level of the seas will continue to rise. The lowest emissions scenario (B1) projects a global average rise between 18 cm and 38 cm, while the highest scenario (A1FI) projects between 26 cm and 59 cm from around 1990 to 2095. The total interval of uncertainty is not directly comparable with figures given in TAR, as a different methodology was used to calculate the uncertainty. These calculations have not included the possibility that the deglaciation processes in Greenland and Antarctica may accelerate as a consequence of the continued global warming. These processes could cause a further rise in sea levels possibly during this century. The increase is expected to continue for several centuries, even if concentrations of greenhouse gases are stabilised. However, it should also be noted that the increase is not spread evenly across the world's seas. Regionally, e.g. in the Baltic Sea and the North Sea, the rise is expected to be 10–20 cm greater than the global average (IPCC, 2007b).

Uneven warming

The warming will not be evenly distributed around the world. It is expected to be considerably higher over the Arctic and the land masses of the northern hemisphere, with the Arctic experiencing around twice the global average. Across the seas of the southern hemisphere and in central parts of the North Atlantic, the warming is expected to be lower than the global average.

Heatwaves and heavy rain more common

It is very likely that heatwaves, heavy rain and winters with little snow will become more common in a warmer climate. In the Arctic region, sea ice may completely disappear during the summer months within this century. It is likely that the number of intense tropical cyclones will increase in a warmer climate. The westerly wind belt at our latitudes is tending to be pushed north, taking with it the path of low pressure areas and precipitation patterns. This trend is supported by observations over the past 50 years.

3.3.3 Feedback mechanisms, climate in the longer term and the risk of sudden climate change

The climate after 2100

Even if concentrations of greenhouse gases in the atmosphere are stabilised over the next century, warming is likely to continue for many decades. Eventually the temperature would level out, but the seas will continue to rise for a very long time. The continued expansion of seawater due to warming could raise sea levels by a metre or so in the long term. (Sweden's Scientific Council on Climate Issues, 2007).

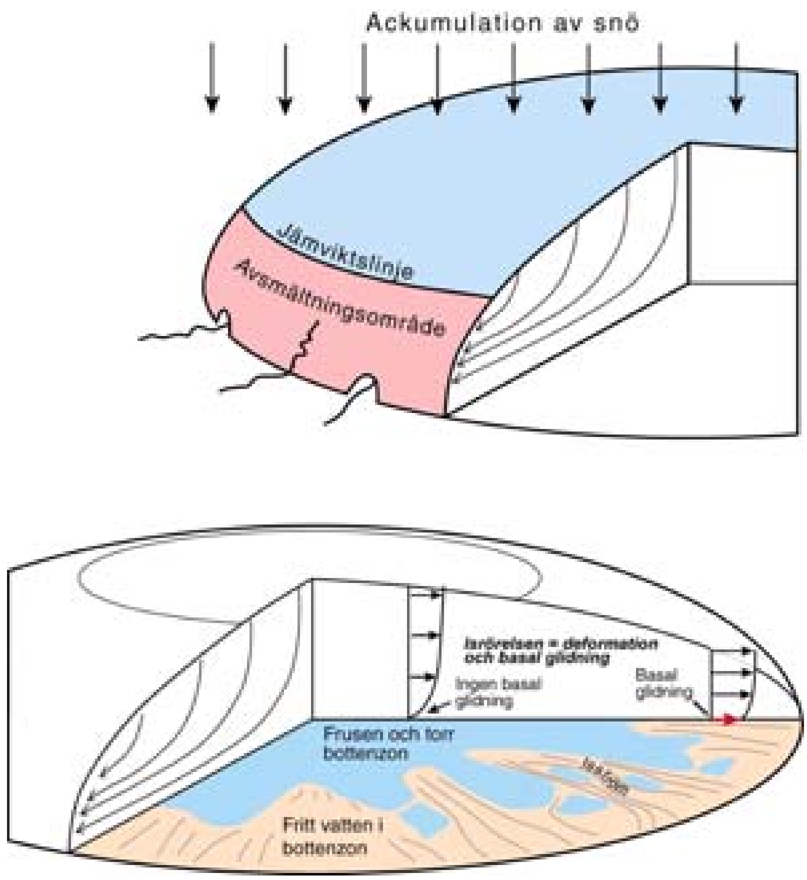
Fears of greater rises in sea level due to melting glaciers

In its 4th Assessment Report (AR4), the IPCC points out that the upper limit in particular for how high sea levels might rise over the next one hundred years is uncertain. Rises in sea levels could accelerate and exceed the 18–59 cm range that the IPCC projects if more of the Greenland ice sheet and parts of the Antarctic ice sheet melt. In TAR, this effect was partly incorporated into the 9–88 cm range. Another difference in the methodology of TAR and AR4 is that the results on future sea levels in AR4 relate to a rather shorter period than the results in TAR. In addition, AR4 covers a somewhat narrower level of probability distribution than TAR (IPCC, 2007b). Compared with the glaciers in the world's various mountain regions, there is much more water in the ice sheets of Greenland and Antarctica. Since these sheets expand and melt depending on precipitation and temperature, the balance is affected by climate change. If the Greenland ice sheet and the ice in Antarctica were to melt completely, the world's oceans would rise by about 7 m and over 62 metres respectively. Clearly, the addition of these masses of water far exceeds what the melting of minor glaciers and the thermal expansion of seawater could achieve. However, the ice sheets are monumentally slow to react.

The Greenland ice sheet

Due to its topographical location, with high central areas, the Greenland ice sheet is relatively stable. The ice reacts to a warmer climate by melting in a reasonably predictable way. The melt zones are found primarily along the coasts. New studies suggest that there has been greater melting in recent years. In a warmer climate, the areas where the ice melts away will expand inwards into central Greenland, see Figure 3.14. Warming over several hundred years, in line with the predictions of the IPCC's scenarios, could lead to the entire Greenland ice sheet melting within a few thousand years. This would lead to a rise in sea levels of around 7 metres. Some studies published in recent years suggest that the melting of the Greenland ice sheet may be progressing faster than was previously thought, see e.g. Meier, F, 2007.

Figure 3.14 Diagram representing the ice balance in an ice sheet



Source: Johan Kleman, 2007.

Accumulation of snow Equilibrium line Melt zone	
Ice movement = deformation and basal sliding	
No basal sliding	Basal sliding
Frozen and dry basal zone	Ice stream
Basal meltwater	

Antarctica

It is believed that considerable global warming would be required to initiate a more extensive melting of the Antarctic ice sheet. The Antarctic ice sheet is a gigantic mass of ice resting on the Antarctic continent. Ice shelves, made of thick, compacted glacial ice, surround significant parts of the continent. These ice shelves help to *keep the ice sheet in place.* The climate in Antarctica is extremely cold all year round and conditions differ from those in Greenland in a crucial way, with an almost total lack of melt zones. Nor is any major increase in melt zones to be expected in a warmer climate. The Antarctic ice sheet is therefore felt to be relatively insensitive to moderate warming. Ice levels in Antarctica may even increase initially, in the event of continued global warming, since precipitation in the area is expected to increase, and it will still be sufficiently cold for ice formation.

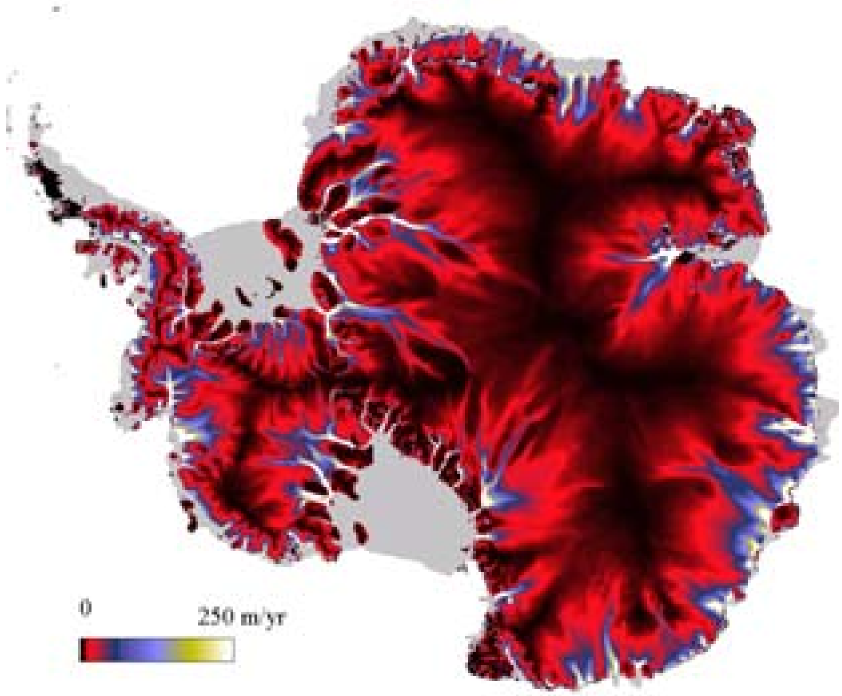
However, parts of the ice sheet, particularly the ice in West Antarctica, may lie in the danger zone. The West Antarctic Ice Sheet holds enough water to raise sea levels by around 5 m. Relatively rapid and major changes to the continental ice sheets cannot be ruled out either in Greenland or Antarctica, but the level of knowledge is not sufficient to make quantified assessments (IPCC, 2007).

During the Antarctic summer of 2002, part of the Larsen ice shelf in the West Antarctic collapsed. Over the course of five years, 5,700 km^2 of the ice has disappeared. The collapse of ice shelves may be caused by global warming. Since the ice shelves rest on the surface of the sea, a collapse has no direct effect on sea levels. However, the ice sheet behind the shelves is able to move more quickly and thin out if an ice shelf disappears.

More widespread collapses of ice shelves could lead to a partial collapse of large parts of the ice sheet in the West Antarctic, and the ice could slide out into the sea. Such collapses are well documented among the ice sheets of the last Ice Age in North America and Scandinavia, but have not yet been observed in today's remaining ice sheets. Collapses of this kind are governed by complex feedback mechanisms at the base of the ice. One controlling factor is friction against the rock below. In the event of rising sea levels, this friction could reduce, which could increase the risk of sliding.

However, the risk of a collapse of the West Antarctic Ice Shelf is not insignificant even without climate change. The lower boundary layer is well insulated from the climate system and the majority of ice carried to the sea follows fast-moving ice streams (see Figure 3.15). These change pattern and can switch off and on over a lifecycle of a few hundred years or a few thousand years. Climate change could increase the risk of a collapse due to rising sea levels. However, at this point in time it is not possible to calculate or predict the risk of such a collapse of parts of the Antarctic ice sheet.

Figure 3.15 Speed of movement of the Antarctic ice sheet (metres/year)



Source: Johan Kleman, 2007.

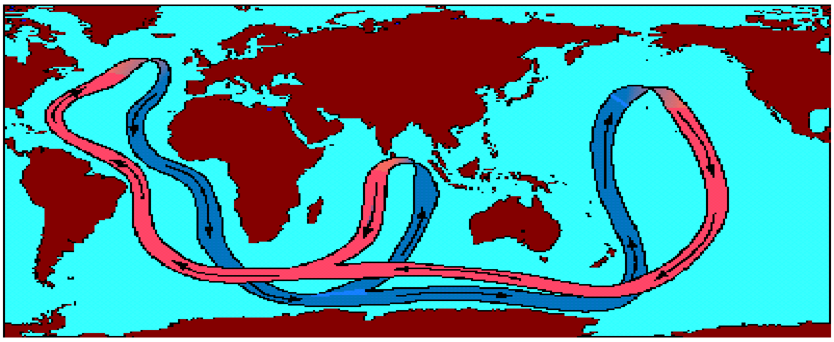
The future mass balance of the Antarctic ice sheet is clearly difficult to predict. Due to its huge volume and the small but not non-existent risk of partial collapses, Antarctica is a risk factor. The IPCC states a large interval of uncertainty regarding how the

Antarctic ice sheet has so far (1961-2003) contributed to raising global sea levels by 0.14±0.41 mm/year (IPCC, 2007).

The Gulf Stream

The question often arises of whether the Gulf Stream will stop or even reverse in a changed climate, and whether this would lead us into a new ice age. Answering these questions requires a certain understanding of how heat is transported around the planet and what drives the ocean currents. The Gulf Stream is part of the thermohaline circulation of the world's oceans, which is driven to a certain extent by differences in density between water masses which arise due to differences in temperature and salinity. Deep water masses are formed primarily in the northern North Atlantic. These deep water masses then move southwards in the Atlantic at a depth of 2 or 3 km, and on into the Pacific and Indian oceans. This outflow of cold deep water is balanced by an inflow of warmer water into the Atlantic nearer the surface. The current that moves north in the Atlantic, close to the surface, is what we call the Gulf Stream. The wind is also of great significance to the Gulf Stream, which transports large quantities of heat to the North Atlantic. Increased precipitation and meltwater from melting ice sheets could reduce salinity in the north, slowing the circulation and reducing its transport of heat, which would have an impact on the climate, particularly around the North Atlantic. Discussions on whether this has happened before often focus on an event around 11,500 years ago, at the end of the last Ice Age, when large quantities of meltwater had built up in North America. When this fresh water then flowed out into the North Atlantic, the effect was so great that the Gulf Stream was affected and the climate, at least regionally, became several degrees colder for a while. However, the Gulf Stream recovered eventually (IPCC 2007b).

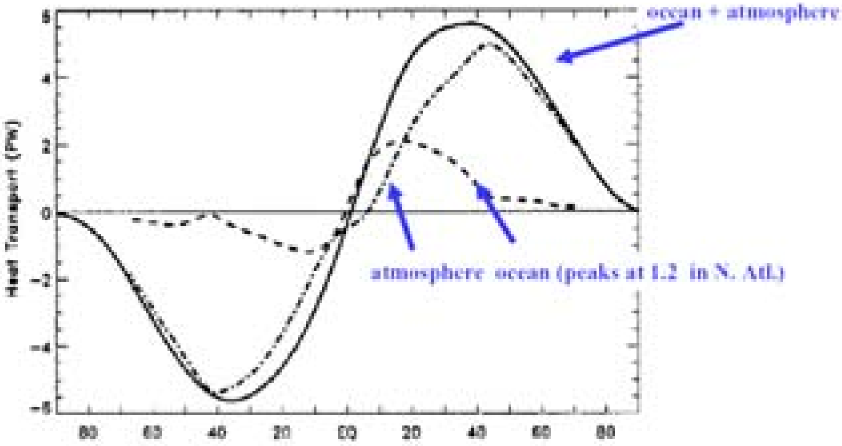
Figure 3.16 Diagram of the global ocean circulation



Source: Johan Nilsson, MISU.

The oceans and ocean currents play a key role, particularly in transporting heat at the lower latitudes. For us, the Gulf Stream, or in fact its north-easterly extension, which is called the North Atlantic Drift, is important, but it does not itself have such power that it alone can explain the relatively mild climate that we have. Heat transport to our latitudes is considering greater via the atmosphere (see Figure 3.17).

Figure 3.17 Heat transport from low to high latitudes. The X-axis shows latitude and the Y-axis shows heat transport. The dotted and dashed line shows transport via the atmosphere and the dashed line transport via ocean currents. The solid line represents total heat transport



Source: Cecilie Mauritzen, 2007.

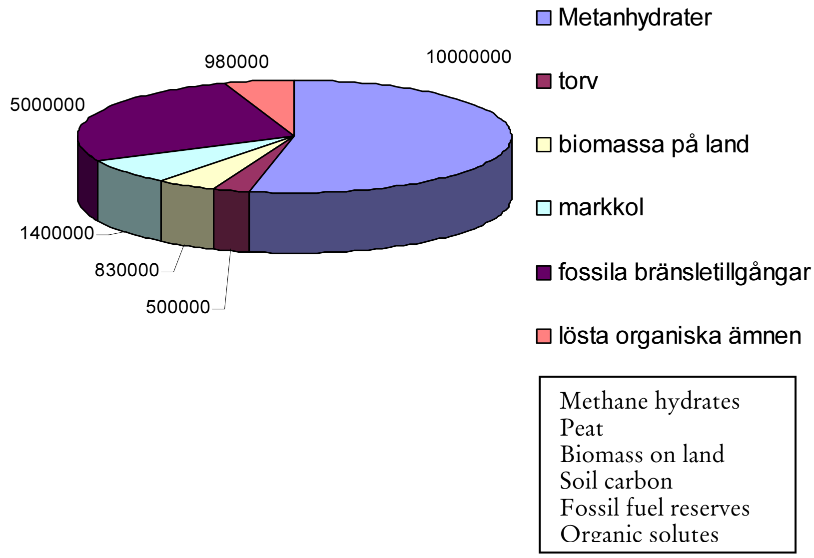
However, the way the Gulf Stream and thermohaline circulation change is of significance for the climate in the North Atlantic area. Continuous studies of how the currents are changing have only been conducted for around 10 years. Some measurement data is available for around the past 50 years.

It would appear that the water in the North Atlantic has become less saline and warmer over the past 50 years. The North Atlantic Drift has also reduced in strength. However, it is uncertain how much it has changed. Model calculations from potential emissions scenarios suggest a weakening of the Gulf Stream due to climate change, but it does not stop or change direction during this century. A very large majority of the climate models show that a generally large warming of northern latitudes may be lessened somewhat in the area south of Greenland, but there is no question of any absolute temperature reduction. The effect on the Nordic region is only marginal.

Release of methane

Methane is the second most important greenhouse gas. Emissions come both from human activity and from wetlands, for example. Methane is naturally stored in various forms and emissions from the stores may be affected by climate change. How methane stored in permafrost will react to climate change is a complex question. It is likely that methane is already being released in significant quantities, as permafrost is eroded and melts, but this probably constitutes a relatively small proportion of the total emissions of methane. The melting of discontinuous permafrost is currently leading to expanding wetlands in the Arctic areas, resulting in increased methane emissions. However, these emissions are also relatively modest. Emissions from lakes in areas of tundra and forest are another source on the rise. Methane hydrates which exist at greater depth are potentially a major source of emissions. Large quantities of methane are stored as methane hydrates on the seabed and to some extent in permafrost in the form of methane gas encapsulated in ice. It is estimated that there is more carbon in these methane hydrates than in the known reserves of coal, oil and natural gas combined, see Figure 3.18.

Figure 3.18 Distribution of carbon in different sources on earth today (million tonnes)



Source: Adapted from Torben Christensen, 2007.

Methane hydrates are heat-sensitive and it is speculated that global warming which reaches down to the seabed could lead to the release of large quantities of methane into the atmosphere. Since methane is an effective greenhouse gas, this could increase global warming considerably, compared with the effect of emissions from human activity. The destabilisation of methane hydrates in the sea may have happened around 55 million years ago, with sudden global warming as a consequence. This could also be a possible explanation for certain other catastrophic periods in the planet's earlier climate history. Today's climate scenarios do not include contributions from methane hydrates. It is currently difficult to assess how great the risk is of a major release of methane hydrates. (Torben Christensen, 2007).

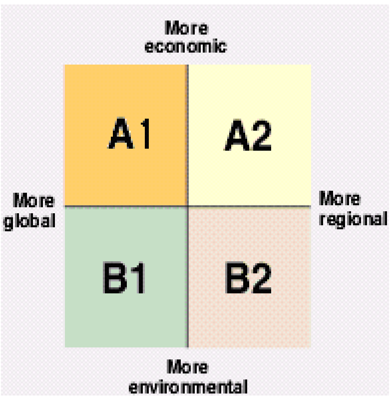
3.4 Choice of scenarios and models

3.4.1 Characteristics of emissions scenarios

The IPCC's climate scenarios are based on socio-economic scenarios. The most recent are presented in the Special Report on Emissions Scenarios, *SRES* (IPCC, 2000). These scenarios represent consistent developmental paths for the key factors which drive emissions of greenhouse gases, namely demographic, social, economic and technical development. However, the scenario descriptions do not cover assumptions about direct actions to reduce emissions.

SRES comprises four different narrative storylines, designated A1, A2, B1, and B2. These are in fact four families of scenarios, but there is a main alternative for each group. A significant difference between the scenarios is the level of globalisation, which is assumed to impact on economic and technical development considerably, with a consequent impact on emissions. In the A-scenarios, the focus is on economic growth, while the B-scenarios show more sustainable development.

Figure 3.19 Characteristics of different emissions scenarios

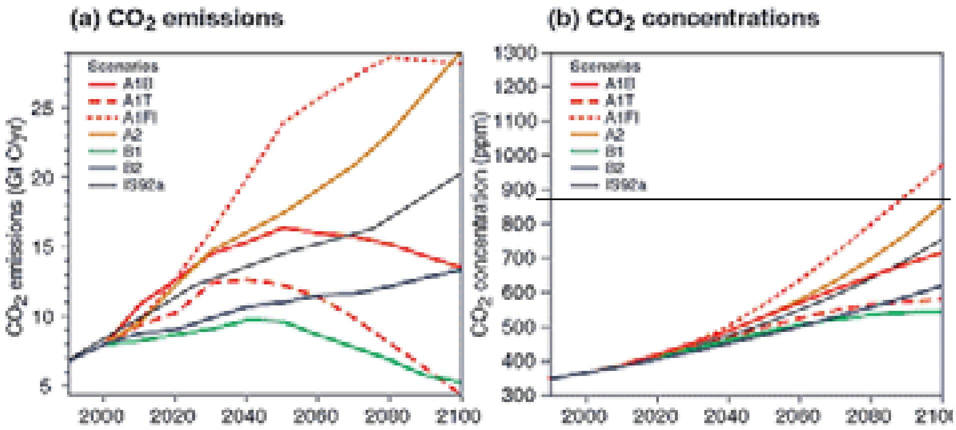


Source: IPCC 2000.

Scenario A1 describes a world characterised by high economic and cultural globalisation, low population growth and rapid economic growth. It assumes a rapid introduction of new technology and the rapid spread of this around the globe. How carbon-intensive the new technology is has a major impact on annual emissions of carbon dioxide. After an initial increase in each A1 alternative, the emissions levels diverge in all cases. By the year 2100 we may be looking at over 30 Gigatonnes of carbon (GtC) according to scenario A1FI or around 4 GtC according to scenario A1T. Global warming will be considerably less towards the end of the century, with fewer emissions overall, rising by 2.4°C in A1T, but 4.0°C in A1FI during the same period.

Scenario A2 represents a heterogeneous world with very different regional development. The population continues to grow due to uneven development and slowly converging fertility patterns. Economic growth per capita and technological development are more fragmented and slower than in the other scenarios. Emissions continue to increase to just under 30 GtC around 2100. The temperature increases in scenario A2 by 3.4°C by the end of the century.

Figure 3.20 Carbon dioxide emissions and concentrations according to different scenarios



Source: IPCC, 2000.

Scenario B1 describes a converging world with the same population development as in A1, but with faster changes towards a service and information economy. This results in reduced material intensity, and a faster introduction of clean technologies. The scenario also assumes increased global equality and has an emphasis on sustainable development. Carbon dioxide emissions level out and then drop beyond 2040. They peak at 10–15 GtC and fall below 1990 levels by 2100. The temperature increase by the end of the century is put at 1.8°C.

Scenario B2 introduces local solutions to economic, social and environmental sustainability. The population increases, but not as quickly as in scenario A2. Economic development is good, but not remarkable, and technical development is less rapid than in scenarios A1 and B1. Development is oriented towards sustainability, but with a local and regional focus. Emissions increase relatively slowly, amounting to around 10–15 GtC by 2100. The temperature increase is put at 2.4°C.

3.4.2 Our choice of scenarios and models

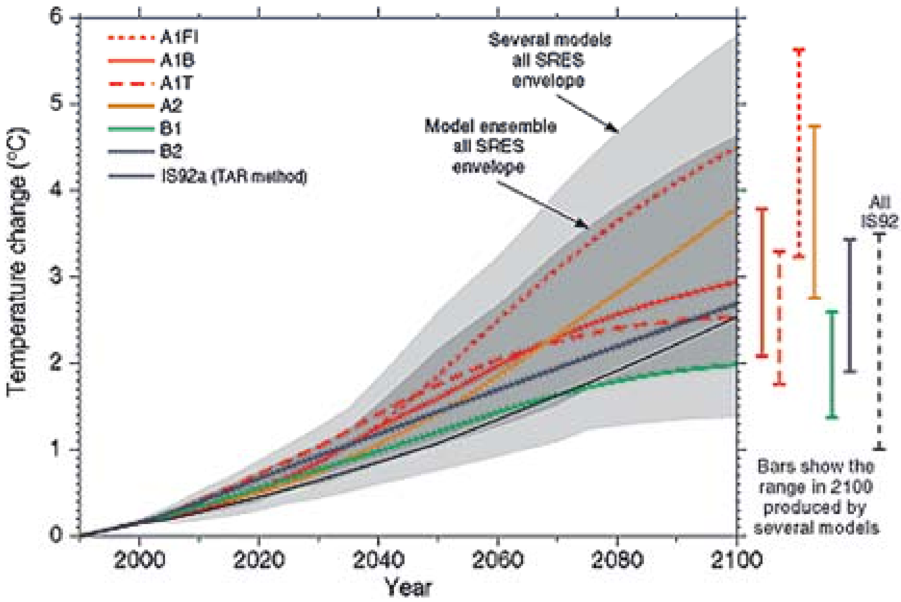
Choice of scenarios

The commission has chosen to focus on scenarios A2 and B2. These scenarios have been chosen for several national adaptation studies in recent years (e.g. Finland). The same scenarios were also chosen for the European Commission's PESETA study, within which a vulnerability analysis is being conducted for Europe. In addition, there is a great availability of global and regional models which have run these scenarios. Both the A2 and B2 scenarios describe a fairly fragmented world with an increasing population and a slow spread of technology. However, in the B2 scenario, there is more of a focus on sustainable development in all its three aspects. Energy consumption is greater in A2 than in the B2 scenario. Actual energy consumption increases in both scenarios, but energy efficiency increases at the same time, so that energy consumption per dollar falls by around 50 percent by 2100 in both scenarios. The proportion of carbon is less in the B2 scenario than in A2 and only increases a little, and fossil-fuel-free energy sources increase more quickly. Several factors, including more rapid population increases in the A2 scenario, mean that emissions increase more than in B2. However, up until around 2050, the difference between the two scenarios in terms of emissions is relatively small. The two scenarios cover a range between low and high emissions. The emissions trend in the B2 scenario projects a concentration of carbon dioxide of around 550 ppm by the end of the century, which is double pre-industrial concentrations. In the

A2 scenario, carbon dioxide concentrations treble to around 850 ppm. A discussion of socio-economic development in Sweden in the long-term is presented in section 4.8.1

Our choice of scenarios has not been made based on socio-economic conditions, but more based on the emissions trend, with the purpose of considering a reasonable range. We have chosen a higher mid-range scenario with A2 and a lower mid-range one with B2. The B2 scenario arrives at a global temperature rise in a hundred years that more or less equals another scenario, A1T. A1T is a scenario of rapid global development and a rapid spread of new technology which keeps emissions down.

Figure 3.21 Global temperature changes according to different climate scenarios



Source: IPCC, 2001.

Global and regional climate models – our choice of models

Global climate models describe the circulation of the atmosphere and the oceans, and interactions between these and land masses, vegetation, etc. Regional climate models are used to scale down the results from the global models to a local and regional level. The chief advantage is that they allow a better description of the topography and distribution of land, sea and lakes. The greater resolution in regional models also allows better simulation of weather conditions at a local and regional level, such as frontal systems. It is therefore desirable to be able to base an analysis of vulnerability in society on the results of regional climate models.

Although different global models give quite comparable global and also continental averages for warming, etc., their descriptions of large-scale circulation patterns vary a great deal, which could have a major effect on regional considerations. As such, it is appropriate to study effects on the regional climate with the help of several global models which have been scaled down using a regional model. We have made use of two global climate models. The full names of these are HadAM3H and ECHAM4/OPYC3. Their choice has been governed to a large extent by the fact that they are the two models which SMHI's Rossby Centre has scaled down using its regional models. ECHAM4 is the only model which has so far (summer 2007) been scaled down within our region using a regional model for the various timeframes, from now until the end of the 21st century, which the commission has studied. ECHAM4/OPYC3 is a coupled atmosphere-ocean model developed by Deutsches Klimarechenzentrum GmbH (DKRZ) and the Max Planck Institute for Meteorology (MPI). HadAM3H is an atmosphere model that forms part of the coupled climate model HadCM3.

For comparisons with historical climate, we have used data from ERA40, which was compiled by re-analysing observational data from the period 1961–2005, as this gives a better description of the actual historical climate than climate models (see below). The results from ECHAM4/OPYC3 and HadAM3H scaled down with regional models show relatively large differences between each other for certain climate parameters. The main differences are in precipitation quantities and wind climate, while agreement is greater between the models with regard to temperature and precipitation patterns. For many climate parameters, the differences between the models are also greater than the differences between emissions scenarios A2 and B2 in the same model by the end of the century.

Characteristics of the regional climate models we used

The uncertainties within the global climate scenarios naturally also affect the regional climate scenarios, but there are also other causes of uncertainty in regional assessments. Knowledge is still limited regarding the impact of particles on the climate. However, it is clear that their impact is greater in some regions than it is globally. One and the same projected level of global warming may also lead to different changes in general circulation, and so to uncertainty regarding the level of warming locally. Finally, natural variations in temperature, precipitation, etc. are generally much greater regionally than on a global scale. Overall, this means a need for several regional scenarios in order to show which results are robust and similar between the scenarios, and where the main uncertainties lie.

In the commission's work, we have made use of two regional climate models from SMHI's Rossby Centre. We used the atmosphere model RCA3 and the coupled model RCAO, which comprises atmosphere model RCA2 and oceanographic model RCO. The RCA3 model has a grid resolution of around 50x50 km. RCO has an even greater resolution for the sea. RCAO, RCO and RCA3 have been assessed against today's climate in earlier studies (Jones et al. 2004; Kjellström et al. 2005; Meier et al. 2003). These studies show that the regional models are well able to recreate many characteristics in today's climate for the Nordic region, in terms of both precipitation and temperature.

However, some characteristics do deviate from observational data. For example, RCAO has a tendency to show too many instances of light precipitation. RCA3 also tends to overestimate precipitation in northern Europe in the summer. RCA3 is otherwise generally an improved model, compared with the country model within RCAO, in terms of recreating temperature and precipitation. RCA3 does, however, show winter temperatures that are too high in north-eastern Europe, an area that affects Sweden. The model also shows too little daily variation. In general, the 95th percentile of the highest temperatures is underestimated by up to around 6°C. A similar picture emerges when estimating the lowest temperatures. This means that the model results give certain systematic errors, for example with regard to the climate index for tropical nights, summer days and cooling degree days. The prevailing definitions (Tmin >20°C and Tmax >25°C and CDD average

>25°C) were therefore adapted in the analyses we conducted to Tmin >17°C, T max >20°C and CDD average >20°C.

In the report, we refer in most cases to the regional downscalings of the global models as follows: ECHAM4/OPYC3 downscaled using the RCA3 model for scenario A2 we call RCA3-EA2. Regional downscalings of HadAM3H using the RCAO model are denoted in the same way, e.g. RCAO-HB2.

Hydrological models

The hydrological runoff model we used in our vulnerability analyses regarding flooding is the HBV model, developed by SMHI in the early 1970s and constantly improved ever since. In the HBV model, the runoff area is divided into sub-areas within which heights and vegetation zones (forest, open land, lakes and glaciers) are classified. The model is a combination of physical and empirical models, where physical laws are applied in simplified form. The HBV model has a simple structure and is essentially built up of three main modules, one for calculating snow melting and snow accumulation, one for calculating soil moisture and a third model for calculating the routes of the water through groundwater, watercourses and lakes. In addition to precipitation and temperature, potential evapotranspiration is also used to drive the HBV model.

We had calculations made of changes in runoff across the country within four different climate scenarios for the period 2071–2100 compared with the period 1961–1990. The calculations were founded on SMHI's regional model RCAO, based on four global climate scenarios – ECHAM4, A2 and B2, plus HadAM3H, A2 and B2. In addition to these four scenarios, a continuous simulation was also conducted for the entire timeframe 1961–2100 using the regional model RCA3 and the global model ECHAM4 B2. Here, a new method (called the scaling method) was used. It is more likely that the changes for extremes (100-year-return flows) are underestimated rather than overestimated under the scaling method. It should be noted that the calculations based on the scaling model are more preliminary than the other calculations. The method is still under development. Furthermore, all results from the HBV model should be used in the first instance for a general interpretation and for identifying where more in-depth studies may be needed.

Uncertainties in analysing society's vulnerability

Our aim is to highlight how different sectors of society and the environment are affected under all four of the climate scenarios we studied. In order to see trends over the coming century, we were referred in the first instance to the ECHAM4 model, since HadAM3H is not downscaled to regional level except for the 30 year period 2071–2100. As, for the whole timeframe from now to the end of the century, we only had access to downscaled climate data in the regional RCA3 model, the analyses of vulnerability for different sectors have primarily been based on conclusions drawn from the results of this regional model.

We also, in certain cases, focused our vulnerability analyses on the A2 scenario of ECHAM4. The main reasons why we chose to focus on this scenario were the fact that we had limited resources and time available, and that greater climate change gives clearer outcomes and greater opportunities to see changes in different sectors of society. In this way, a broader spectrum of consequences is covered. However, we may have overestimated the effects of climate change in some cases, since A2 is a scenario which projects relatively extensive – but not extreme – climate change. At the same time, we have striven to conduct sensitivity analyses involving the B2 scenario and both the A2 and B2 scenarios modelled using HadAM3H, where significant differences exist. Similarly, we have, as far as possible, compared the results from two different regional models, RCA3 and RCAO. By choosing this approach, we believe that we have, to a reasonable extent, accounted for the uncertainties which may exist.

3.5 How will the climate change in Sweden and our immediate vicinity?

Warming in Sweden is expected to be greater than the global average. Climate change over the next few decades is dependent primarily on historical emissions of greenhouse gases, due to the inertia of the climate system. The size of the temperature increase towards the end of the century depends on the levels of future global emissions of greenhouse gases. Major changes to precipitation patterns are also expected, although the extent that the wind climate will change in Sweden is less certain.

In this section, we describe how climate change manifests itself according to the scenarios we chose to apply. These scenarios reflect a likely development, but the uncertainty is great and the change could be greater or smaller, and may also differ in geographical details if other scenarios are used. However, the broad outcomes in the chosen scenarios match the regional climate change signals projected by a large number of global climate models in the most recent IPCC report (Christensen et al., 2007). This means the greatest warming in the winter, primarily in the north-east. Precipitation is expected to increase throughout the year and across the country. However, in southern parts of the country the scenarios show a reduction during the summer. All the changes described in this section are based on averages for the reference period 1961–1990. We refer to the period 2011–2040 as the 2020s, and so on.

Table 3.2, below, presents the main features of climate change in Sweden for the chosen scenarios within the different timeframes. The intervals in the table represent differences between different parts of the country. The map data in sections 3.5.1–3.5.4 is based on data provided by SMHI.

Table 3.2 Changes on land in Sweden to average temperature, average precipitation and average wind speed according to different scenarios, compared with corresponding values during the reference period 1961–1990

	1991–2005	2011–2040	2041–2070	2071–2100
Average temperature, °C				
Winter				
RCA3-ERA40	+ 1–2			
RCA3-EA2		+ 2–3	+ 3–4	+ 4–7
RCA3-EB2		+ 1–3	+ 2–4	+ 3–6
RCAO-HA2				+ 3–5
RCAO-HB2				+ 2–4
Summer				
RCA3-ERA40	+ 0–1			
RCA3-EA2		+ 1–2	+ 1–3	+ 2–4
RCA3-EB2		+ 0–2	+ 1–3	+ 2–3
RCAO-HA2				+ 2–4
RCAO-HB2				+ 1–3
Average precipitation, mm/month				
Winter				
RCA3-ERA40	+ 0-50			
RCA3-EA2		+ 20-50[1]	+ 40-50[1]	+ 40-50[1]
RCA3-EB2		+ 20-50[1]	+ 30-50[1]	+ 40-50[1]
RCAO-HA2				+ 40-50[1]
RCAO-HB2				+ 30-50
Summer				
RCA3-ERA40	+ 0–50[1]			
RCA3-EA2		-30 – +30	-30[2] – +20	-30[2] – +40
RCA3-EB2		-30 – +30	-30 – +30	-30[2] – +30
RCAO-HA2				-30[2] – +30
RCAO-HB2				-30[2] – +20

	1991–2005	2011–2040	2041–2070	2071–2100
Average wind speed, m/s				
Winter				
RCA3-EA2		+ 0–0.6		+ 0.2–0.8
RCA3-EB2		+ 0–0.6		+ 0.0–0.6
RCAO-HA2				-0.2 – +0.2
RCAO-HB2				-0.2 – +0.2
Summer				
RCA3-EA2		-0.2 – +0.2		-0.4 – +0.2
RCA3-EB2		-0.2 – +0.2		-0.2 – +0.2
RCAO-HA2				-0.2 – +0.2
RCAO-HB2				-0.2 – +0.2

1) The increase may be greater than 50 mm.
2) The decrease may be greater than 30 mm.

3.5.1 Considerably warmer in the future

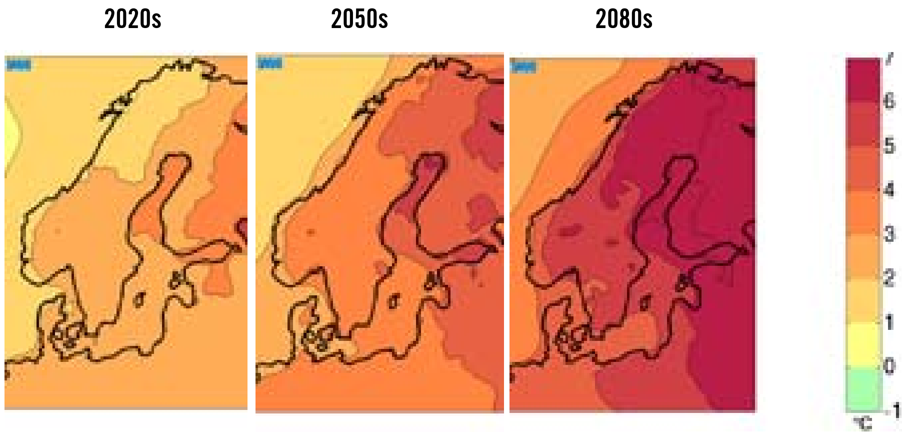
Average temperatures increase gradually and climate zones shift north

Looking at average temperatures, by the 2020s warming will be around 2°C, mostly during winter, slightly less in spring and autumn and least in summer. With this warming, Skåne's previous average temperature will be experienced in Mälardalen. The central Norrland coast will have an average annual temperature similar to that of the Småland coast in the previous climate. By the 2050s, warming is put at 2–3°C, with the same seasonal distribution. By the 2080s, warming is up to around 3–5°C, mostly in the north-easterly parts of the country. In terms of temperature, Mälardalen's climate will be similar to that of northern France today.

Winters up to 7°C warmer by the end of the century

By 2020, the average temperature in January will increase by between 1.5°C and 2.5°C across large parts of the country. By the 2050s, the increase is around 2.5–4°C and by the 2080s we are looking at an increase of 5–6°C in Götaland and 6–7°C in large parts of Norrland according to the RCA3-EA2 scenario. One of the main causes of this considerable warming is a reduction in the duration and thickness of the snow cover.

Figure 3.22 Change in average temperature in January, RCA3-EA2

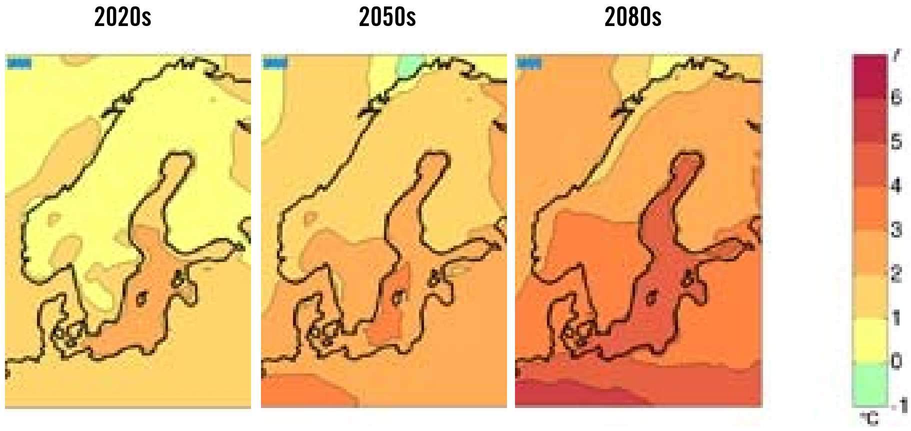


The Norrland coast experiences the greatest increases, with reduced snow cover and less ice in the Gulf of Bothnia contributory factors. Patterns for February are similar, possibly with a slightly more marked warming along the Norrland coast. The increase is generally somewhat less in December than in January and February. The increase is generally 1–2°C less by the 2080s in RCA3-EB2 than in RCA3-EA2. The increases are also less in RCAO-HA2. There, the increase stops at around 3–4.5°C, with a clear maximum in eastern parts of the country. The increase is even less in RCAO-HB2. However, both RCAO-H scenarios project a somewhat greater increase for December than the two RCA3-E scenarios, at least in north-eastern Norrland.

The summers will also be much warmer

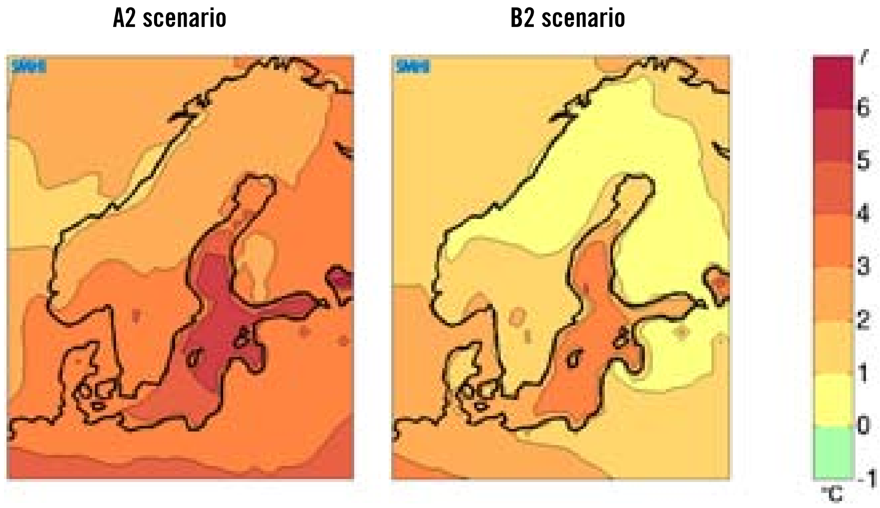
According to RCA3-EA2, the average temperature in July will rise by 0.5–1.5°C by the 2020s, by around 1.5–2.5°C by the 2050s and by 2–4°C by the 2080s. Generally, the increases are greater along the coasts, particularly around and above the Baltic. The increases are of a similar magnitude in June and August.

Figure 3.23 Change in average temperature in July, RCA3-EA2



In RCAO-HA2, the increase in summer temperatures over the land by the 2020s is of a similar size, but in the RCAO-HB2 scenario, the increase stops at 1–1.5°C in July across most of the country. Generally speaking, the RCAO-H scenarios project an even greater increase in temperatures across the Baltic Sea in the summer, up to 5°C in July across central parts in the A2 scenario for the 2080s.

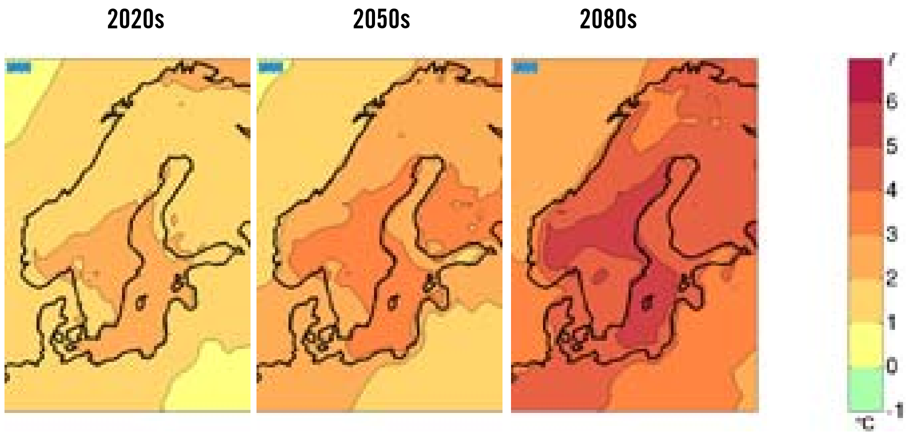
Figure 3.24 Change in average temperature in July by the 2080s, RCAO-H



Warming will be greater in spring and autumn than in summer

Warming in April is around 1.5–2.5°C by the 2020s across the majority of the country, around 2–3.5°C by the 2050s and 3.5–5°C by the end of the century, according to RCA3-EA2. The greatest increase in temperatures is expected to occur in central Sweden, particularly along the east coast. This pattern is confirmed in many of the results from both RCAO-H scenarios. RCA3-EB2 and RCAO-HB2 project a warming that stops at around 2.5–3.5°C by the end of the century, with largely the same geographical pattern.

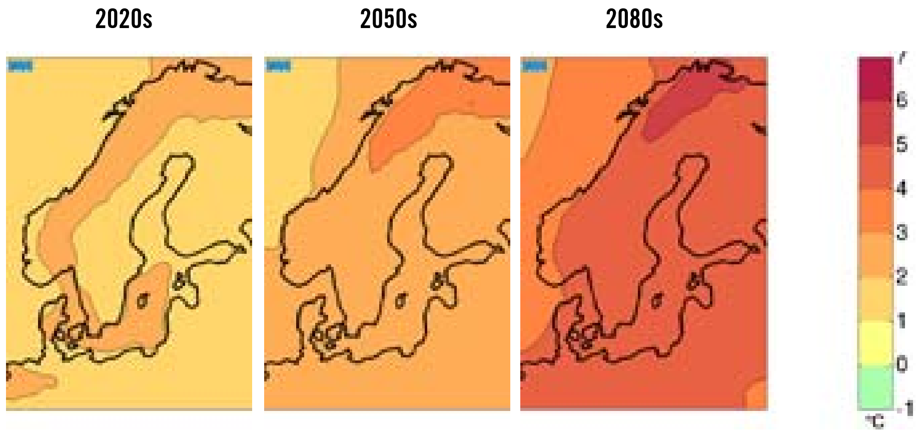
Figure 3.25 Increase in average temperature in April, RCA3-EA2



The warming is generally greater in March, almost comparable with January and February, and is slightly less in May.

In autumn, the warming is greatest in November in northern Sweden, up around 6°C by the end of the century. In October and in southern parts of the country in November, the warming is less, around 1.5–2°C by the 2020s, around 2.5–3°C by the 2050s and around 4–4.5°C by the 2080s, according to RCA3-EA2. The warming is slightly less in September.

Figure 3.26 Increase in average temperature in October, RCA3-EA2



According to both RCAO-H scenarios, warming during the autumn months is somewhat greater by 2080 than in corresponding RCA3-E scenarios, particularly in the sea areas. According to RCA3-EB2 and RCAO-HB2, the warming will stop at around 2–3°C for the majority of the country, but will be higher in November according to RCAO-HB2.

Major increase in hot days and tropical nights, largely in southern Sweden

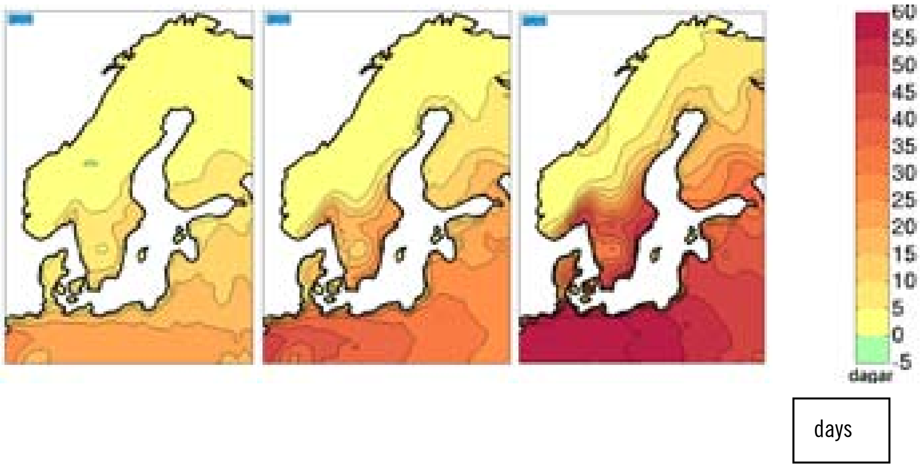
One manifestation of the warmer climate we can expect is that the number of days in the summer with a maximum temperature above 20°C will increase. According to the scenarios, we will have many more hot days, particularly in southern Sweden.

The increase is modest by the 2020s, with just under 10 more such days at most, but by the 2050s the increase is over 20 days in large parts of southern Sweden's coastal areas, and by the 2080s the projection is for over 40 more days over 20°C, according to the RCA3-EA2 model. In the RCA3-EB2 scenario, the increase is less, with around 30 more days at most in eastern parts of Götaland and Svealand by the end of the century. The RCAO-H scenarios give similar results, but here the increase is more pronounced across the whole of southern Sweden.

It should be noted that the models used have inherent systematic errors, which mean that the daily amplitude and the annual amplitude are underestimated. A projected top temperature of 20°C should therefore in reality be more like 25°C, i.e. the temperature usually used to define a summer day, see also section 3.4.1.

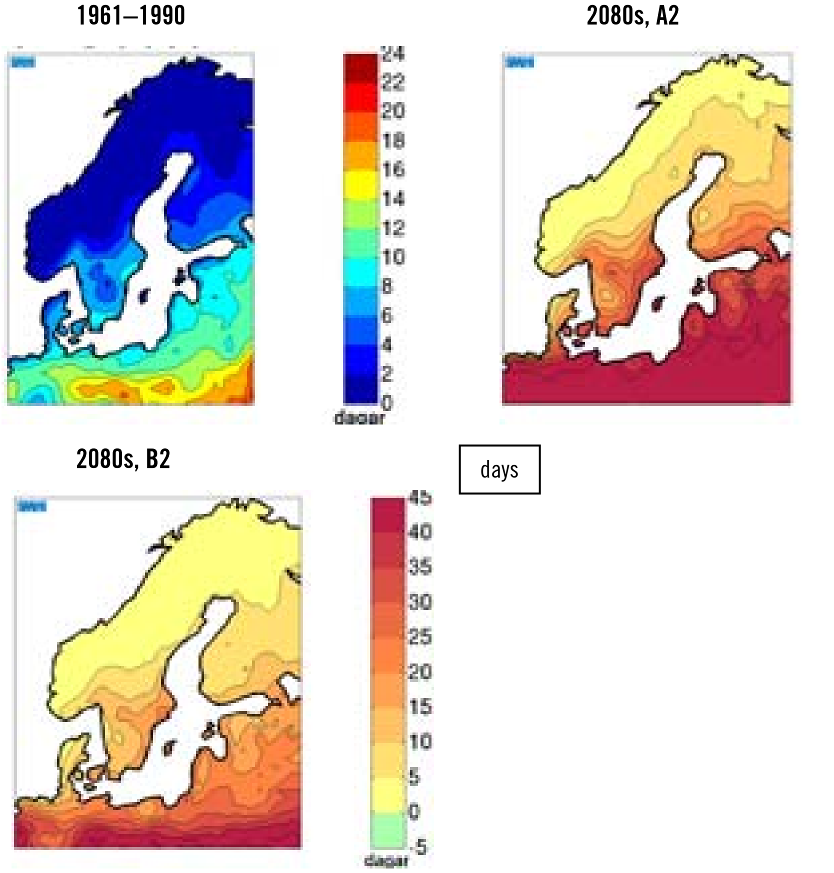
Figure 3.27 Increase in the number of hot days with a top temperature of over 20°C, RCA3-EA2

2020s **2050s** **2080s**



The higher summer temperature also means that heatwaves, with several hot summer days in succession, will be more common and more prolonged. Figure 3.28 below shows how many more days in succession the temperature will exceed 20°C on average during the summer at the end of the century, compared with the reference period 1961–1990, according to the two scenarios. It clearly shows a tripling in the number of days in southern Sweden in the RCA3-EB2 scenario. In the A2 scenario, the increase is even greater. According to the RCAO-H scenarios, the increases are slightly less, but they still project a doubling in southern Sweden.

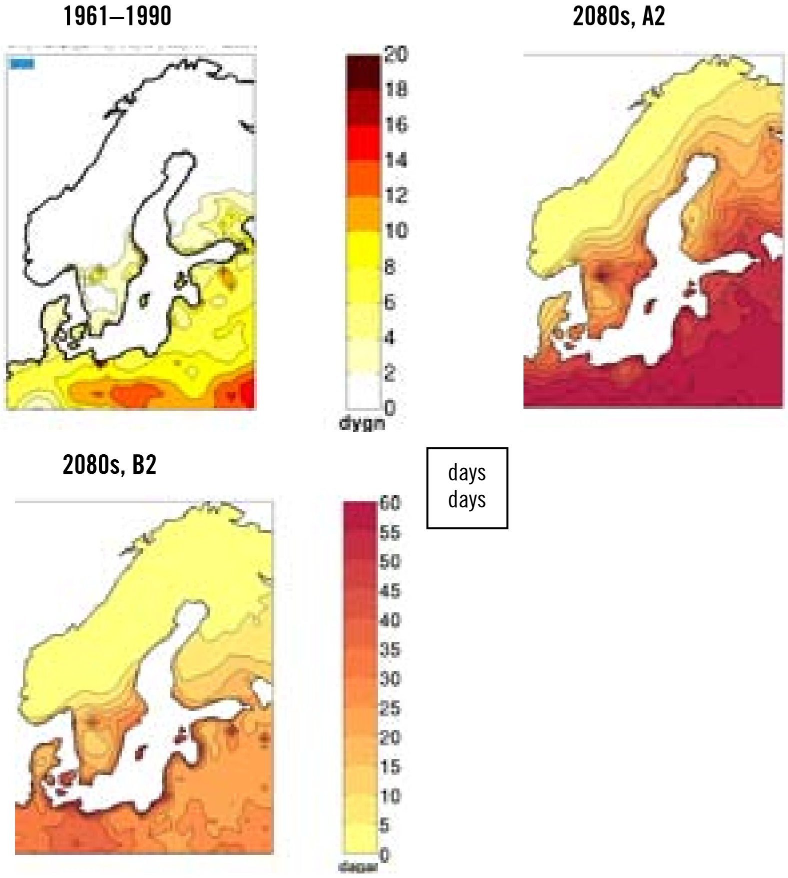
Figure 3.28 No. of consecutive days during the period 1961–1990 on which the temperature exceeded 20°C, RCA3-ERA40, and increase in the no. of consecutive days on which the temperature exceeds 20°C by the 2080s, RCA3-E



Another manifestation of the warmer climate is the occurrence of tropical nights, when the temperature does not fall below 20°C. Here, it should be noted that the systematic errors of the models have been compensated for by using a lower threshold value of 17°C. This can be considered equivalent to 20°C, which is the accepted threshold for tropical nights.

Towards the end of the century, along the coast of southern Sweden, we may have up to 40 tropical nights per year, according to the scenario RCA3-EA2, with RCA3-EB2 projecting a lower increase. In today's climate, tropical nights essentially only occur along the coast, and even during hot summers, there are rarely more than a handful.

Figure 3.29 No. of tropical nights during the period 1961–1990, RCA3-ERA40 and no. of such nights per year in the 2080s, RCA3-E



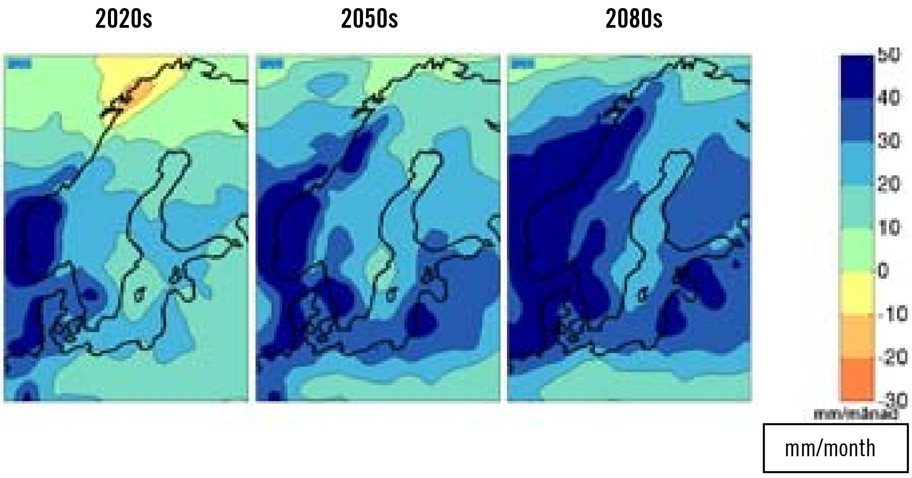
3.5.2 Wetter winters, drier summers in the south, higher flows

The trends and large-scale patterns for precipitation change are similar across the climate scenarios studied by the commission. Precipitation increases generally, but mostly in western Sweden and during the winter.

Increased precipitation during the winter

According to the RCA3-EA2 scenario, precipitation increases by around 20–50 mm, or approximately 50 percent, in January by the 2020s. The increase is less in absolute terms further east and further north. By the 2050s, the increase amounts to 40–50 mm in parts of western Sweden, less in the east. By the 2080s, the increase is more than 50 mm in the most affected areas, which is near enough double the figure for the period 1961–1990. The increase is generally less in February, while the changes in December are similar to those in January.

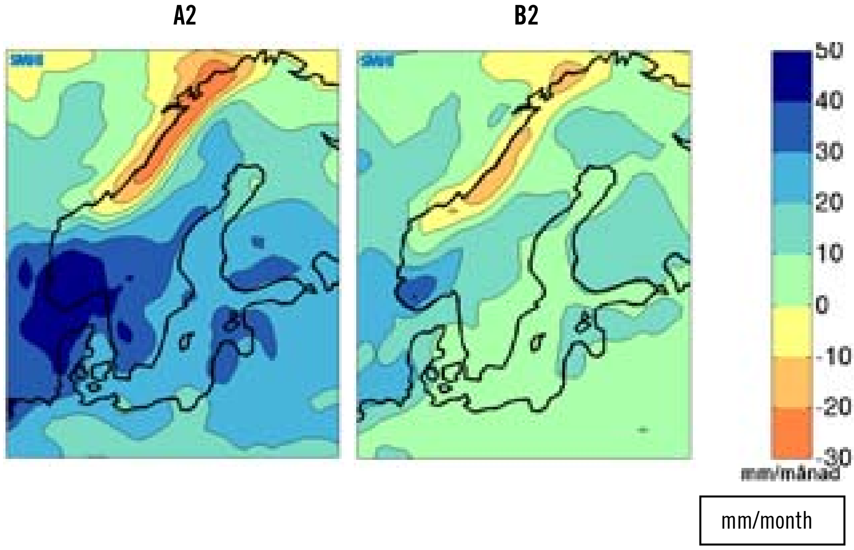
Figure 3.30 Change in average monthly precipitation in January, RCA3-EA2



In contrast to the RCA3-E scenarios, the RCAO-H scenarios project a reduction in precipitation in the Norrland mountains. The reduction is greatest in the mountains of Jämtland and Lapland

and in the A2 scenario. The increase in Västra Götaland and Svealand is, however, similar to that given in the RCA3-E scenario.

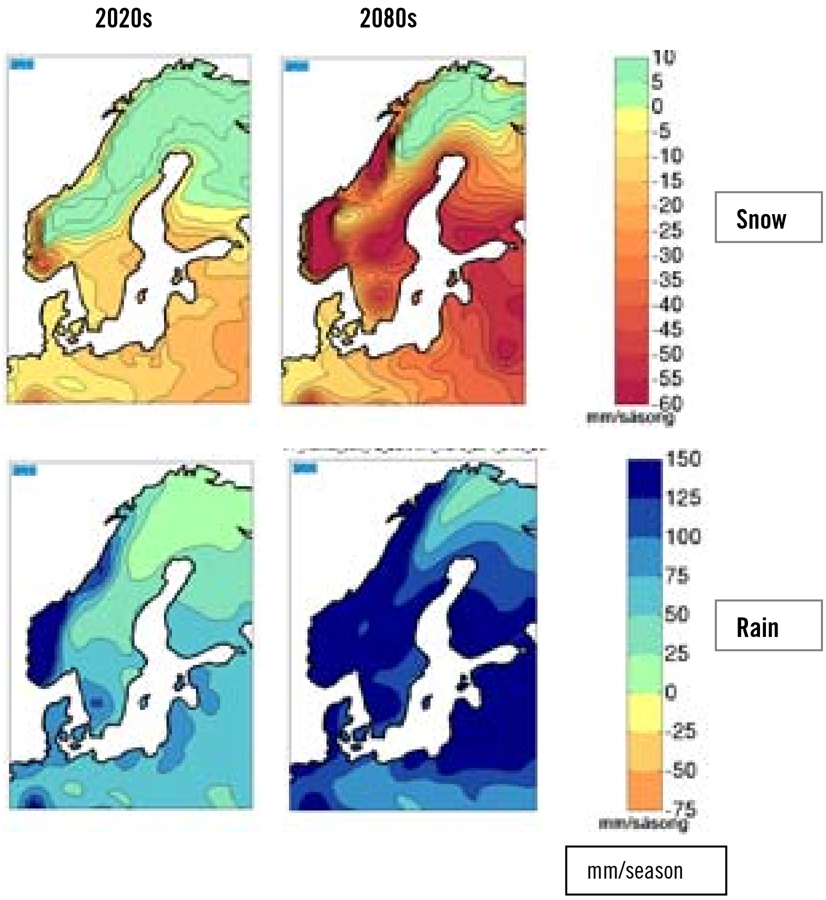
Figure 3.31 Change in average monthly precipitation in January by the 2080s, RCAO-H



Winter precipitation increasingly falls as rain

By the 2020s, the proportion of precipitation during the winter that falls as rain is expected to double up as far as northern Svealand. At the same time, the quantity of precipitation that falls as snow reduces, except in inland Norrland, where a small increase is expected. However, the amount of rain in winter also increases in the north. Then, the proportion of rain gradually increases further and further up the country. By the 2080s, the quantity of precipitation falling as snow will have dropped significantly across the majority of the country. All winter, only a few decimetres of snow fall across much of Svealand, while snow becomes very rare in the coastal areas of Götaland. Amounts of rain increase significantly in almost all parts of the country. However, inland northern Norrland may still experience a slight increase in snowfall during the winter.

Figure 3.32 Changes in levels of precipitation falling as snow and rain during the winter months (December-February) by the 2020s and the 2080s, RCA3-EA2

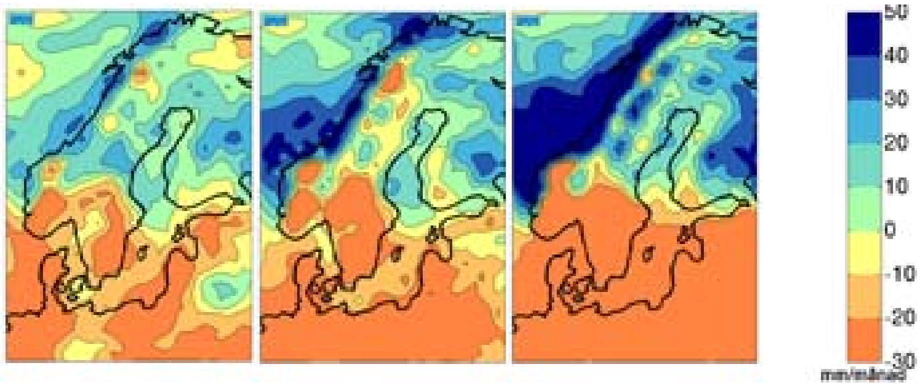


Less precipitation in southern Sweden during the summer

The climate scenarios are a little more difficult to interpret when it comes to changes in summer precipitation. An increase is expected in the majority of Norrland, while a reduction is usually projected for southern parts of the country. This is particularly true during mid- to late-summer (July–September). Exactly where the border between increased and reduced precipitation will lie depends on which model you choose to study. However, the models we studied agree that the weather will become drier in Götaland during the summer months. Other global models (Christensen et al., 2007) showed that the border between drier and wetter conditions may fall south of Sweden, and that even southern Sweden could have rather wetter weather in the summer.

Figure 3.33 Change in average monthly precipitation during the summer months (June–August), RCA3-EA2

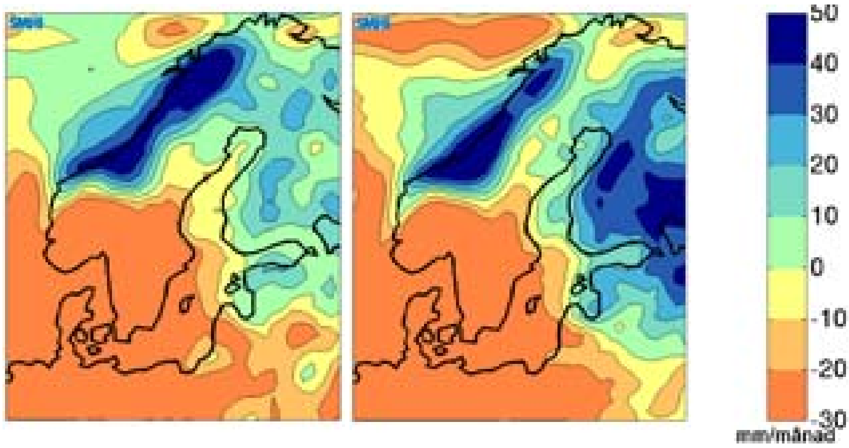
2020s 2050s 2080s



mm/month

Figure 3.34 Change in average monthly precipitation during the summer months (June–August) by the 2080s, RCAO-H

2080s, A2 2080s, B2

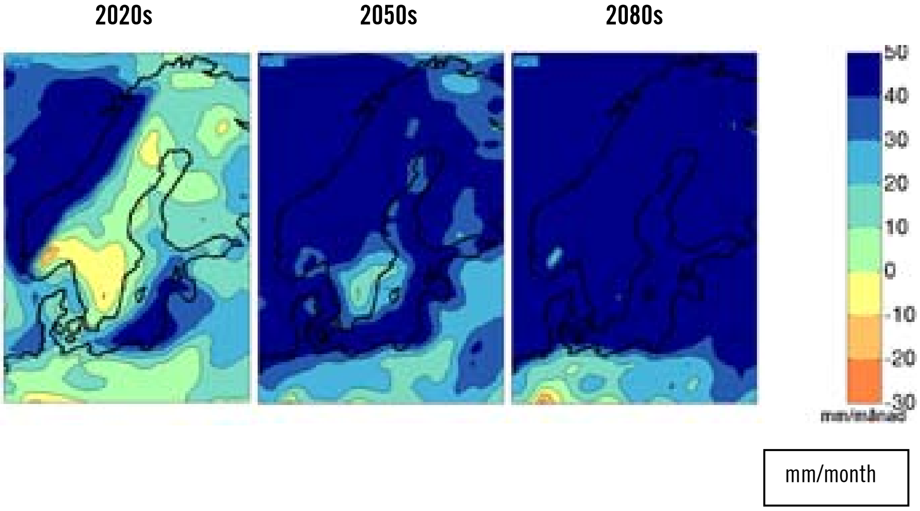


mm/month

Also more precipitation during the autumn across the majority of the country

In the autumn, precipitation will increase according to all scenarios and across all timeframes according to RCA3-E. The increase will be more pronounced the further into autumn we go and the further north-west in the country we move. However, around the 2020s there is a projected reduction in parts of southern and eastern Sweden. According to RCAO-H, the dry late summer outweighs the increases which can be expected later in the autumn by the end of the century.

Figure 3.35 Changes in average monthly precipitation during the autumn months (September–November), RCA3-EA2

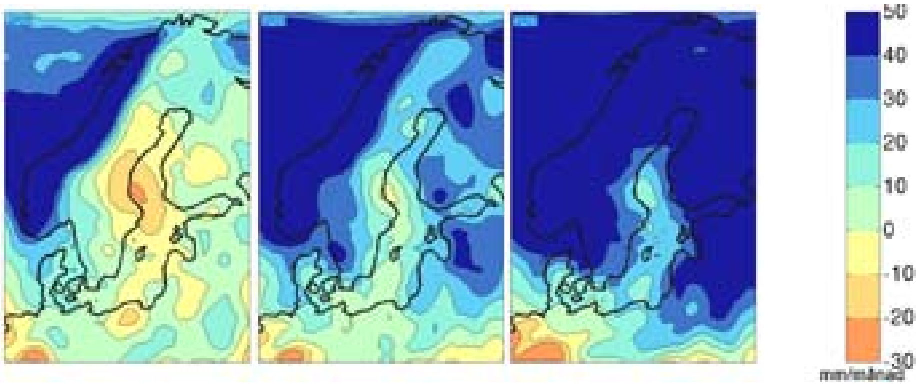


Damper springs

Precipitation is expected to increase across the majority of the country, particularly in the longer term, according to RCA3-E, and particularly in the western parts of the country. By the 2020s, a reduction is expected in parts of eastern Sweden. The increases over the longer term are similar in the A2 and B2 scenarios. However, there are major differences between RCAO-H's A2 and B2 scenarios. While the results of the RCAO-HA2 scenario give precipitation increases similar to those in the RCA3-E scenario, the RCAO-HB2 scenario projects drier weather in the mountains of Norrland.

Figure 3.36 Changes in average monthly precipitation during the spring (March–May), RCA3-EA2

2020s **2050s** **2080s**



mm/month

Increase in the number of heavy downpours in autumn and winter, reduction in the summer

The number of days with heavy precipitation in the winter increases considerably according to RCA3-EA2. B2 also shows a significant increase, but not as large. RCAO-H projects a somewhat smaller increase both in the A2 and B2 scenarios. Also in spring and autumn, there is a trend towards increases in heavy precipitation, at least over the longer term, although they are not as pronounced as during the winter. During the summer months, there is a projected reduction in the number of days with over 10 mm of rain, at least in southern Sweden, according to all models and scenarios.

Figure 3.37 Change in the no. of days with over 10 mm of precipitation during the winter months (December–February), RCA3-EA2

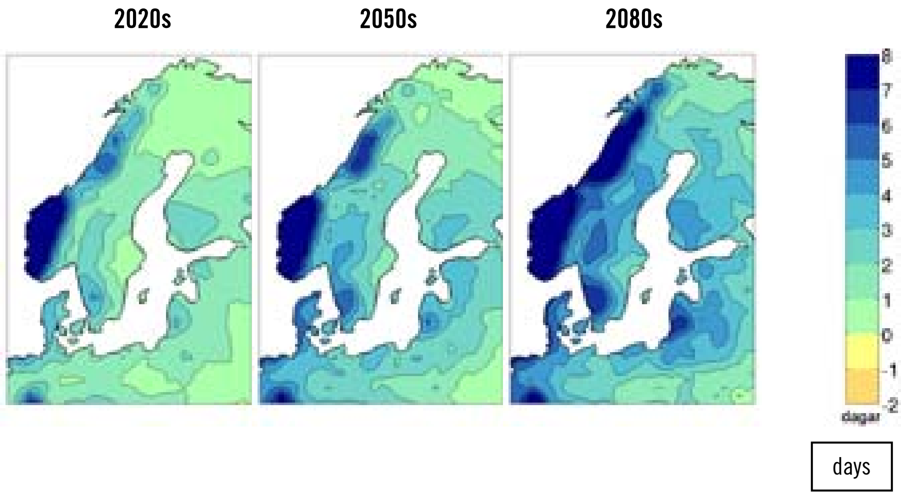
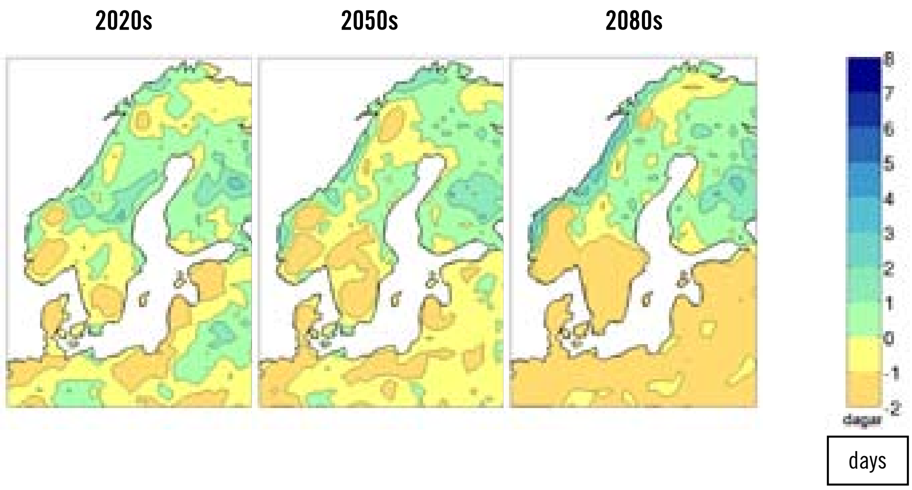


Figure 3.38 Change in the no. of days with over 10 mm of precipitation during the summer months (June–August), RCA3-EA2

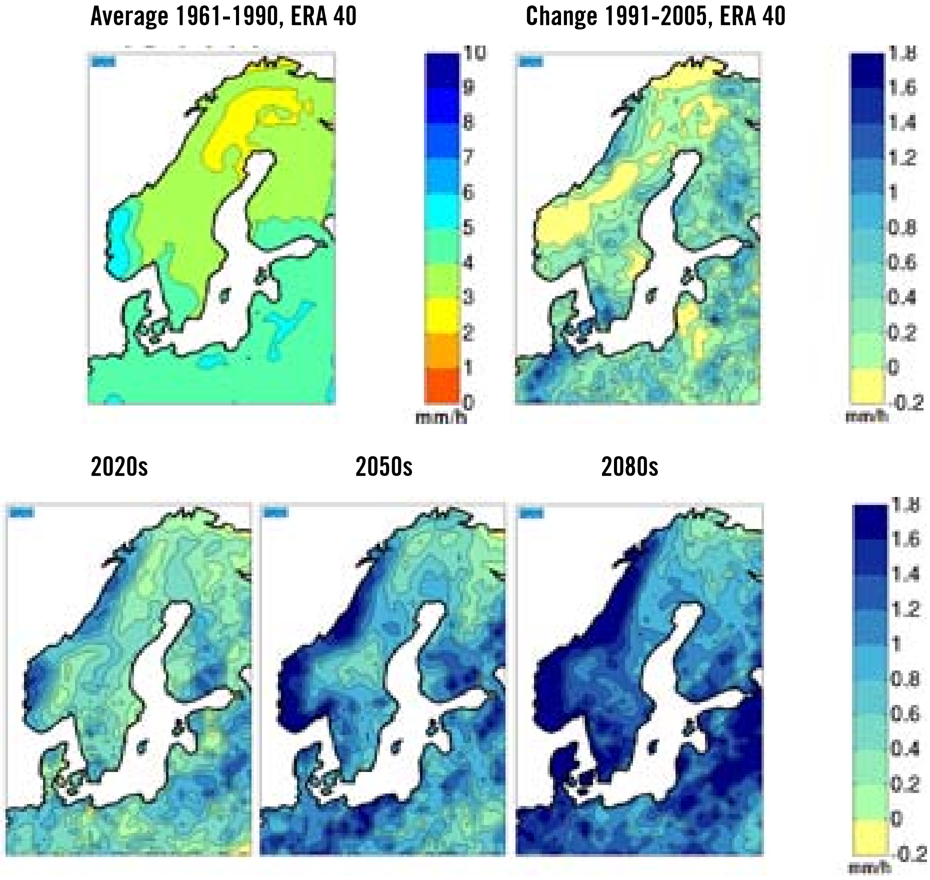


Increase in most intensive rainfall

It is projected that there will be quite significant increases in the most intensive rainfall. The increases are more marked in the long-term and are greatest in the western parts of the country. A trend towards this development can already be discerned from the period

1991–2005, according to modelling based on re-analysis of observational data, RCA3-ERA 40.

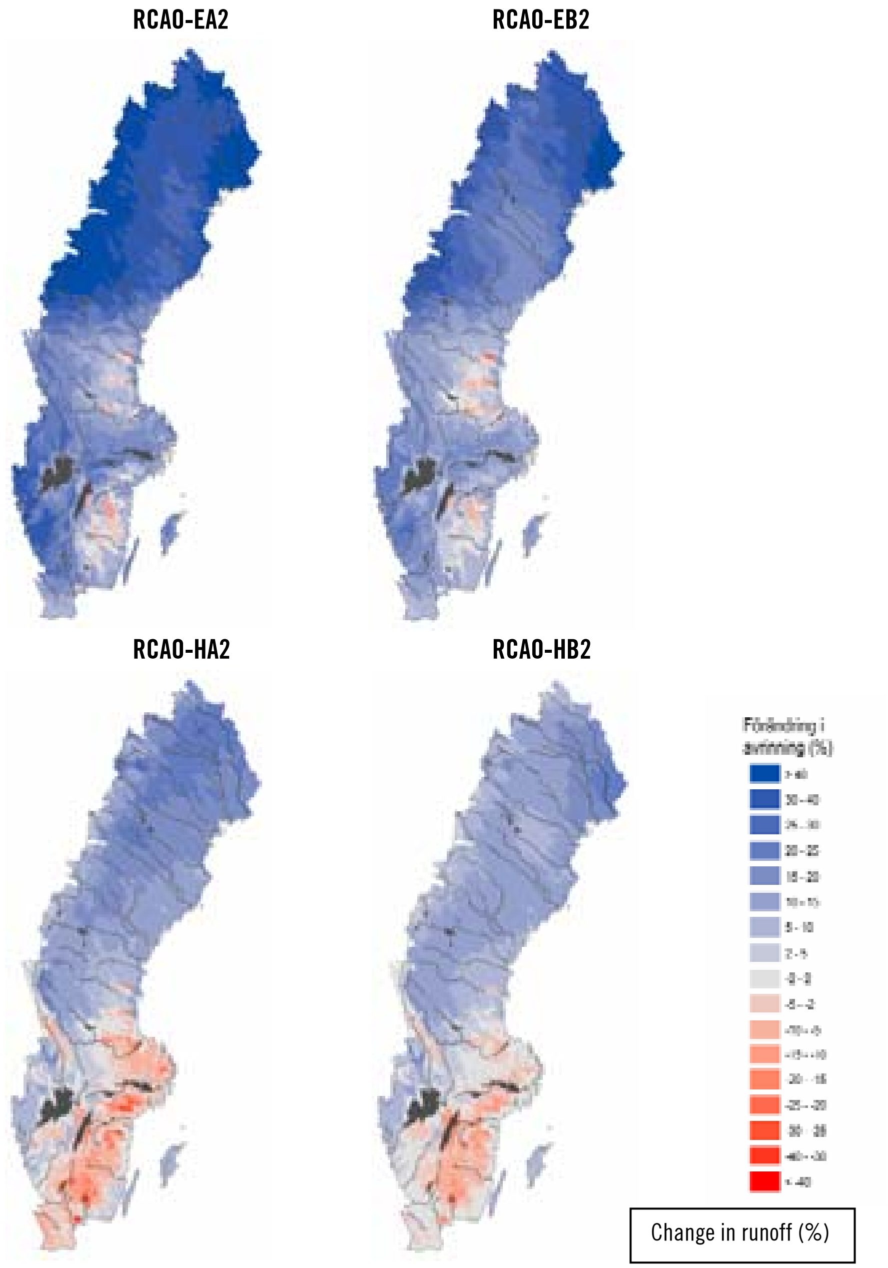
Figure 3.39 Intensity of the heaviest rainfall during the period 1961–1990 and changes in relation to this, RCA3-ERA 40 and RCA3-EA2



Higher flows and more frequent floods, but not across the whole country

According to hydrological calculations by SMHI, average annual runoff will increase across most of the country, particularly in the Norrland mountains and in western Götaland, see Figure 3.40. The maps show local runoff changes, and are not accumulated along watercourses.

Figure 3.40 Change in local runoff in Sweden 2071–2100 relative to 1961–1990 in a normal year according to the various climate scenarios

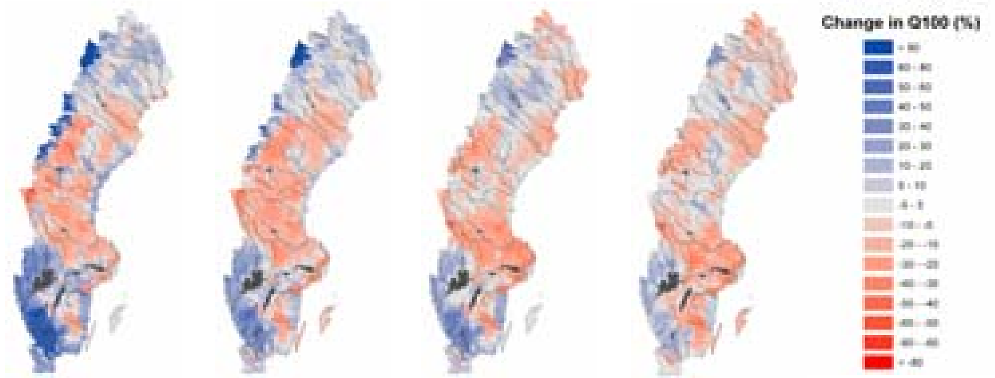


Source: Bergström et al., 2006.

If we instead consider the changes in more extreme flows, western Götaland, south-western Svealand and north-western Norrland are the main areas to stand out, with an increase in local 100-year-return flows in all scenarios. A 100-year-return flow is the statistically highest flow in a watercourse over a 100-year period, i.e. the flow has a return period of 100 years.

Figure 3.41 Change in local 100-year-return flows in Sweden 2071–2100 relative to 1961–1990

RCAO-EA2 RCAO-EB2 RCAO-HA2 RCAO-HB2



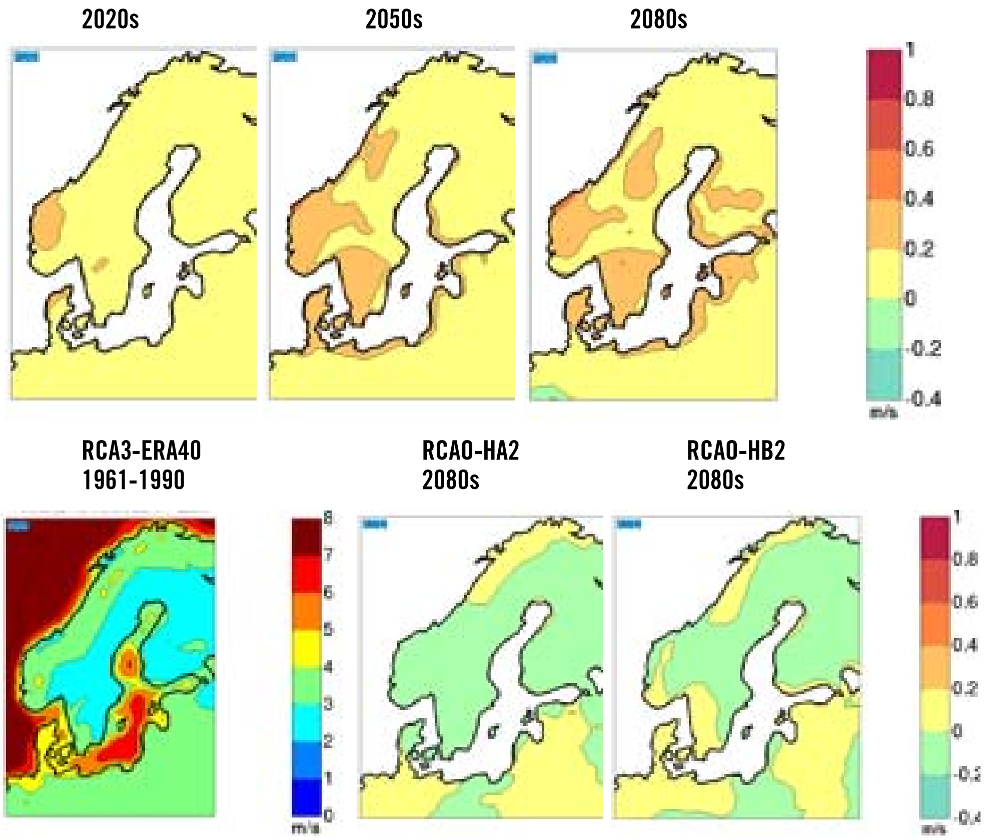
Source: Carlsson et al., 2006.

There is also a difference in the return period which today's local 100-year-return flows are expected to have in a future climate. Shorter return periods for today's local 100-year-return flows and more frequent severe flooding are expected in the aforementioned parts of the country. In other parts of the country, the return period may instead extend, particularly if the most favourable climate scenario is realised. However, there is a risk that the increased local 100-year-flows in the mountain regions may have a knock-on effect along the regulated watercourses. Unfortunately, calculations for these have not generally been possible, but see sections 4.2.2 and 4.3.1. It is more likely that the maps charting changes in the 100-year-return flows underestimate future extremes rather than overestimate them.

3.5.3 Windier or not?

It is not completely clear whether the weather will become windier or not. Different models give partially differing results. As such, RCA3-E projects an average increase in wind speed (7–13 percent in winter in the A2 scenario), while RCAO-H shows small changes for most of the country. Looking at the results for Scandinavia in other models, there is a trend towards an increase in average wind speed in most models. However, some models instead give a reduced wind speed, and it is not possible to identify a change with any statistical certainty (Hovsenius and Kjellström, 2007).

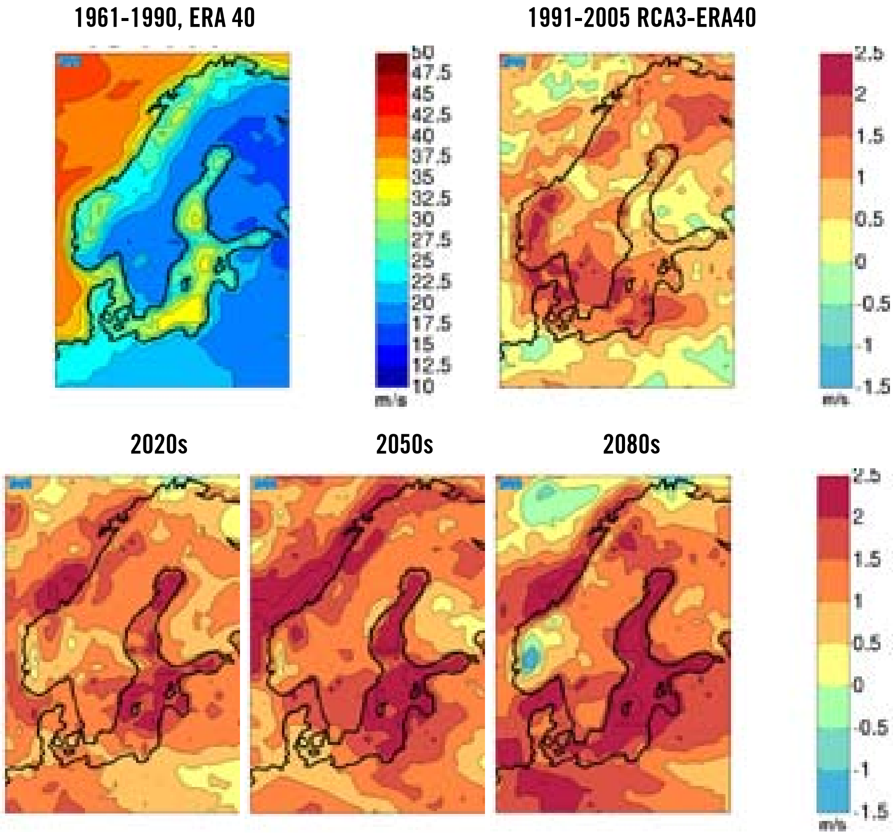
Figure 3.42 **Average wind speed. The upper maps show successive changes over the century according to RCA3-EA2. The lower maps show average wind speed for the period 1961–1990 according to RCA3-ERA 40 and changes by the 2080s according to RCAO-H**



Increased wind gusts?

It has only been possible to calculate the speed of wind gusts using the RCA3-E model. The results show a certain increase in most of the country, with the greatest increase in coastal regions and in Götaland and northern Norrland. A model study of re-analysis data from the period 1991–2005 (RCA3-ERA 40) shows a pattern similar to that predicted by the model.

Figure 3.43 **Average annual highest wind gust speed during the period 1961–1990, ERA 40 and changes in the period 1991–2005, RCA3-ERA40 and over the 21st century, RCA3-EA2**

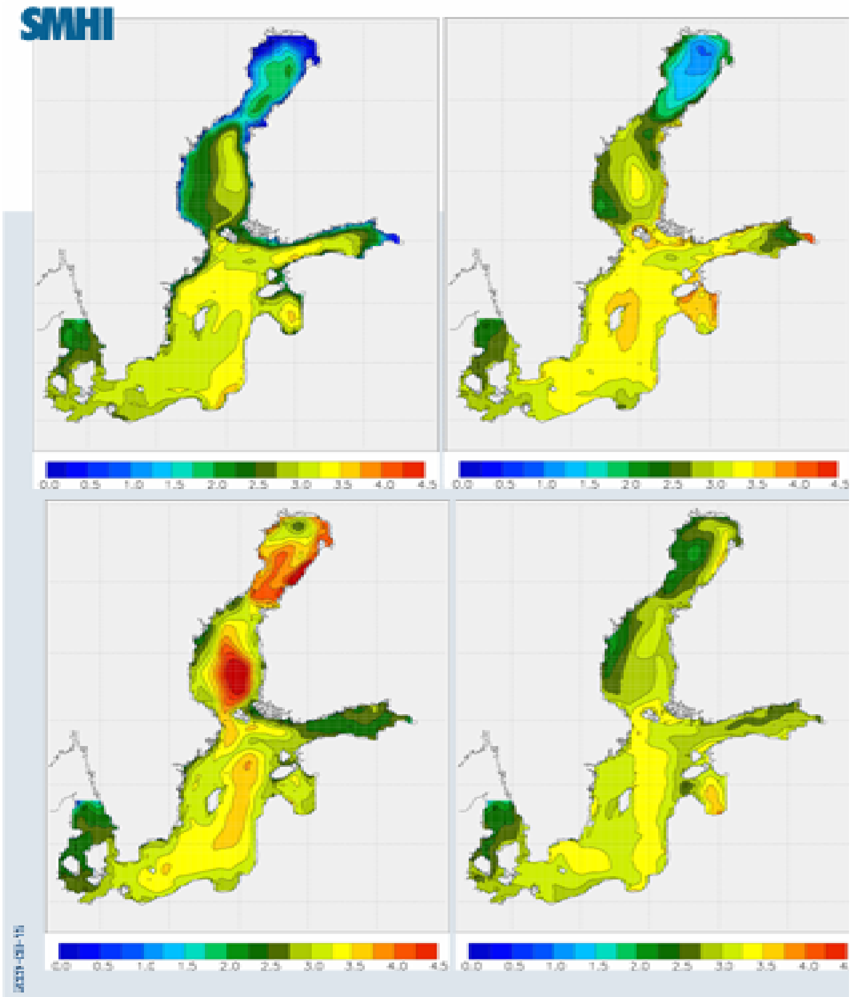


3.5.4 Changes in the Baltic Sea

As air temperatures rise, the surface temperature of the sea will also rise. Changes on an annual basis vary from scenario to scenario. In RCA3-EA2, the temperature increases by over 4°C across the whole of the Baltic Sea. The increases then tail off towards the north. The increases are less in RCA3-EB2 and RCAO-HA2 and in RCAO-HB2 they stop at around 2°C on average.

In terms of how the temperature changes across the seasons, taking an average of the climate scenarios, the increase will be small in the winter in northern parts of the Gulf of Bothnia and along the coast throughout the Gulf, as ice cover is still expected by the end of the century. The temperature increase is also small during spring in the Gulf of Bothnia, which can also be explained by the fact that ice will be present at least part of the time. In the summer, however, the increases will be greatest in the Gulf of Bothnia, at more than 4°C in many places. Elsewhere, the temperature increases vary between just over 2°C and 3.5°C.

Figure 3.44 **Change in sea surface temperature according to an average of the climate scenarios during the 2080s (winter, spring, summer, autumn)**



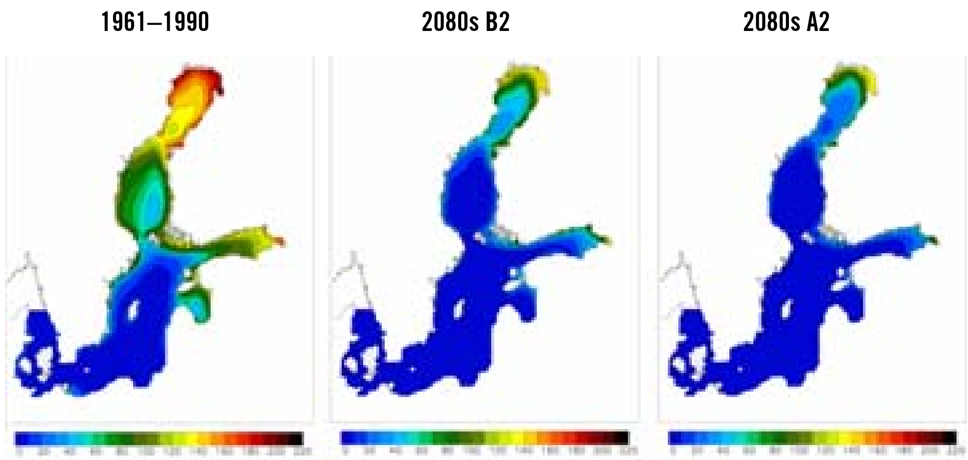
Source: Meier, 2006, with the kind permission of Springer Science and Business Media.

Changes in ice cover

The amount of sea ice is expected to fall dramatically. There will be less of a peak geographical spread and a shorter ice season, primarily caused by earlier melting. According to RCAO-E and RCAO-

H, hardly any sea ice will form in the Baltic Sea by the end of the century. Only in the Gulf of Bothnia will sea ice occur to any great extent, and then only for around 1–3 months per year, depending on the climate scenario. The ice cover will lie a little longer merely in the northernmost archipelagos.

Figure 3.45 **No. of days per year with ice cover according to an average of RCAO-H and RCA3-E**

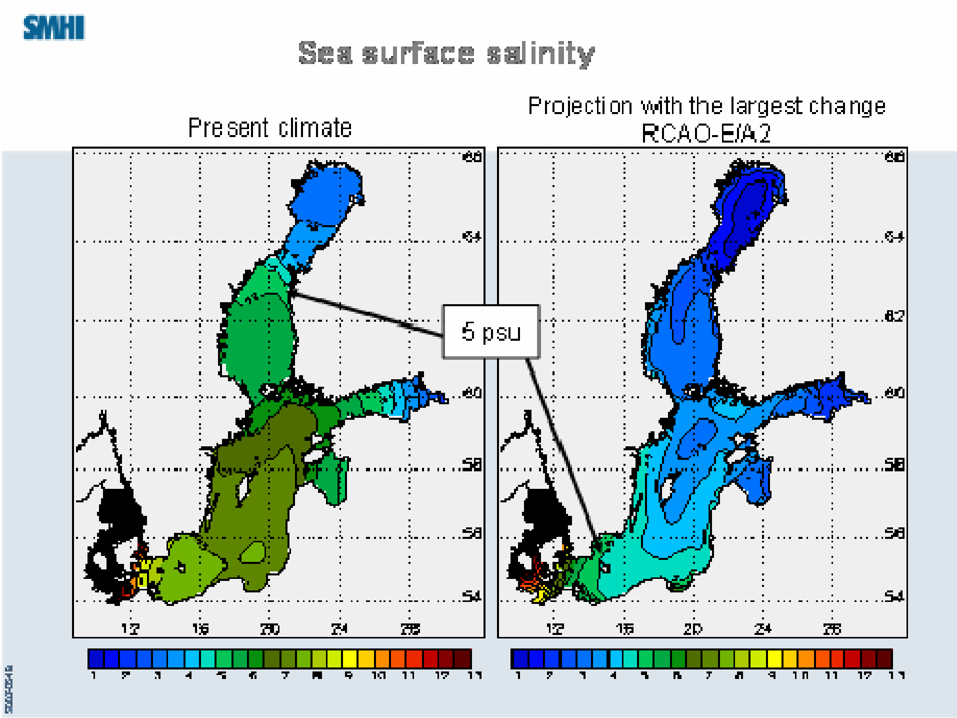


Source: Meier et al., 2004.

Changes in salinity

The salinity of the Baltic Sea will change as a consequence of differences in the inflow of fresh water from rivers and watercourses, and as a result of changes in wind patterns. However, there is great uncertainty regarding the extent of the change. SMHI has analysed 16 different models for salinity changes based on various global climate models. The results vary, showing everything from an average fall in salinity at the sea surface of 45 percent to a statistically insignificant increase of 4 percent. While the models based on Hadley's global climate model show modest reductions in salinity, those based on ECHAM's model show a considerable decrease. RCA3-E A2 projects the greatest reductions due to a major increase in precipitation and inflow of fresh water, combined with wind conditions which reduce opportunities for significant inflows of salt water. The interface between salt water and surface fresh water (the halocline) will remain, but will be around 10 metres deeper than today.

Figure 3.46 **Salinity change at the surface, RCA3-EA2. 5 psu means 5 parts per thousand of salt**

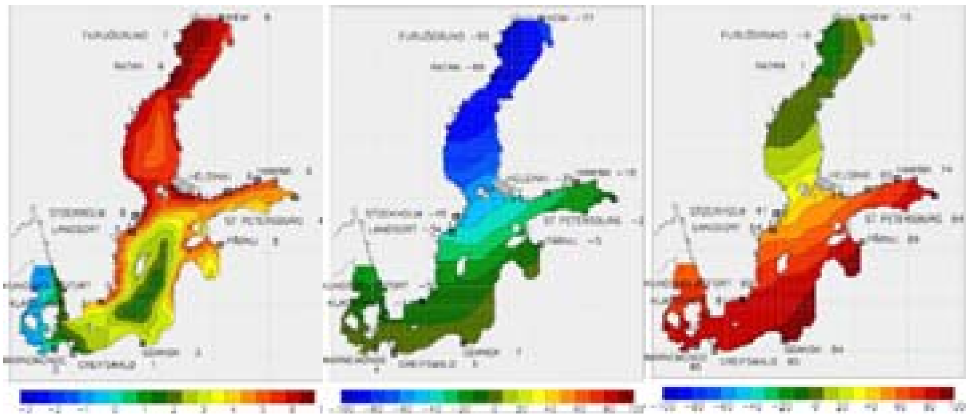


Source: Meier, 2006b with kind permission of Springer Science and Business Media.

Changes in sea level

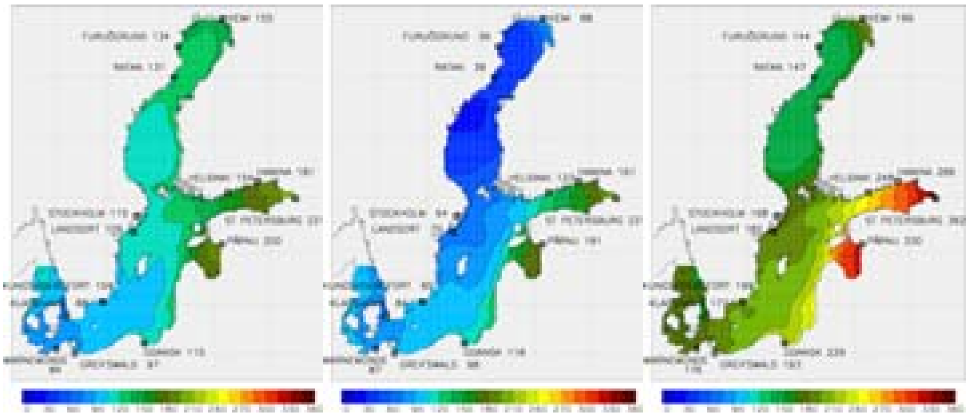
Global changes in sea level will also cause sea levels to rise in the Baltic Sea. This increase is countered by rises in land levels, but is boosted by the fact that westerly winds are expected to increase in frequency. In simulations by SMHI of how sea levels in the Baltic change by the end of the century in various scenarios for global sea levels, the level along Sweden's coastline increases by anything from a few centimetres to 80 cm in the southern Baltic, while along the Svealand coast there may be anything from a fall of almost half a metre to an increase of a similar size. Along the coast of northern Norrland, projections range from a continued rise in land levels of just under 1 metre to the rises in land and sea levels cancelling each other out, see Figure 3.47. Extremes of high water are expected to increase by more than the average water level, see Figure 3.48.

Figure 3.47 Average sea level in winter at end of century according to low scenario (centre diagram) and high scenario (diagram on right) compared with average sea levels in 1903–1998. The left diagram shows water levels in 1961–1990 relative to the same reference period. Scale in cm



Source: Meier et al., 2004b, with the kind permission of Inter-Research.

Figure 3.48 100-year-return sea levels in winter at end of century according to low scenario (centre diagram) and high scenario (diagram on right) compared with average sea levels in 1903–1998. The left diagram shows water levels in 1961–1990 relative to the same reference period. Scale in cm



Source: Meier et al., 2006 with the kind permission of Springer Science and Business Media.

This sea level rise due to climate change is expected to continue for several hundred years, practically irrespective of any future restrictions on greenhouse gas emissions, due to the inherent inertia of the seas.

3.5.5 Specific climate indices for analysing vulnerability

In dialogue with sectoral representatives and SMHI, the commission has identified a large number of climate parameters or indices which are of interest when analysing vulnerability and impacts within different sectors of society. The parameters drawn up for the commission are presented in table 3.2 below. The commission has also had access to another, smaller set of parameters and indices of a similar type which were primarily compiled by SMHI for other purposes. In total, we have made use of almost 60 different parameters and indices. Several maps describing how these indices and parameters change according to the climate scenarios are presented in the SMHI report *Climate indices for vulnerability assessments* (Persson et al., 2007). Where specific indices have been of particular significance when analysing vulnerability in a sector, these are presented in chapter 4 or in the background reports in Annex B.

Table 3.3 Climate parameters and indices drawn up by SMHI for the commission

Climate index	Unit	Time period
No. of days with cloud base below 100 m	days	season
Evapotranspiration	mm	month, season, year
Freezing rain (max temperature < 0 and at least 0.5 mm precipitation)	days	year
Average wind speed	m/s	season, year
Maximum wind gust speed	m/s	year
No. of days with wind gusts > 21 m/s	days	year
Ice clearing in lakes	day	year
Ice thickness in lakes > 15 cm	days	year
Incoming longwave radiation	W/m^2	season
Effective precipitation = precipitation-evapotranspiration	mm	season/year
Highest precipitation over 7 days	mm	year
Longest dry period (with < 1 mm/day)	days	season
Dry days (with precipitation < 1 mm)	days	month
Heavy precipitation > 10 mm/24 hours	days	season/year
Extreme precipitation > 25 mm/24 hours	days	season/year
Total precipitation	mm	month, season, year
Maximum precipitation intensity	mm/h	year
Total rain	mm	season/year
Total snow	mm	season/year
Net runoff	mm	month (April-September)
Relative humidity > 90% and average temp. > 10°C	days	season
Snow cover	days	year
Snow depth 0–10 cm	days	year
Snow depth 10–20 cm	days	year
Maximum snow depth (calculated as water content)	mm	year
Hours of sunlight	hours	year
Incoming shortwave radiation	W/m^2	season
Cooling degree days (max temperature > 20°C)	CDD	month/year
Heatwave (consecutive days with max temperature > 20°C)	days	year

Climate index	Unit	Time period
24-hour max temperature	°C	month, season, year
Hot days/summer days (max temperature >20°C) *	days	season/year
Cold days (max temperature < -7°C)	days	year
End of vegetation period (last day in consecutive 4-day period with average temp. > 5°C	day	year
End of vegetation period for certain species (last day in consecutive 4-day period with average temp. > 2°C)	day	year
Start of vegetation period (last day in consecutive 4-day period with average temp > 5°C)	day	year
Length of vegetation period (average temp. > 2°C)	no. of days	year
Length of vegetation period (average temp. > 5°C)	no. of days	year
Degree days with average temp. >20°C	degree days	year
Degree days with average temp. > 8°C during vegetation season (> 5°C)	degree days	year
Heating degree days (with average temp. < 17°C)	HDD	month, year
24-hour minimum temperature	°C	month, season, year
Last day of spring frost (minimum temperature < 0°C)	day	year
Frosty days (minimum temperature < 0°C)	days	season
Tropical nights (minimum temperature >17°C)*	days	year
24-hour minimum temperature	°C	month, season, year
Zero crossings (no. of days with highest temp. > 0°C and lowest temp < 0°C)	days	season
Days with ground temp. -7°C	days	year

* The index has been adapted to take account of systematic deviations in the models.

The results and the full map data can be found in Swedish on the SMHI website:
(http://www.smhi.se/cmp/jsp/polopoly.jsp?d=8783&l=sv) or
(www.smhi.se >Klimat >Klimatscenarier >Klimatscenariokartor)

Bibliography

Andréasson, J. (2007). *Resultat från modellen HBV Sverige* (Results from the HBV Sweden model). SMHI.

Christensen, J.H., B. Hewitson, A. Busuioc, A. Chen, X. Gao, I. Held, R. Jones, R.K. Kolli, W.-T. Kwon, R. Laprise, V. Magaña Rueda, L. Mearns, C.G. Menéndez, J. Räisänen, A. Rinke, A. Sarr and P. Whetton. (2007). *Regional Climate Projections. In: Climate Change (2007). The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Christensen, T. (2007). *Föredrag vid regeringens klimatseminarium den 7 mars 2007* (Lecture at the government's climate seminar of 7 March 2007).

Ds 2005:55. *Sweden's fourth national communication on climate change.*

Hovsenius, G. and Kjellström, E. (2007). *Konsekvenser för vindkraften i Sverige av klimatförändringar* (Impact of climate change on wind power in Sweden). Elforsk report no. 07:33.

IPCC (2000). *Emissions Scenarios.* Special report of the Intergovernmental Panel on Climate Change. [Nakicenovic, N. and Swart, R. (eds.)] Cambridge University Press, UK. pp 570.

IPCC (2001). *Climate Change 2001: The Scientific Basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change* [Houghton, J.T., Y. Ding, D.J. Griggs, M. Noguer, P.J. van der Linden, X. Dai, K. Maskell, and C.A. Johnson (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 881 pp.

IPCC (2007). *The Physical Science Basis, AR 4, WG1.* Summary for policymakers.

IPCC (2007b). *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 996 pp. [Not yet in print, see also (last verified 27 August 2007) http://ipcc-wg1.ucar.edu/wg1/wg1-report.html]

Jones, C.G., et al. (2004). *The Rossby Centre Regional Atmospheric Climate Model Part I: Model Climatology and Performance for the Present Climate over Europe.* Ambio 33:4–5, 199–210.

Kjellström, E., Bärring, L., Gollvik, S., Hansson, U., Jones, C., Samuelsson, P., Rummukainen, M., Ullerstig, A., Willén U. and Wyser, K. (2005). *A 140-year simulation of European climate with the new version of the Rossby Centre regional atmospheric climate model (RCA3).* Reports Meteorology and Climatology 108, SMHI.

Kleman, J. (2007). *Föredrag vid regeringens klimatseminarium den 7 mars 2007* (Lecture at the government's climate seminar of 7 March 2007).

Mark F., Meier F., Mark B., Dyurgerov, Ursula K. Rick, Shad O'Neel, W. Tad Pfeffer, Robert S. Anderson, Suzanne P. Anderson, Andrey F. Glazovsky (2007). *Glaciers Dominate Eustatic Sea-Level Rise in the 21st Century.* Science 19 July 2007

Mauritzen, C. (2007). *Föredrag vid regeringens klimatseminarium den 7 mars 2007* (Lecture at the government's climate seminar of 7 March 2007).

Meier, H. E. M., et al. (2003). *A multiprocessor coupled ice-ocean model for the Baltic Sea: Application to salt inflow.* J. Geophys. Res., 108(C8), 3273, doi:10.1029/2000JC000521.

Meier, H.E.M. (2006). *Baltic Sea climate in the late twenty-first century: a dynamical downscaling approach using two global models and two emission scenarios.* Clim. Dyn., 27(1), 39–68, doi: 10.1007 / s00382-006-0124-x.

Meier, H.E.M., E. Kjellström, and L. P. Graham (2006). *Estimating uncertainties of projected Baltic Sea salinity in the late 21st century*. Geophys. Res. Lett, Vol. 33, No. 15, L15705, doi: 10.1029/2006GL026488

Meier, H.E.M., R. Döscher, and A. Halkka (2004). *Simulated distributions of Baltic sea-ice in warming climate and consequences for the winter habitat of the Baltic ringed seal.* Ambio, 33, 249–256.

Meier, H.E.M., B. Broman, and E. Kjellström (2004b). *Simulated sea level in past and future climates of the Baltic Sea*. Clim. Res., 27, 59–75.

Nilsson C, Stjernquist, I, Bärring, L, Schlyter P, Jönsson A-M, Samuelsson H. (2004). *Recorded Storm Damage in Swedish Forests 1901–2000.* Forest Ecology and Management, 199:165–173.

Persson, G, Bärring, L., Kjellström E., Strandberg, G. and Rummukainen, M. (2007) *Climate indices for vulnerability assessments,* SMHI Reports Meteorology and Climatology, No 111.

Rankka, K. and Rydell, B. (2005). *Erosion och översvämningar. Underlag för handlingsplan för att förutse och förebygga naturolyckor i Sverige vid förändrat klimat* (Erosion and flooding. Technical report for plan of action in order to identify and prevent natural hazards in Sweden due to changed climate). Technical report 2. SGI, Varia 560:2.

SGI (2006). *På säker grund för hållbar utveckling. Förslag till handlingsplan för att förutse och förebygga naturolyckor i Sverige vid förändrat klimat* (On safe ground for sustainable development. Proposals for a plan of action in order to identify and prevent natural hazards in Sweden due to changed climate). Reg. no. 3-0503-0151.

SMHI (1998). *Väder och Vatten, december 1998* (Weather and Water, December 1998).

SMHI (2001). *Höga flöden juli år 2000. Sammanställning av hydrologiska förhållanden, skador, räddningsåtgärder och problem vid dammar* (High flows in July 2000. Summary of hydrological conditions, damage, rescue efforts and problems with dams). SMHI report commissioned by Svenska Kraftnät, 2001 No. 15.

SMHI (2001b). *Väder och Vatten under ett århundrade 1900–1999* (Weather and Water for a century 1900–1999) (*December 1999, reprint June 2001*), Fact sheet no. 7 (formerly Fact sheet no. 3).

SMHI (2006). *Klimat i förändring. En jämförelse av temperatur och nederbörd 1991–2005 med 1961–1990* (Changing climate. A comparison of temperatures and precipitation in 1991–2005 with 1961–1990) . SMHI Factsheet no. 29 (October 2006).

SMHI (2007). *Väder och vatten juli 2006–juli 2007* (Weather and Water July 2006 – July 2007).

SOU 2006:94 *Översvämningshot, Risker och åtgärder för Mälaren, Hjälmaren och Vänern* (Flood threat, risks and actions for Lakes Mälaren, Hjälmaren and Vänern). Interim report of the Swedish Commission on Climate and Vulnerability.

SRA (2002). *Ökade vattenflöden – Behov av åtgärder inom väghållningen* (Increase water flows – The need for actions in road maintenance). Publication 2002:156.

SRA (2006). *OH presentation.*

Svenska Kraftnät (2006). *Kort information angående tidigare väderrelaterade haverier och åtgärder i Svenska stamnätet* (Brief summary of earlier weather-related power cuts and actions in the Swedish trunk network). Memorandum 2006-06-26.

Swedish Energy Agency (2005). *Stormen Gudrun och uppvärmningen. Erfarenheter från elavbrott med inriktning på uppvärmning av byggnader* (Storm Gudrun and global warming. Experiences from power cuts with a focus on the heating of buildings). ER 2005:033.

Swedish Energy Agency (2005b). *Stormen Gudrun – Konsekvenser för nätbolag och samhälle* (Storm Gudrun – Consequences for energy suppliers and society). ER 2005:16.

Swedish Environment Protection Agency (2007). *FN:s klimatpanel 2007. Den Naturvetenskapliga grunden* (The UN's Climate Panel. The Scientific Basis). Report 5677.

Swedish Forest Agency (2006). *Stormen 2005 – en Skoglig analys* (The storm 2005 – a forestry analysis). Swedish Forest Agency Meddelande 1.

Swedish Insurance Federation (2007). *Statistik från Försäkringsförbundet – beräkningar och uppskattningar från de fyra största försäkringsbolagen åren 1997–2007* (Statistics from the Swedish Insurance Federation – calculations and estimates from the four largest insurance companies for the years 1997–2007).

Swedish Ministry of Enterprise, Energy and Communications (2005). *Memorandum 10 March 2005.*

Swedish National Post and Telecom Agency (2005). *Elektroniska kommunikationer och stormen den 8–9 januari 2005. Hur uppnås robustare elektroniska kommunikationer?* (Electronic communications and the storm of 8–9 January 2005. How can we achieve more robust electronic communications?) Report no. PTS-ER-2005:9.

Swedish Rail Administration (2001). *Utredning enligt Banverkets regleringsbrev – behov av åtgärder inom banhållningen med anledning av i framtiden befarade plötsliga högre vattenstånd* (Investigation in line with the Swedish Rail Administration's letter of appropriations – need for measures in track maintenance due to fears of sudden higher water levels in the future). Investigation, 20 December 2001.

Swedish Rail Administration (2005). *Banverket och orkanen Gudrun* (The Swedish Rail Administration and hurricane Gudrun). Report from workshop on 27–28 April 2005.

Swedish Rail Administration (2006). *Raset i Västsverige* (Landslide in western Sweden). Press release 12 December 2006

Swedish Scientific Council on Climate Issues (2007). *A Scientific Basis for Climate Policy.* Environmental Advisory Council report 2007:03.

Vaughan, D.G. (2007). *West Antarctic Ice Sheet collapse – the fall and rise of a paradigm. Climatic Change.* (Not yet in print, see also http://nora.nerc.ac.uk/769/).

Vedin, H., Raab, B. (2005). *Klimat sjöar och vattendrag* (Climate, lakes and watercourse). National Atlas of Sweden.