English

Naturhistoriska riksmuseet

# Uppdrag: KLIMAT

## Mission: Climate Earth

**Introduction**

**"Everybody talks about the weather, but nobody does anything about it."**

— *Charles Dudley Warner*

The temperature of the earth is rising. Are we on the verge of a major climate change?

There are more and more signs that you and I are adding to the atmosphere's greenhouse effect.

Our mission Climate Earth is a challenge. There is only one earth. Life style, justice, creativity, and faith in the future— these are some of the key concepts.

**The greenhouse**

**The greenhouse effect— essential to life on earth**

If there were no atmosphere, it would be 30° C colder at the earth's surface.

When the rays of the sun warm the earth, resulting heat radiates back toward space. Greenhouse gases in the atmosphere capture some of it and return a portion of it to the earth's surface, effectively making it warmer.

The effect has been likened to that of a greenhouse. When we increase emissions of greenhouse gases, the effect is strengthened.

But unlike a greenhouse, our atmosphere does not have a roof vent that can be opened if it becomes too hot. . . .

**More carbon in the air**

Carbon is present in all living things. Plants take up carbon dioxide as they grow. Carbon is also present in the ocean and the soil. It is also present in the air, primarily as carbon dioxide gas which is formed when materials are burned and when humans and other animals breathe out.

Oil, coal and natural gas have been formed from plants and animals that died millions of years ago. When we burn such fossil fuels, the amount of carbon dioxide in the air increases more than what plants are able to make use of or what can be dissolved into the ocean. As that happens, the amount of carbon dioxide in the atmosphere increases.

The result of this is an enhanced greenhouse effect and a global warming.

# The sun – motor of the climate

**Without the sun, we would not exist. In just a few days, the sun radiates as much energy to the earth as that contained in all of the planet's known reserves of oil and gas.**


## A planet with just the right conditions for life

**Our planet abounds with plants and animals. This is partly because it is the right distance from the sun, and has an atmosphere with the right composition. The temperature is suitable for water to exist in liquid state and for the flourishing of life.**

**Venus— too hot**
Our neighbouring planet, Venus, is closer than earth to the sun. The atmosphere of Venus is dense, and 96 per cent of it is carbon dioxide— a fraction almost 2500 times greater than in the earth's atmosphere.

Due to the high level of carbon dioxide in its atmosphere, the Venus greenhouse effect is very intense. The planet's surface is as hot as a pizza oven, over 400° Celsius. Water is present only in gaseous form.

**Mars— too cold**
The orbit of Mars is more distant from the sun than earth's.
The Martian atmosphere is thin, and the greenhouse effect is slight. Temperatures at night can fall to minus 130° C,.

It is difficult to imagine what it would be like to stand on a planet with such thin air. If a storm blew up, you would hardly notice it. The air is so thin that its motion would not be felt on the skin.

# Natural variations

**If the earth always followed exactly the same path around the sun, its climate would not have varied so much throughout history as it has.**

As early as 150 years ago, scientists knew that the earth's climate had often changed in the past. But it was not understood how and why, for example, ice ages and warmer periods occurred.

Milutin Milankovich, a Serbian mathematician came to an explanation of the processes involved in the 1920s.

Those processes are now called Milankovich cycles, and they explain a great deal about rather characteristic cycling of warm and cold periods during the past few million years.

**Changes in the earth's orbit**
In a cycle lasting about 100,000 years, the earth's orbit around the sun changes from a nearly perfect circle to a slightly oval shape, then back to a circle again. The orbit is currently in its circular phase, which means that the amount of solar radiation that reaches the earth does not vary as much as when the orbit is oval. The shape of the Earth's orbit around the Sun is called eccentricity.

**Changes in the axis of the earth**
The axis of the earth is not exactly vertical relative to its plane of travel about the sun (obliquity). That is why we have changing seasons. This tilt of the Earth changes in a cycle of 41,000 years. The greater the angle, the colder the winters and the warmer the summers.

**The wobbly earth**
The earth does not rotate evenly on its axis. It wobbles somewhat, like a spinning top might do. The Earth's slow wobble as it spins on axis is called precession and can be though of as a rotation of the somewhat elliptical orbit of the Earth.

This affects the timing of the seasons, in a cycle that lasts about 22,000 years.

Ten thousand years from now, the month of July will be mid-winter in the northern hemisphere and January will be mid-summer.

*Throughout the history of the earth, colder periods have alternated with warmer periods. Those natural variations are due to several factors, including the periodic changes in the Earth's orbit around the sun and its axial tilt.*

## Energy balance

### Solar radiation in = heat radiation out

The rays of the sun warm the earth. That energy is converted to thermal radiation that beams back toward space.

The atmosphere lets much of the incoming solar radiation in, but impedes a great deal of the thermal radiation on its way out from the Earth's surface. As a result, the surface of the earth is warmer than it would be if there were no atmosphere.

The thermal radiation's escape is also impeded by clouds.

In the end, however, the earth strives for an energy balance: The amount of energy leaving the atmosphere should be the same as the amount coming in. When the climate is stable, this applies. Climate change is caused by some imbalance in the energy balance. That climate changes can be taken as a manifestation of the strive of the Earth system to reestablish its energy balance.

*Using the knob you can move the model of the earth in a circular orbit around the sun. Push the button on the knob to see how the rays of the sun strike the earth. Our changing seasons are due to the tilt of the earth's axis. We have summer in the northern hemisphere when it tilts toward the sun, and winter when it tilts away. The month being demonstrated is indicated beneath the model of the earth.*

## The colour of the earth's surface has an effect

Bright colours reflect more light than dark colours, which absorb more light and become warmer. It is well-known, for example, that black asphalt becomes very hot on warm summer days.

A measure of reflectivity of a surface or body is called its albedo.

Snow reflects up to 80 per cent of the solar radiation that falls upon it. The reflected amount does not warm up the earth's surface. Thus, compared with bare ground, the effect of snow-covered areas is to lower the temperature.

The albedo of water is only ten per cent.

The albedos of clouds vary, depending on their thickness and the detailed properties of the water droplets and ice crystals that make up the clouds.

The earth's overall albedo is one of the factors that affects its climate in both the short and long run.

## Whirling air

**Tornadoes**
On extremely warm summer days, the ground in southern Sweden can become very hot.
The air near the ground is also warmed, and rises upward– sometimes so rapidly that it forms a rotating column called a whirlwind.

Whirlwinds in Sweden usually do not become strong enough to lift anything heavier than roof tiles or tree branches.

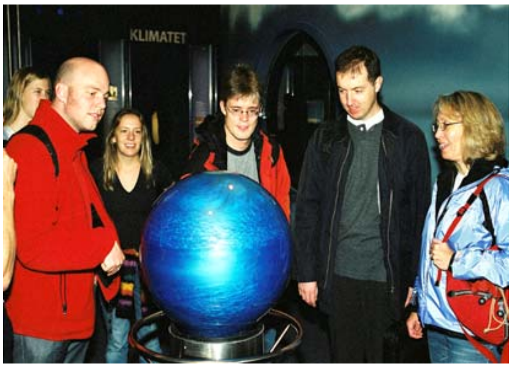
In the United States, they can be much stronger. The strongest are called tornadoes and can be so powerful that they tear up entire trees and rooftops.

**Hurricanes**
The largest storms of whirling air are called hurricanes and typhoons. They can be formed above parts of the tropical seas where the surface temperature is above 25° C. They may rotate at speeds of over 200 kilometres per hour and measure hundreds of kilometres across.

Hurricanes and typhoons are immensely powerful and can cause great damage in a short time.

As the temperature of the earth rises, dramatic weather events such as hurricanes may also be affected.

## The earth in a spin




The rotation of the earth affects weather systems and water currents.

Winds and ocean currents are deflected counter-clockwise in the northern hemisphere, and clockwise in the southern. The actual movements are affected also by othe factors.

## HOW THE CLIMATE WORKS


## If the earth were like the moon…

**. . . with no atmosphere, no water, and with a temperature difference of 300° C between day and night: In that case, life as we know it would never have arisen on our planet.**

**No atmosphere, no life**
The barren landscape of the moon is no place for life. The daytime temperature of the moon is very hot—about 115° C.When the sun sets on the craters and mountains of the moon, the temperature sinks very rapidly.

Without an atmosphere to maintain a fairly even temperature, the difference between day and night is very great. Nights are cold— as low as minus 185° C.

Since the moon is smaller than the earth, its gravity is not as strong. The moon can not hold on to an atmosphere.

**Moon dreams**
The dream of living on the moon has long titillated the human imagination. There has been speculation about living inside large domes with self-contained ecosystems, sustained by energy from the sun and water from the lunar mountains.

But it has turned out to be much more difficult and costly than first imagined. Interest in such gigantic and risky projects subsided.

Perhaps the dream remains. But, now, efforts are focused on saving our own planet.

*If the earth were like the moon, with no water and no atmosphere, we could not exist. The temperature on the moon is 115° C during the day and as low as minus 185° at night.*

## The atmosphere

**Enveloping our planet is the atmosphere. Without it, the earth's average surface temperature would be 30° C lower than it is today.**

**A thin layer around the earth**
Most of the atmosphere is contained within a space stretching 10-15 kilometres over our heads. The atmosphere thins out very rapidly with increasing altitude.

There is no sharp boundary for the upper limit of the atmosphere. Traces of atmospheric gases have been detected as far as 10,000 kilometres from the earth.

The atmosphere shields us from meteors and harmful ultraviolet radiation. It also traps heat that radiates upward from the earth. The atmosphere reduces temperature differences between day and night. Changes in the atmosphere have both short- and long-term effects on the weather, the oceans and life on earth.

**Not only oxygen**
The atmosphere consists of gases and tiny particles of various substances. Of the gas component, about 78 per cent is nitrogen and about 21 per cent is oxygen.

Over one hundred other gases are naturally present, as well. Some of them contribute to the warming of the earth and are called greenhouse gases. The two most important of these are carbon dioxide and water vapour.

Carbon dioxide now comprises close to 0.04 per cent of the atmosphere. The amount of water vapour varies from place to place. On the whole, about 0.4 per cent of the atmosphere is comprised of water vapour.

Atmospheric particles are microscopic in size. They include dust, sea salt and other substances.

*When solar radiation warms the earth, the atmosphere functions like a sort of sleeping bag. It traps outgoing thermal radiation, raising the temperature at the surface (inside the sleeping bag). The atmosphere is very thin in relation to the earth. If the planet were as small as an apple, the atmosphere would be no thicker than the peel.*

## Equatorial warmth spreads out

**The heat of the sun is most intense at the equator. Winds and ocean currents carry the warmth toward the poles, distributing it more evenly around the globe.**

**From equator to the poles**
The heat of the sun is most intense at the equator. Winds and ocean currents distribute the heat more evenly around the globe by

transporting it toward the north and south poles.

If you shine a torch on the floor of a dark room, you will notice that the light is most intense when aimed straight down. If you aim to the side, the light is not as strong.

It is the same with sunlight on the earth. At the equator, the sun's rays come straight down. In Sweden, the same amount of incoming solar radiation hits the surface in an angle and is spread over a larger area. As a result, the solar heating effect of this is less than near the equator.

If the earth did not rotate, the warm air at the equator would rise and spread out toward the north and south poles. Along the way, it would cool down, settle, and flow back toward the equator along the surface of the earth.

But the earth *does* rotate, and that makes the situation more complex. . .

**Gulf Stream warms the North**
Ocean currents distribute a large portion of equatorial warmth around the globe. They act as gigantic pumps that are driven by density differences between water masses of different temperature and sainity. They move in enormous sluggish loops.

One of the greatest ocean currents warms the climate of the Nordic region. It carries water that is heated close the Atlantic equator and moves it northward along the ocean surface. A part of this ocean circulation is known as the Gulf Stream.

The water becomes cooler as it moves north, becoming heavier until it sinks off the coasts of Greenland. The now colder water then moves back southward deeper down in the ocean. Without the Gulf Stream, less heat would be transported from the equator to the Nordic region, which would then have a much colder climate.

*The circulation of warm and cold water in ocean currents results in added warmth for the climate of the Nordic region.*

*Winds and ocean currents spread heat from the equator toward the poles. If the earth did not rotate, the atmospheric transfer of heat would look like this.*

## Competing forces

**The complexity of weather patterns is due largely to the effects of two competing forces— one that tends to even out temperature differences, and one that keeps the earth spinning on its axis.**

**Fascination of meteorologists**
The movements of winds and oceans are among the largest processes on earth.

Those movements are influenced by the earth's rotation, with consequences that affect us all. Winds and ocean currents are deflected counter-clockwise in the northern hemisphere, and clockwise in the southern.

At Swedish latitudes, masses of air build circular patterns that are called low pressure (cyclones) and high pressure (anti-cyclones) systems. These systems move and vary in size and duration. The most stable ones can last for up to several weeks.

The uneven solar heating and the earth's rotation are the principal causes of the atmospheric circulation patterns that are dealt with in meteorology.

If the atmosphere were only influenced by the earth's rotation, its movements would look like this.

**Affects movements**
You do not notice the effect of the Earth's rotation when you throw a ball, for example, because the distance is so short. But imagine what would happen if you could throw it incredibly high, up to the clouds. Then, if you were in the northern hemisphere, you would see that it curved counter-clockwise. If there was no wind, the ball would move in a wide circle. After fourteen hours, it would come back to roughly the same place that it started.

If you threw the ball at higher speed, it would make a wider circle. At a slower speed, the circle would be smaller. But it would always take fourteen hours to make a complete circle.

*The earth's rotation affects winds and currents and deflectes them counter-clockwise in the northern hemisphere, and clockwise in the southern.*

## Greenhouse gases trap heat

**Water vapour, carbon dioxide and nitrous oxide are called greenhouse gases because they allow incoming solar radiation to pass through, but impede outgoing thermal radiation from passing directly out into space.**

**Natural greenhouse effect**
Greenhouse gases have been naturally present in the atmosphere since long before human beings evolved. They do not have much of an effect on solar radiation on its way down to the earth's surface.

The solar heating of our planet leads to thermal radiation back to space. Greenhouse gases intercept this outgoing radiation and send some of it back down, making the surface even warmer.

Levels of greenhouse gases in the atmosphere have varied throughout the long history of the earth. During periods when their levels have been higher, the climate has also been warmer.

**Varieties of greenhouse gas**
The effects of the various greenhouse gases depend on their amounts in the atmosphere, how efficiently they trap thermal radiation, and how long they remain in the atmosphere.

Methane and nitrous oxide trap thermal radiation many times more efficiently than does carbon dioxide. But they are present in much smaller amounts and break down after some time in the atmosphere. The greenhouse gases that currently have the greatest effect on climate are water vapour and carbon dioxide. The amount of water vapour in the atmosphere is dictated by the hydrological cycle and how warm the Earth is.

Carbon dioxide does not break down in the atmosphere. It remains there until it is taken up by plants or by the ocean.

*Greenhouse gases contribute to the warming of the earth. The two natural greenhouse gases which have the greatest effect on climate are included in the breath you exhale– carbon dioxide and water vapour.*

## Airborne particles

**Small particles in the air block out a portion of incoming sunlight and are essential to the formation of clouds. Their effect on climate varies from place to place.**

**Different sizes and composition**
The particles that whirl around in the atmosphere are tiny— often only one thousandth of a millimetre or less.

Particles that are formed naturally on land or at sea contain pollen, sea salt, bits of plankton, bacteria, viruses and compounds such as sulphur.

Mineral dust particles are blown into the air from deserts and dried-out lakebeds. Soot and plant residue rise from forest and grass fires and other burning.

Particles can float in the air for several days. Eventually, they settle or come down with rain on the places where wind and weather has taken them.

**Cloud-builders that float and shade**
If there were no particles in the air, it would be more difficult for clouds to form.

Atmospheric water vapour fastens easily to particles and forms at first small, invisible water drops. When the tiny drops then start to collide with each other, they combine to form increasingly larger drops. Finally, they can become so large and heavy that they fall towards the ground— as raindrops.

Both particles and clouds reflect incoming sunlight, preventing some of it from reaching the surface and from warming it up. The amount of reflection depends on a variety of factors, including the sizes and composition of the particles and the clouds.

Soot particles are an exception. Instead of reflecting, they absorb solar radiation and warm the atmosphere.

Particles influence the atmosphere in ways that we are struggling to understand better.

*Particles float about in the atmosphere. They can be or contain microscopic bits of sea salt, plant residue, and compounds such as sulphur . With the exception of soot, particles cool the earth.*

## Humans warm and cool the earth

**Humans warm the earth with emissions of greenhouse gases, which are increasing. But there are also emissions that increase the amount of particles that cool the areas which they shade.**

### Greenhouse gases— global effects

During the past 150 years, humans have increased the levels of greenhouse gases in the atmosphere.

We do that primarily by using fossil fuels coal, oil and natural gas. When these fuels are burn, carbon dioxide and other substances is formed.

Carbon dioxide has increased by 33 per cent in the atmosphere since the preindustrial era, nitrous oxide by 17 per cent and methane by 150 per cent. Levels of atmospheric methane and nitrous oxide increase due to modern agriculture, among other things.

We have also manufactured and released artificial substances such as freons. As a result, new greenhouse gases end up in the atmosphere, intensifying the greenhouse effect even further.

Our emissions of greenhouse gases affect the entire planet. Many of the substances released into the atmosphere today will remain there to affect climate for hundreds of years into the future.

### Particles influence local climate

When we burn fossil fuels, the result is not only an increase in greenhouse gases. The emissions also give rise to particles in the atmosphere.

Particles block incoming solar radiation especially in the northern hemisphere, where the emissions are the largest.

Most of human-made emissions come from industry, generation of electricity, householdsand transportation.

Population levels in virtually all major cities of the world are increasing. In areas where emissions are not sufficiently clean, levels of airborne particles are also increasing.

The peoples of underdeveloped countries, in particular, suffer increasing harm due to urban air pollution. Several million people die and many more become ill every year from increasingly polluted air.

*The aeroplanes, cars, factories and agriculture are increasing the levels of greenhouse gases in the atmosphere. The greenhouse effect is becoming stronger and the earth is becoming warmer. Emissions also cause more particles in the atmosphere that cause some cooling effect. The warming effect is stronger.*

## Make your own cloud!

Press the edge of the apparatus.
A cloud rises upward.

Formed in the apparatus are clouds whose water molecules clump together to form visible drops.

Clouds obscure over sixty per cent of the earth's surface and cool the Earth on the average. How are real clouds formed, and how do they effect climate?

Clouds consist not only of water vapour. Water vapour fastens first to airborne particles to form small drops or crystals. These collide with each other and combine into larger ones.

Water drops in clouds are around one-hundredth of a millimetre in size. It takes about one million tiny drops to from a raindrop heavy enough to fall to earth.

A typical cloud contains about one billion water drops, all of which began with a single airborne particle.

**Particles and the nature of clouds**
The effects of a cloud vary, depending on its thickness, altitude and composition.

Clouds that are close to the ground tend to shade the earth and cool the surface.

Clouds with many small water drops are relatively difficult for solar radiation to penetrate. They reflect a larg proportion of the radiation back into space without warming the earth. Such clouds appear white in the sky.

Clouds with fewer, larger drops are not as reflective and have a brownish-grey appearance.

**Drier and colder?**
Humans are now increasing the quantity of particles in the air with transportation and industrial emissions, and with modern agricultur.

When the number of airborne particles increases, but the amount of water vapor is the same, there is less water vapour for every particle. This results in more and smaller water drops, and therefore whiter clouds.

It can thus be said that "dirty" clouds are white, and "clean" clouds are brownish-grey.

When there are more white clouds that reflect more solar radiation, there is a cooling effect on the surface of the earth. Also rain is affected, because such clouds have many small water drops that combine less often to form raindrops.

Thus, more particles in the atmosphere as such may contribute to a cooler and drier climate in a complex system that we are just beginning to understand.

## WEATHER– AN INSTANT OF CLIMATE


**Humans have always tried to predict the weather.**

**In olden times, things like the spinal stripes of perch and the migrations of swallows were used for that purpose.**

**Today, things like satellites and weather radar are used, instead.**

## Superstition– the weatherman's predecessor

Two hundred years ago, there was no Swedish Meteorological and Hydrological Institute (SMHI). Most Swedes were farmers who depended on the forces of nature for survival.

If you wanted to know what the weather would be in those days, the available wisdom was very different than today's. It was often expressed in proverbs that were easy to remember.

Today, there are not many who believe in the old folk wisdom. The daily weather report is simpler and seems more reliable.

But perhaps one bit of ancient wisdom for predicting the weather still applies: Count on the weather tomorrow being the same as today's. For, the fact is that a given type of weather, sunny or overcast for example, often continues for several days. The wisdom does not, of cause, suffice to predict changes in the actual weather that often are rather interesting.

*"In autumn, observe the stripes along the spines of perches. If the stripes near the head are the darkest, it will be coldest at the start of winter. If the stripes nearest the tail are darkest, it will be coldest at the close of winter."*

When the pied wagtail returns, it is time to let out the sheep and do the spring planting.

*"Pied wagtail, sheep bell, wheatear— planting stick is near."*

If it rained on St. Gallus Day, the 16th of October, the harvest would be good no matter where one sowed.

*"If it rains on Gallus Day, the grain will grow explosively."*

## Is that a beehive, or a. . . ?

This is what most Swedish weather stations have looked like for most of the the 20th century. Each has three thermometers— one showing the current temperature, the other two showing the highest and lowest temperatures since the previous reading.

They used to be read several times a day by a human observer. Nowadays, nearly all Swedish weather stations are computerized.

Beside the thermometer screen is a rain gauge. High above is Meteosat, one of the European weather satellites. Today, meteorologists also make use of weather radar, systems for detecting lightening, weather balloons, and ocean weather buoys.

Information on such factors as temperature, humidity, wind speed, air pressure and solar radiation are recorded and put through calculations on very powerful computers to provide the basis for weather reports.

## Weather data from outer space

Satellites photograph clouds and measure radiation either from or passing through the atmosphere. The information gathered tells about the clouds, atmospheric humidity, winds, temperature and conditions at the surface.

Two of the series of satellites that SMHI makes use of are Meteosat and NOAA. The latter continually circles the earth at an altitude of 850 kilometres, collecting data along its passage.

Meteosat remains stationary at an altitude of 36,000 kilometres and constantly monitors the European region. A recent photo from Meteosat is displayed to the side. There are other such satellites monitoring other regions of the Earth in a similar fashion.

## It has always been worse

**Many recall stories of the rainstorm over Mt. Fulufjället in 1997, or the snowstorm in Gävle in 1998.**

**Have extreme weather events become more frequent in recent times?**

**Weather during the 20th century**
On close inspection, major storms appear not to have become more frequent since the beginning of the 20th century. But it appears that precipitation has increased in Sweden and it has become warmer.

For the past twenty years, annual precipitation has been above the 20th-century average in Sweden. During the same period, average temperature has also increased throughout the country— especially during winter: Some of the warmest years ever recorded in Sweden have occurred during the past fifteen years.

Are extreme weather events a sign of fundamental climate change?

## Swedish weather records

**Rain**
198 mm at Fagerheden on 28 July 1997

**Rain during 24-hour period**
276 mm over Mt. Fulufjället, 30-31 August 1997

**Warmth**
38° C at Målilla on 29 June 1947

**Cold**
–53° C at Malgovik on the morning of Santa Lucia Day, 13 December 1941

**A remarkable local snowfall**
150 cm at Gävle during 4-5 December 1998

**Biggest hailstone**
7-8 cm and 200 grams, at Ramnäs on 4 July 1953

**Most destructive hurricane**
22 September 1969
Swept over much of Sweden but caused most damage on the west coast

## What does a weather satellite see?

Live image from Meteosat showing current weather

**Cumulus clouds**
Clouds that look like bunches of cotton are a sign of clear weather.

**Cumulus congestus clouds**
If cumulus clouds assume a "cauliflower" shape, there may be rain within a few hours.

**Cumulunimbus clouds**
If cumulus congestus clouds extend further upward and become darker below, bad weather is on the way. Count on heavy rain and possibly thunder.

**Cirrus uncinus clouds**
A clear summer day, with only thin feathery clouds in the sky. But if they become dense near the horizon and "hooks" form on the other end, there is likely to be rain somewhere nearby within twelve hours.

**Cirrostratus clouds**
A thin veil of clouds covers the sky, and a halo forms around the sun. Both are signs that bad weather is on the way. Cirrostratus clouds have a blueish colour on satellite images.

**Altostratus clouds**
Misty clouds at low altitudes obscure the sun. Now, there is only an hour left before the rain begins.

**Rainclouds**
In the dense rainclouds, ice crystals or water drops have joined together and begun to fall.

**Fog**
Clouds of mist and fog appear yellow on satellite images.

## Weather and climate

How can we be certain that the earth is becoming warmer?

In addition to collecting actual information, we can go back in time and compare with what the weather/climate used to be like,

**Climate: a summary of weather conditions in a given area during a certain period of time.**

## Display of weather instruments

### Temperature

The first thermometers were developed about 400 years ago.

After fifty years, the first scale was devised. It consisted of two temperatures— the melting points of water and butter!

Anders Celsius, a Swedish scientist, decided that there should be 100 degrees between the freezing point and the boiling point of water. That was 250 years ago, when the mercury thermometer was already in use.

Today, temperature is usually measured at Swedish weather stations by resistance thermometers which are better for the environment. Temperature is given in degrees Celsius.

The maxi-mini thermometer displayed here was constructed in 1840. It cost ten Swedish kronor, a large sum at that time. The wall thermometer dates from the 19th century.

Thermometers on loan from the Swedish National Museum of Science and Technology.

### Solar radiation

Heliographs were used in the 19th century to send messages with reflected sunlight. They were also used to measure sunshine duration.

The large glass ball focuses the light on a narrow point. If the light is strong enough, it burns a hole in a paper fixed by the ball.

Today, meteorologists use a pyranometer to measure solar radiation. It has a black plate that is warmed by the sun. The temperature of the plate indicates the sunlight's strength.

Solar radiation is expressed in watts per square metre ($W/m^2$)

Older German heliograph, on loan from the Swedish National Museum of Science and Technology.

### Humidity

Have you noticed that some people's hair becomes curly when the air is humid. Hair contracts in varying degree, depending on the level of humidity. A hair hygrometer actually consists of hair connected to a pointer and a scale.

Humidity can also be measured with a psycrometer which has two thermometers, one of which is covered with a cloth gauze that is dampened.

The evaporation of water from the gauze  depends on ambient humidity. The evaporation lowers the temperature of the thermometer it covers. The difference between that and the other thermometer yields a measure of humidity.

Humidity is expressed as a per cent of the maximum possible at a given temperature (i.e., relative humidity).

An old hair hygrometer that was once owned by the Swedish Central Bank, and a thermohygrograph from 1930.

Both on loan from the Swedish National Museum of Science and Technology.

**Atmospheric pressure**
If you put two empty, closed laboratory measures of different volume on a balance scale, you will observe that the balance arm shifts occasionally. This was noted in the 15th century by Leonardo da Vinci. His explanation of this phenomenon was that it was due to changes in the density of the trapped air, and he was – sort of - right.

The aneroid barometers operate on the principle that Leonardo came by. They contain an enclosed measure which is compressed in a varying degree depending on atmospheric pressure.

Atmospheric pressure is stated in hectopascals (hPa). Earlier a measure called millibar (mb) was used.

An aneroid barometer from 1862, a small barometer with altitude scale for use in the field, and a barometer of foreign manufacture from 1889 with marble base.

On loan from the Swedish National Museum of Science and Technology.

**Wind speed**
How to measure the wind and with what index? One of the first such scales to be developed was used in England 300 years ago and had five steps: calm, light wind, strong wind, half storm and full storm. Since then, the wind has been measured in various ways with a variety of instruments.

Today we use a modern version of the anemometer invented in 1923 by J.W. Sandström of Sweden, which makes one complete rotation for every five metres of air movement. Wind speed in Sweden is now measured in metres per second.

A Swedish anemometer with cups (skålkors) from the mid-1920s, and a German model from the mid-1950s.

Both on loan from the Swedish National Museum of Science and Technology.

**Precipitation**
Jupiter, the Roman weather god, had many nicknames. When it rained, he was called Pluvius, which has inspired the name of the modern rain gauge.

The pluviometer is perhaps the simplest of all weather instruments. The cylinder into which rain falls has a precisely measured opening. The water collected in the gauge is poured into a graduated measuring glass to determine how much rain has fallen.

Rain volume is given in millimetres. One millimetre of rain corresponds to one litre per square metre.

This rain gauge is from the 1940s and is on loan from the Stockholm City Museum.

# CLIMATE IN THE PAST, PRESENT AND FUTURE?

## Continental drift

**Millimetre by millimetre…**

**The movements of the continents have influenced the climate over very long periods of time.**

**Shifting ocean currents**

The movements of the continents force the ocean waters to change position. Great currents of warm and cold water take other routes, giving rise to regional or global climate change.

One hundred million years ago, the earth's climate was warmer than it is today. The continents were close together. The ocean currents had an easier run to transport heat from the waters near the equator.

Some 30-35 million years ago, Antarctica began to move away from the other continents. The ocean currents changed their routes to get around the icy continent.
The southern hemisphere "quickly" became colder in a process that took only a few thousand years.

**Tropical jungle on Greenland?**
What was the climate like 250 million years ago? Clues are provided by the plant fossils from that time which have been discovered.

By comparing the discovery sites of the fossil plants with the current locations of their modern-day relatives, we can draw conclusions about the climate when the fossilized plants were living.

Many of the plants and animals that did not become fossils instead became black coal, oil or natural gas. Such materials are called fossil fuels.

*Fossil of a breadfruit tree in Greenland from 80 million years ago. Occurs naturally today in Asia and is grown in tropical areas around the world.*

*Fossil of a fern from Skåne in southern Sweden from 200 million years ago. Its closest modern relative lives in Asian rainforests.*

## Glacial ice— a climate archive

**Small bubbles in an ice sheet can yield information about the climate of the past back to as long as 800,000 years ago.**

**Hidden in the snow…**
The ice has stored its history in the ice of Greenland and Antarctica for many thousands of years,.

It is only recently that we have been able to understand what the ice can disclose. The clues are to be found trapped in the ice. They tell about the past temperature and atmospheric composition.

Air was trapped when the snow that fell long ago was compressed into ice by the weight of additional snow that fell on top of the earlier snow.. The deeper the ice, the older it is. One of the oldest samples of ice has been bored out at the Vostok Research Station in the Antarctic. That ice core contains a record of climate stretching 400,000 years back in time. It shows a fairly constant level of particles in the atmosphere during the past 10,000 years, when the most recent glacial came to an end.

But around one hundred years ago, that pattern was broken. Particles of human-made air pollution spread as far as the polar regions. The average temperature gradually began to increase, especially during the past 25 years.

**Life at a research-station**
“To live and work at a remote location on an ice sheet for months at a stretch is a special experience. The weather is extreme and the working conditions are very difficult. It can be minus 40 degrees Celsius in summer, despite intense sunlight around the clock. The savage, desolate landscape is beautiful and magnificent.
"It is exciting to extract a core of primeval ice— the oldest bored out thus far going back about 800,000 years. But it requires great patience, and things do not always go as planned. If something breaks, it is necessary to rely on one's ingenuity; for, it is a long way to the nearest repair shop!"

*Malin Stenberg, PH.D., Stockholm University*
*The ice cores displayed here are from the Tarfala Glacier on Mt. Kebnekaise in northern Sweden.*

*Thanks are due to Stockholm University for the ice cores, and to the Electrolux Company for making it possible to display them here.*

*This is ice that has been taken from a glacier near the mountain Kebnekaise. Glacial ice can provide clues about the climate of the past. Among other things, the level of carbon dioxide trapped in air bubbles can be measured. Glacial ice from Greenland and Antarctica can be many hundred thousands of years old.*

## Nature's climate memory

**Stalactites and stalagmites, lake sediments and peat bogs serve as climate archives. Built up layer by layer, they can tell much about climatic conditions.**

**Drops from 7000 years ago**
In underground caves, the only thing that moves is often the water that seeps from the roof. If the water contains calcium, stalactites and stalagmites are formed.

Thin layers are slowly built up from the minerals and other bits of soil absorbed by the water during its passage through the earth above the cave.

By analysing the oxygen and carbon in stalactites and stalagmites it is possible to determine ground surface conditions in the past, for example how much warmth and rain there has been.
In South Africa there are stalactites and stalagmites that are around 7000 years old. They can provide information on how warm it was during the Viking Era, and much more.

*Thanks to Stockholm University for the loan.*

**Sedimentary layers**
The forest's inhabitants live and die. Remains of plants and animals are rapidly broken down in the soil. But in lakes, seas and watery bogs, the process goes much more slowly. Year after year, residues of dead organisms accumulate in layers.

In order to learn which plant and animal species previously inhabited an area, samples can be taken at various depths.

Pollen grains and bits of plants and animals reflect the type of climate that existed when they were deposited. It is now possible to analyse the oxygen and carbon in a sample to learn more about the climate of the past.

*Annual rings are clearly visible on this core sample from a lakebed.*

## What tree rings reveal

**Trees do not move, so they are only able to utilize the light, warmth and water where they stand. Tree growth thus reflects the history of rain, temperature and sunlight at the places where they grow.**

**Warm summers, broad growth rings**

Every summer, trees add a few millimetres of wood just beneath the bark. During years, when summer temperature and precipitation are optimal, the amount of growth is large. If conditions are unfavourable, there may be hardly any growth.

By comparing the width of successive tree rings, it is possible to learn something about the summer climate of successive years.

Sometimes, traces of dramatic events can be seen in tree rings. In 1883, there was an enormous eruption from Krakatau, a volcano in what is now Indonesia. Vast amounts of volcanic ash were flung into the atmosphere. The following year was called "the year without a summer"; it was so cold that the growth of trees was retarded all over the earth.

**Ancient tree trunks**
The "ancient pines" in the mountains of Jämtland have lived long lives in a harsh climate. Generations of pines have grown in the region.

Sometimes a tree falls and ends up in a small mountain lake, where it is eventually buried in bottom sediments that contain very little oxygen. The lack of oxygen arrests the process of decay so that the tree is preserved.

Numerous trees from various periods have been drawn up from lakes. The widths of the annual rings yield information about climatic conditions over time.

In this way, it has been possible to develop a picture of summer weather conditions for some areas for the past 7500 years.

*The annual growth rings of trees indicate what the climate has been like in the past. Trees grow during the summer months. Warm and rainy summers result in wider rings.*

*This pine was almost 300 years old when it was felled in the autumn of 1946. It is believed to have grown near the Museum of Natural History, in what is now an ecopark. The first annual ring was formed in 1675.*

## The earth is getting warmer

**The possibility of it was first discussed more that 100 years ago, and that it is happening has become evident during the latest 25 years: The earth's climate is becoming warmer at an increasing rate.**

**Change reflected in nature**
The more carbon dioxide in the air, the warmer the climate. That relationship is clear from the study past climates with the help of ice cores, stalactites, and sediment samples.

Now, we are increasing the levels of carbon dioxide and other greenhouse gases in the atmosphere through the use of fossil fuels.

There is more carbon dioxide in the air than there apparently has been during the past twenty million years, and the temperature is rising faster than it has done for of the past ten thousand years.

The temperature increase is not the same everywhere on earth. It has been greater in the northern hemisphere than in the southern. There are also regional variations within each hemisphere.

**IPCC's collective wisdom**
What will the climate be like in the future? The Intergovernmental Panel on Climate Change has been established by the U.N. that . It collects climate researchers and governments from all over the world.

IPCC provides information on the climate science, emissions, climate change and the consequences of climate changes, and how it might be possible to mitigate climate change.

As no one knows exactly how the world and its human inhabitants continue to develop, the IPCC has worked with several possible scenarios regarding:

- world population growth
- the development and spread of new technology
- efforts to promote social justice and ecological sustainability.

## Future global climate

**The climatic changes we already see today could be just a start to more dramatic changes during the coming decades.**

**We influence future climate**
The climate of the future depends to a great extent on the quantities of greenhouse gas and particles and particle precursors that are emitted.

It will take time to lessen our dependence on fossil fuels. As this is likely to take time, the earth may become as much as 1.4–5.8° C warmer by year 2100. The changes will vary from place to place, and they will depend on how exactly atmospheric and ocean currents react to the increased warmth.

The changes will affect both averages and extremes. A hundred years from now, the temperature may occasionally rise to 40° C in southern Sweden. In Central Europe, highs may reach 50° and above. Peak temperatures in Northern Africa may become hotter than ever recorded during the modern era— up to 60°.

**Warmth leads to rain**
According to the United Nations' climate panel IPCC, future warming will be greater over land than over water.

When the temperature rises, more water evaporates from the earth's surface. When the atmosphere contains more water vapour, the amount of precipitation also increases— but not in equal measure around the globe.

There is much to indicate that rain will increase in areas that are already comparatively wet.

Some areas that are already dry will most likely receive even less precipitation. Mexico, Central America, the Mediterranean region, southern Africa and Australia will probably become even drier.

## Future European climate

**The rise in temperature is expected to be greater in Europe than for the earth as a whole. Even within Europe, the change will be uneven.**

**Wetter and warmer in the north**
Also in our part of the world, precipitation and temperature changes will vary between countries and seasons.

Winter temperatures will rise most in the north and east. An increasing number of areas which today are covered in snow will remain bare during winter. Northern Europe is expected to receive more precipitation in winter and possibly less in summer.

Summer temperatures are expected to increase the most in Middle and Southern Europe. The amount of precipitation will decline in those areas. The ground will dry out more often and more thoroughly.

There will be changes in sea level, the amount of snow and sea ice, and possibly in the frequency of different weather extremes.

**Sweden in 2100**
Attempt to project future climate requires making use of advanced climate models and supercomputers.

A computer model can include many factors and processes that influence climate. A 100-year projection of the earth's climate requires billions of calculations.

Despite the increasing capacity of supercomputers, model simulations can only provide us with estimates. It is difficult to specify the future climate of Sweden or any other particular place with full certainty. The climate is a very complex system and how emissions will evolve is not certain either.

SWECLIM was a Swedish research programme that was run in 1996-2003. The researchers developed climate models and used these to project the climate of Sweden and all of Europe by years 2071-2100.

## Feel the earth

**A few degrees warmer…**
By 2100, the earth's average temperature may have increased from the present about 14 to 16-20 degrees Celsius. That may not sound very dramatic, but the consequences can be enormous.

The last time that Sweden was an average of four degrees colder, the land was covered by a kilometre-thick layer of ice. That was during the most recent glacial.

The temperature of the three small globes is 10,14 and 18 degrees Celsius. Feel the difference.

## Global climate zones

**The Earth's climate can be divided into a number of climate zones that more or less encircle the earth in broad belts— from the polar region and tundra in the north, to steppes and deserts to the south. Each zone has its own characteristic species that are adapted to its particular conditions.**

Precipitation and temperature are key determinants of climate zones.

A major climate change can rapidly move the boundaries between climate zones.

Polar region

Tundra

Taiga

Broad-leaved forest

Mediterranean region

Tropical rainforest

Steppe and savannah

Desert

## WHAT COULD HAPPEN?


**Climate change is already in progress. How will it affect us?**

**There is considerable uncertainty, and the effects may vary widely around the globe. Here are several examples of what might happen. . .**

## Water— a scarce resource

Drought and crop failure may increase in countries that already tend to suffer water shortages. Many of those with scarce resources will suffer even greater deprivation.

The number of environmental refugees from poor, dry parts of the world may increase to become many millions.

## Melting of the ancient ice

Many large mountain chains around the globe have glaciers— large areas of ice that remain in place year round. Glacial meltwater feeds mountain streams even during hot and dry periods.

But glaciers all over the world are now melting at a worrying pace.

## Increase in weather disasters?

In recent years, powerful storms around the world have caused heavy damage. But this does not necessarily mean that such storms have become more frequent or destructive.

Will extreme weather events become more common in the future? Perhaps, but it is not yet known with much certainty if they will or how they might otherwise change.

## Diseases may spread

Many insect species thrive better in a warmer climate. If they carry parasites, those will also increase in number and distribution and affect humans, animals and vegetation.

There is a risk that malaria will be further spread by mosquitoes, especially in areas near the equator which become both wetter and warmer.

In Sweden, ticks are spreading northward and, with them, the diseases borrelia and TBE.

## Rising sea level

As the earth becomes warmer, the ocean volume expands and sea level rises. Melting glaciers also contribute to the rise in sea level.

The U.N. climate panel IPCC reportsthat global mean sea level can rise between 9 and 88 centimetres during the next hundred years. Regional and local changes might be somewhat smaller or even larger. If sea level rises one metre, forty million inhabitants of Bangladesh will be forced to move, for example.

## Altered ocean currents

Sweden lies as far north as Alaska, but the climate here is warmer. That is because of the Gulf Stream, which carries warm water from near the equator.

If the Gulf Stream should change because of global warming, it would cause an additional agent of change of climate of the Nordic region.

## Future of the Wasaloppet ski race?

A warmer climate could make snowy winters rare in central and southern Sweden. Wintertime sea ice on the Baltic Sea would also be affected.

Will the next generation enjoy skiing and long-distance skating to the same extent that we do today?

## Thousands of species disappear?

A higher temperature changes conditions for life on earth.

Some species will probably benefit, but many will find it more difficult to survive. It is possible that thousands of species will become extinct.

**"Winners"**
Dandelions, flying insects, rats and cockroaches. Species that can survive in many different types of habitat, change location quickly or thrive in proximity to humans.

**"Losers"**
Species that occupy special niches, such as the Java rhinoceros and the panda. They are species that would have difficulty relocating if the climate were to change significantly. Trees, which are immobile and grow slowly, would also be among the losers.

**Alpine barrens—a threatened ecosystem**
When the climate becomes warmer in Sweden, the tree line on mountain slopes moves upward.

The current plants and animals of the mountain barrens will increasingly be displaced. Fast-growing grasses and shrubs would thrive at higher altitudes. One vulnerable animal species is the Arctic fox.

## Combined effects

It is difficult to foresee outcomes when many different factors are involved. What happens when a species in an ecosystem declines in number?

One example is provided by the bacteria that live on the underside of polar ice. Such bacteria are a source of food for oceanic plant plankton. They are eaten by animal plankton, which are in turn eaten by krill, tiny crustaceans. Krill are the principal food source of many fish and several whale species.

If the polar ice melts and the supply of bacteria declines, the consequences could be grave for many other species including whales, the world's largest animals.

No one can predict with certainty how climate change affects millions of plants and animals, or what the consequences might be for humans.

## Overheated coral reefs

Coral reefs are among the most biological diverse ecosystems on earth. They provide food for millions of people, as well as income from tourism and protection against shoreline erosion. Coral reefs are also a source of raw materials for various medicines.

As a result of increasing levels of carbon dioxide in the atmosphere, ocean temperature increases and the amount of calcium carbonate in the water decreases. Those conditions make it more difficult for coral reefs to grow and survive. They also become more sensitive to environmental toxins, nutrients and overfishing.

One-third of the earth's coral reefs are already damaged. More marine reserves and fewer emissions of greenhouse gases would help. It is still not too late to save many coral reefs, but the need for action is urgent.

## North and South

**Who affects, and who is affected?**
The effects of climate change vary among the regions of the world.

The poor are hit the hardest, even though their contribution to the greenhouse effect is least.

**How does the future look?**
The living conditions of many poor people are improving. Like everyone else, they deserve a higher standard of living, greater freedom and travel opportunities.

Today, the amount of carbon dioxide released into the atmosphere by an average U.S. resident is twenty times that of an African. What will happen when Africans "catch up"?

**New technology for all**

That the Third World is developing is something positive, of course.

Properly distributed, economic growth means that fewer children starve and fewer die of disease.

We can not and should not hinder such development. But it would be useful to assist with technology that has less impact on climate.

When a half-billion Chinese acquire cars, it should be made possible for them to purchase models powered by biofuels or fuel cells.

Of course, we must provide a good example, ourselves.

## Anna from Sweden and Chai from Cambodia

**Human impacts on climate are a challenge for everyone on earth to resolve. The solution requires justice, as well as dialogue between the wealthy and the poor of the world.**

**Anna**

14 years old.
Lives in Trosa, Sweden.
Attends school six hours a day.
Owns 40 tops and 15 pants.
Principal non-school activities: paints and spends time with friends.
Family cooks with an electric stove.
Favourite dish: Meatballs and macaroni.
Family owns two cars.
Wants to become fashion designer.

An average Swedish 14-year-old accounts for about 1700 kilograms of carbon dioxide emissions annually.

Average annual carbon dioxide emissions for Sweden are 6.5 tonnes per inhabitant. That is below the European *per capita* average which is around 8 tonnes. The corresponding figure for the United States is 20 tonnes *per capita*.

Climate change is likely to make Sweden become warmer, it will rain a bit more, and perhaps storm a bit more in Sweden.

Sweden has already made some progress in preparing for climate change.

**Chai**

14 years old.
Lives in Kâmpóng Saôm, Cambodia.
Attends school 6 hours a day.
Owns 4 tops and 2 pants.
Principal non-school activities: sells fruit and spends time with friends.
Family cooks with wood stove.
Favourite dish: Fish and rice.
Family owns one moped.
Wants to become physician.

An average Cambodian 14-year-old accounts for about 140 kilograms of carbon dioxide emissions annually.

Average annual carbon dioxide emissions for Cambodia are 0.1 tonne per inhabitant.

The primary occupation in Cambodia is farming, which is dependent on a stable climate of alternating dry and wet seasons. Climate change poses the risk of the weather becoming less predictable. If the dry season is prolonged or the amount of rain increases substantially, Cambodia will be severely affected. There would also be a risk that large areas might be flooded by the Mekong River and/or rising sea level.

One of the poorest countries in the world, Cambodia lacks the means to prepare for such changes.

## SOLUTIONS ARE AVAILABLE

**Everywhere, efforts are under way to reduce the human impact on climate. There is a need for co-operation at all levels.**

## Kyoto— global co-operation

**Climate change is a global problem. The nations of the world must solve it together.**

The first step was taken in 1992. In that year, 166 countries signed a U.N. framework convention to prevent human emissions of greenhouse gases from becoming so great that the impact on climate would be dangerous.

The next major step was taken at the Japanese city of Kyoto in 1997, when plans were made for a first implementation phase of the 1992 Framework Convention.

**How to reach the objectives?**
It was decided in Kyoto that developed countries should reduce their joint emissions by five per cent by years 2008-2012. No demands for reductions were yet made on developing countries.

Since then, it has been agreed how the collective emission reduction target is divided between the countries. Most must reduce their emissions. Some countries are permitted to increase their emissions and some are allowed to maintain current levels, depending on various factors.

## Kyoto in effect starting 2005

As of March 2005, the Kyoto Protocol had been ratified by 125 countries, including 33 classified as underdeveloped.

In order for the Protocol to be valid, it was necessary that it be ratified by countries whose combined emissions accounted for at least 55 per cent of the world total. That qualifying threshold was reached in late 2004 when Russia ratified the agreement.

Many countries, including Sweden, began working toward their emission goals even before the agreement went into effect.

**International co-operation**
To make it easier for underdeveloped countries to reach their emission goals, the Kyoto Protocol includes so-called flexible mechanisms.

They are based on the principle that it makes no difference where emissions are reduced. The effect on the earth's atmosphere is the same.

One flexible mechanism is trade in emission credits. Each credit grants the right to release one tonne of carbon dioxide. If a company or other source reduces its emissions below its allotted share, it may sell the unused portion to another source that would like to release more than its allotted quota.

With this system, costs increase for those who exceed their quotas. Since the number of credits remains constant, the total volume of emissions cannot increase.

## Sweden's climate policy

**Sweden has committed itself to reducing its emissions of greenhouse gases by four per cent by year 2012. A more long-term goal is to cut total emissions to half of today's level by year 2050.**

Those goals were established in the spring of 2002 as part of a Swedish environmental policy entitled "Limited Climate Impact".

Today, an average Swede accounts for six tonnes of carbon dioxide emissions annually. That is a fairly small amount compared with many other European countries or the United States. Two explanations for Sweden's low emission level are its energy taxes and the use of district heating plants to warm many buildings.

Many problems remain to be solved. The biggest of them is the continuing increase in road traffic.

**Sweden and Kyoto**
Along with most other European countries, Sweden signed the Kyoto Protocol in May of 2002. When the European Union assigned quotas to all the member-states, Sweden was allowed to increase its emissions by four per cent.

But shortly thereafter, the Swedish parliament decided that we should not increase our emissions , but instead *decrease* them by four per cent.

In order to achieve that goal, the Swedish government has decided on a number of measures, including the following:
• higher tax on carbon dioxide emissions
• lower tax for environmentally friendly cars and biofuels
• public education on climate change

• grants to municipalities and companies willing to invest in measures to reduce the risk of harmful climate change.

## One step at a time

Some of the measures adopted in 2002 have already been implemented. The tax on carbon dioxide emissions has been raised, and funds have been provided for climate-related measures of municipalities and companies.

During 2002-2003, the Swedish Environmental Protection Agency conducted a public education campaign on the greenhouse effect. The general level of knowledge and awareness was raised, and climate issues are now discussed more often than previously in Swedish media.

*Road traffic is the worst*
*Road traffic now accounts for nearly 40 per cent of Swedish carbon dioxide emissions.*

## Windpower storming ahead

**Europe is investing heavily in windpower. It is predicted that, by year 2020, windpower will supply electricity to 195 million European homes.**

**Twenty years ago, windpower generators were small and based on the mainland. Today, they are large, more efficient, and often sited on islands or in offshore waters.**

Windpower could supply some of the electricity in many parts of the world, including Sweden. There is room for many more windpower generators along our lengthy and windy coasts.

Today, less than one per cent of Sweden's electricity comes from windpower. But new generators are being planned and built.

**Many investing heavily**
At present, the total amount of electricity generated by European windpower equals that produced by fifteen nuclear power plants of the size operating in Sweden. It is estimated that the windpower equivalent will be one hundred nuclear plants by year 2020. The European countries that are investing most heavily in windpower are Germany, the United Kingdom and Denmark. German windpower, alone, corresponds to that of 7-8 nuclear power plants.

In Sweden, only one-third of nuclear power is expected to be replaced by windpower. Our goal is to produce 10 TWh annually by year 2015. In order to reach that goal, current windpower must be increased by a factor of twenty.

(TW = terawatt = one billion kilowatts)

**A noisy eyesore?**
One reason that more windpower generators have not been built is that it has been difficult to win local approval for construction sites. People who live near wind generators might feel that they spoil the view and are too noisy. There are also concerns that some offshore installations might disturbe marine life.

**When the wind subsides**
There is no guarantee that the wind will blow all the time as needed. When generators stand still, there must be other power sources to rely upon.

In Sweden, those other resources consist largely of hydropower plants. When the winds are supplying power, some of the water used for hydropower can be stored until later.

In the future, it should be possible to use windpower to produce hydrogen gas, which can be used for a variety of applications, including fuel cells.

## Fuel cells

**Some of the world's largest auto manufactures now produce electric cars that are powered by fuel cells.**

Fuel cells are easy to manufacture, very energy-efficient, require no fossil fuel, and emit only water vapour.

Fuel cells function somewhat like a battery, but are powered by hydrogen gas which can be extracted from water, methanol, biogas and many other sources.

Since fuel cells do not require inputs of electricity, it is well-suited to many applications.

Products powered by fuel cells are being developed in many countries. Many such products are already available, including mobile phones, laptop computers and heating elements.

If the use of fuel-cell vehicles is to increase, they must become cheaper to manufacture, and a suitable system for producing and distributing hydrogen gas must be developed.

Much remains to be done, but there are already buses operating in Stockholm that are powered by fuel cells. In 15–20 years, fuel-cell cars will probably be a common sight on our streets.

***Hydrogen gas + oxygen =water+energy***
*Solar cells supply energy to a catalytic converter which separates water into its components of hydrogen and oxygen. The oxygen is led into one pipe. The hydrogen is led via the other to the fuel cell, which produces electricity for the pinwheel.*

## Electricity from the rays of the sun

We humans have long used the sun's energy to keep warm, and to dry and cook food. When we can turn solar radiation into electricity in solar cells, we can do almost anything we want with the sun's energy! What's more, solar cells do not emit pollutants and they last long.

Electricity produced with solar energy has long been much more costly than other energy sources. But with improved technology, it will become less costly.

The first solar cells were not very efficient: Of the sun's energy which they captured, they could only convert a few per cent to electricity. The efficiency of today's solar cells is much greater— around fifteen per cent.

**World leader in Uppsala**
The Ångström Laboratory in Uppsala has a research team that has developed one of the most efficient solar cells in the world. It consists of a film that is much thinner than the width of a human hair.

The "solar film" can be easily applied to a pane of glass or a sheet of metal. It is much more efficient and cheaper to produce than the silicon-based solar cells that are most commonly used today.

**No electric grid needed**
Solar cells are useful for locations that are not serviced by an electric grid. This makes them especially suitable for sunny underdeveloped countries, but also for isolated summer cabins in Sweden.

**And if it is cloudy?**
Since the sun does not always shine, it would be useful to have some way to store electricity produced with energy from the sun.

In the future, it will be possible to use solar energy to produce hydrogen gas which can be stored for later use in heat-electric plants or fuel cells.

**Less is more**
Today, the worldwide total amount of electricity produced by solar cells is equal to that of one average-size nuclear power plant. That may not seem like very much, but interest in solar cells is increasing all over the world.

Total worldwide sales of solar cells in 2003 amounted to over 40 million Swedish kronor. The sales increase by thirty per year.

## Transportation– a decisive issue for the future?

**For those who want to travel or transport goods without affecting the climate, more and more alternatives are becoming available.**

**New types of fuel, new technology, and investments in public transport are making it easier to decrease the use of fossil fuels.**

But transportation is still the biggest source of greenhouse gas and particle emissions. There are now numerous alternatives to petrol and diesel fuel. Biogas, ethanol and rapeseed oil are a few examples of fuels whose net effect on climate is almost nil. Also, the exhaust cleaning systems of new cars are being constantly improved.

Nevertheless, traffic-related emissions of carbon dioxide continue to increase because the number and total length of trips continues to increase. Transportation is still the biggest human source of greenhouse gas emissions.

The release of greenhouse gases is not the only problem associated with vehicular traffic. In Sweden, around 500 people are killed and 4000 are seriously injured every year in traffic accidents.
In addition, many premature deaths are directly or indirectly caused by

exhaust gases— around 800 every year in Stockholm, alone.

**More air travel**
Today's aeroplanes are quieter, cleaner and more fuel-efficient than their predecessors. But air traffic is steadily increasing, and greenhouse gas emissions along with it.

In order to reduce global emissions, it is necessary to devise an agreement on international regulations.

Airports operated by the Swedish Civil Aviation Administration charge higher landing fees for planes that are relatively noisy or release large amounts of emissions. But as yet, there are no energy or carbon dioxide taxes on air traffic.

**Climate-friendly travel**
One-third of all traffic emissions are related to human transport. Here are some tips on how to travel ways that are more climate-friendly:

- When travelling within Sweden, take the opportunity to see our beautiful country through a train window.
- Cycle shorter distances instead of taking a car or bus. Both your health and your finances will benefit.
- Cars emit carbon dioxide at a rate that is 35 per cent higher during the first five kilometres than afterward.
- If you must travel by air, choose a plane that releases fewer emissions. Ask about emission levels when you book your flight.
- By driving gently and evenly in city traffic, you can reduce petrol consumption by ten per cent. On the open road, the best fuel economy is attained driving in the highest gear at low rpm— usually around 60-70 kilometres per hour. By driving at 90 instead of 110 kph, you can reduce fuel consumption by 10-20 per cent.

## Energy-saving tips for the climate and the pocketbook

**Reducing our impact on climate by using less energy benefits households, businesses and nations. This is understood by more and more people.**

**Ecological sustainability is, after all, largely a matter of giving a second thought: What is the best solution in the long run?**

In countries all over the world, investments are being made in renewable energy. Swedish municipalities compete with each other to be the most environmentally friendly. A growing number of Swedish companies are environmentally certified.

We have made significant advances. But if our way of life is to be sustainable in the long run, more is required.

Eventually, we must replace fossil fuels and nuclear power with renewable energy sources such as wind, solar, hydrogen and biofuels.

But in order to reduce our impact on the earth's climate, we must also use existing resources more sparingly.

We can start right now!

**Your choices make a difference**
Obviously, political and business leaders have important responsibilities for the reduction of our impact on climate. But today, nearly half of Swedish emissions of greenhouse gases come from households.

Accordingly, individual choices regarding travel, housing and consumer goods have great significance. The following simple measures can make a big difference for your impact on the climate and your pocketbook:

- Lower indoor temperature by one degree Celsius. You will save 500–1000 kronor per year.
- Buy energy-saving light bulbs. They are five times more efficient than incandescent lamps and last ten times longer.
- Turn off electric appliances when not in use. VCRs, computers, TVs and stereos use energy even when on standby.
- Buy energy-efficient household appliances.
- Recycle instead of buying new.
- If possible, warm your home with bedrock heat or biofuels.
- Choose environmentally certified electricity. Your money will go to a renewable resource.
- Review your travel routines. Perhaps you can cycle short distances instead of taking the car?

Most of these energy tips can be applied generally at home, on the job or at school. They are small steps which lead to large benefits for everyone in the long run, and not least for our climate.

## Valuable climate initiatives

**Do my actions make any difference?**
Is it not up to political and business leaders to do something about the climate? How important are the choices I make?

Swedish households account for half of the country's carbon dioxide emissions. This means that everyone's choices make a difference. Of course, policies that make it easier to make the right choices are also needed. But we can all contribute through the choices we make at school, at work and in the community.

**Horses warm their own riding school**
In the Swedish town of Timrå, the riding school is heated with stable straw and horse manure.

The school's furnace was adapted to burn stable waste instead of pellets. The conversion was so successful that the riding school has saved 130,000 kilowatt hours of electricity in less than half a year.

**Switch from petrol to ethanol**
It is easy to adapt a combustion engine so that it runs on ethanol instead of petrol. A company in Karlstad has done so for over 100 cars and some 50 lawnmowers.

The biggest improvements are achieved when older cars and lawnmowers are converted. They then no longer affect the climate as much, and are less costly to operate.

**House warmed by body heat**
In the town of Lindås, near Göteborg, there are houses with no heating elements.

Instead, they have solid doors and windows, heat exchangers and thick insulation.

Body heat and waste heat appliances are from lamps and other electrical sufficient to keep the buildings warm.

**Solar-powered minitaxis in Sri Lanka**
Many Asian cities with multi-million populations have serious problems of air pollution; it affects the local climate and causes illness among the inhabitants.

A "tuk-tuk" is a type of small three-wheel taxi that is very common in many Asian cities. Currently being tested in Sri Lanka is a new model that is powered by solar cells mounted on the roof.

**5000 members in a Bremen carpool**
The German city of Bremen wants to provide its inhabitants with alternatives to private cars.
A comprehensive system for public transport, taxis, hired bicycles and carpools results in fewer cars on city streets. With fewer cars and parking spaces, there is more room for green areas and playgrounds.

There are similar systems at several other locations in Europe, and the new ideas are spreading.

**Fossil-free Växjö**
The Municipality of Växjö is planning to cut its carbon dioxide emissions in half by year 2010.

A reduction of twenty per cent has already been achieved by investing in public transport, supporting alternative fuels, and expanding the district heating network.

Växjö's vision of its future is to become entirely free of fossil fuels.

**Tired of your car? Eat it up!**
The Ford Motor Co. has produced the prototype of a car which is almost completely recyclable.

The top and the carpets are made of corn starch, the seats of soy beans, and interior details of recyclable polyester. It is powered by fuel cells and called the Model U Green Car.

**Solar electricity in South Africa**
Some 50,000 homes in South Africa are being supplied with solar electricity units.

The units are free of charge. The user buys an electricity card— much like a debit card or mobile phone card— and uses that to purchase electricity from solar cells.

**Zero emissions in 50 years**
Iceland is planning to become the first country in the world with a hydrogen economy. Today, Iceland has among highest *per capita* emissions of carbon dioxide in the world.

The plan is for fuel cells to supply the entire society with energy within fifty years.

The hydrogen gas for the fuel cells will be produced using energy from the island nation's hot springs.

**Produces its own biofuels**
In Brazil, over four million cars run on ethanol, a biofuel. All petrol used in the country is blended in a mixture with 25 per cent ethanol.

Brazil has been producing ethanol from sugar beets and molasses since the 1970s. The country is now planning to increase production by fifty per cent.

**Beijing Olympics with no emissions**
China is developing at record speed. But even if it were to buy the entire world annual supply of fossil fuels, it would soon not be enough to supply future needs. Therefore, China is investing heavily in research on alternative energy sources. One intermediate objective is for all transportation during the Olympic Games in Beijing to yield zero emissions of greenhouse gases.

## FUTURE PERSPECTIVE

“Millions of people in the tropics are already dying of malaria every year. If the climate becomes warmer, mosquitoes and malaria parasites will spread to new areas.

I am working on a new medicine against malaria. Climate change is one reason why it is important to develop it quickly."

Mita Maini-Thapar
Malaria Laboratory, Karolinska Hospital

“If the prognoses of climate scientists are correct, there is going to be more rain in Sweden.

In that case, the enormous reservoirs of our hydropower stations must be able to handle more water.

I am one of those who calculate how dams need to be upgraded in order to meet the challenges posed by the climate of the future."

Carl Oscar Nilsson Dammsäkerhet, Graninge

"Climatic changes pose risks for future markets. That is a fact that must be confronted now.

As a reinsurance company, we invest heavily in efforts to project the consequences of climate change and to inform clients and the general public about them."

Bruno Porro Chief Risk Officer at Swiss Re, Switzerland

"The transportation of people and goods increases every year. Today, all transportation is entirely dependent on oil, a fossil fuel which aggravates the greenhouse effect. Furthermore, the supply of oil will soon come to an end.

Our transportation fuels must instead be renewable, and it would also be preferable if they could be produced locally.

Therefore, my colleagues and I are seeing to it that as many buses and trains as possible are powered by renewable energy sources such as biogas, ethanol, hydropower and windpower."

Jonas Strömberg
Environmental Officer, Stockholm Transport

"Large parts of the world that already have a warm climate will become even drier and hotter.

In order for the populations of those areas to survive, they will have to grow more drought-resistant crops.

Trees and other plants also bind the soil so that it is not washed away when rain does come."

Rael Koech
Farm manager OPAC
(Olof Palme Agroforestry Centre)

"Kristianstad is the lowest-lying city in Sweden. The ground is up to more than two metres below sea level, and we have to pump rainwater from the city streets.

The Helge River which runs through the city has flooded several times during the past twenty years. That is more than normal.
If the sea level rises or precipitation increases, the city's situation can become critical. We are building more dykes around Kristianstad in anticipation of such a development."

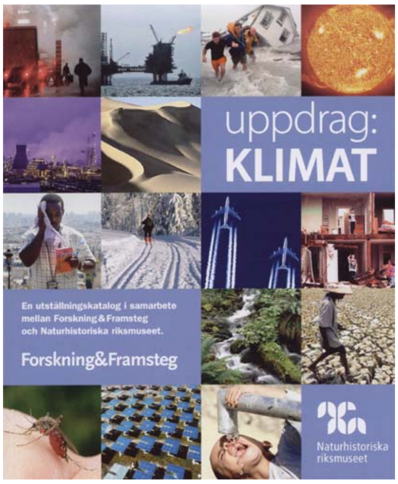
Fredrik Wettemark
Head of project to protect Kristianstad from flooding.

## Want to take the exhibition home?

Take the “Climate Card“ with you around the exhibition and use it to register at the stations that most interest you. The card provides access to your own climate web site when you come home. Hold the bar code under the scanner until you hear a beep. There are nine stations.

We have assembled interesting climate-related articles in an exhibition booklet produced in co-operation with the popular-science magazine, *Forskning & Framsteg.*

**The Climate Card and the catalogue are on sale in the museum shop.**



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# Map of Exhibition

FUTURE PERSPECTIVE - Framtidsperspektiv
SOLUTIONS ARE AVAILABLE – Lösningarna finns
WHAT COULD HAPPEN? – Vad kan hända
EYE OF THE STORM – Stormens öga
CLIMATE IN THE PAST, PRESENT AND FUTURE? –Klimatet: Då, Nu och Sen?
HOW THE CLIMATE WORKS – Så funkar klimatet
WEATHER– AN INSTANT OF CLIMATE – Väder Klimat I ett ögonblick
THE SUN– MOTOR OF THE CLIMATE – Solen – Klimatets motor