CLIMATE CHANGE

It is not too late if farmers act now

REPUBLIC OF SLOVENIA
MINISTRY OF THE ENVIRONMENT AND SPATIAL PLANNING
ENVIRONMENTAL AGENCY OF THE REPUBLIC OF SLOVENIA

CLIMATE CHANGE:

It is not too late if farmers act now

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FOREWORD

There hardly goes a day without hearing the phrase "climate change". Being aware that in living our current lifestyle each of us contributes to this trend, this phrase induces in us a feeling of uneasiness, which is growing ever stronger as since scientists are unable to determine clearly what this climate change actually implies. Does it imply that our unprotected exposure to the sun is becoming harmful due to the hole in the ozone layer? Does it imply that the climate is changing to such an extent that it will eventually result in shifts in climatic zones? Does it imply that life in this climatic zone will never be as it was before? Is this change an unprecedented event on our planet?

Throughout the history of mankind, weather and climate constituted a major reason for unceasing migrations of peoples across the planet, since the search for better living conditions was a completely natural response to unfavourable weather situations, as well as to the overpopulation in environments favourable for living. Even the earliest known civilizations such as Sumeria, Egypt or China, left undeniable traces of their interest in weather events and the adjustment of their agricultural production to given climate conditions. Interestingly, in modern Egypt today we can still come across traditional farming instructions stemming from the very times of the Pharaohs. These instructions are thus older than 5000 years yet still applicable today.

Developments in knowledge and technology, particularly over the course of the last 200 years when weather conditions in a vast number of places have become subject to systematic monitoring and individual data on the state of the atmosphere has become subject to measurements, have also enabled systematic research on climate change in individual areas. It has been established that the climate has been undergoing changes throughout the known geological and human history and that it was precisely these changes in climate that provided the preconditions for dramatic changes in the evolution of life on Earth. However, these changes took place at a relatively slow pace. Modern development of civilization, particularly over the last 200 years, has required ever increasing energy resources which has been primarily obtained by burning fossil fuels, and this still remains the case. The Earth's atmosphere is receiving enormous quantities of various gases and particulate matter which gradually influence its change. The altered composition of the Earth's atmosphere, in turn, dictates changes in weather and thus also climate at a much faster pace than in the past.

In what way, where and how fast the consequences will occur as well as what their nature will be - these are the questions to which the correct answer has not yet been found in spite of the immense efforts invested by numerous scientists around the world. Yet, we are well aware that this process is on-going and that we should both prepare ourselves and adjust to modified conditions.

The World Meteorological Organization (WMO), i.e. the primary international organization coordinating and integrating systematic monitoring activities as well as research focusing on the state of the atmosphere across the world, already began to warn in the 1970's of increasingly clear signals that our atmosphere was undergoing changes. So, in 1988 the WMO established an Intergovernmental Panel on Climate Change (IPCC) in partnership with the United Nations Environment Programme (UNEP) and invited all UN members as well as WMO members to cooperate. The fundamental role of IPCC is to assess the likely impacts of climate change and the ways of managing and mitigating its consequences on the basis of comprehensive, objective, transparent, scientific, technical and socio-economic information. To date, the IPCC has published three climate change assessment reports, most recently in 2001. The next report is due by 2007.

Under the WMO, the impact and consequences that climate change has on agricultural production are dealt with by the Commission for Agrometeorology, one of the constituent bodies of the WMO. Both the WMO and IPCC investigate climate change and the likely impact thereof at the world (global) level. Each state, however, shall be obliged to arrange for more in-depth research within its territory as well as to prepare specific measures for the management and mitigation of consequences. In October 2002, the Commission for Agrometeorology held its regular session in Ljubljana. As it has already become a tradition on such occasions, the WMO organized an international scientific workshop entitled "Reducing Agriculture and Forestry Vulnerability to Climate Change" immediately before the Commission's session. The Government of the Republic of Slovenia entrusted the arrangements for both the above mentioned events to the Environmental Agency of the Republic of Slovenia (EARS). At the workshop, the viewpoint was clearly expressed that there was credible evidence of global atmospheric warming that had triggered temperatures rises across the entire planet as well as evidence of modified precipitation regimes. As a consequence of these changes we can already note vegetation modifications in many regions of the world, especially tropical zones. The declaration adopted at the workshop, calls on governments and international organizations to support their efforts aimed at reducing greenhouse gas emissions into the atmosphere by immediately commencing preparation of programmes for reducing the consequences of climate change in agriculture. When the Government of the Republic of Slovenia considered the report at the session held by the WMO Commission for Agrometeorology and the course of the workshop in January 2003, it entrusted the Environmental Agency of the Republic of Slovenia with the preparation of an overall report on the agriculture and forestry vulnerability in Slovenia that was due by the end of 2003. Pursuant to the Government's decision, EARS started a project entitled "Agriculture and Forestry Vulnerability to Climate Change" at the beginning of 2003.

All the players that were able to contribute to the project's success were invited to participate, in particular, the Biotechnical Faculty of the University of Ljubljana, the ministry responsible for agriculture and relevant agriculture research organizations.

The outcome of the year round efforts invested by the project team was the report that EARS submitted to the Government for discussion in December 2003. The report is the result of the project and the first overall attempt to treat such problems in Slovenia. Owing to limited material and human resources, our implementation of individual tasks often had to be restricted to selecting simpler methods. Nevertheless, important work has been done clearly indicating that climate change deserves serious consideration in Slovenia as well and that a concrete plan to mitigate its consequences is to be developed in cooperation with agricultural expertise in the nearest possible future. The occurrence of droughts during the recent years and particularly in 2003 undoubtedly delivers a serious warning. In this brochure, the results of the project have been prepared on a more popular basis in order to inform the broadest possible public. In this way, EARS strives to fulfil one of its fundamental missions, i.e. to raise public awareness of the impact of human activity on the environment.

Jožef Roškar
Head of Meteorology Office, EARS

Silvo Žlebir, Phd
Director General of EARS

INTRODUCTION

Climate and its changes

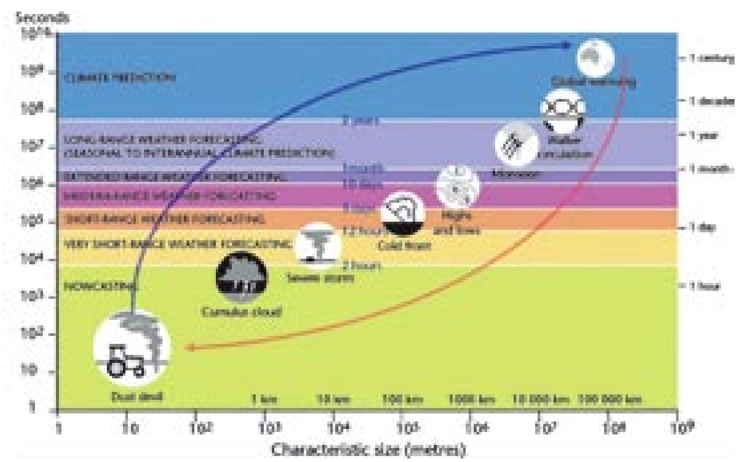
The Earth's climate is the result of numerous interdependent processes which take place within the climate system. The atmosphere, water, ice, Earth's surface and living nature are determined by various factors most essential among which are solar radiation, the atmosphere's composition, the Earth's surface characteristics (gradient, geographical position, solar radiation reflectance) as well as atmosphere and ocean circulation. Due to natural changeability of the climate-specific factors, climate conditions were frequently subject to change in the past. Since recent times however, mankind has also become an important agent in determining climate by altering the composition of the atmosphere.

We can be confident in our claim that the considerable rise in temperature within the last few decades has resulted from human activity involving emissions of greenhouse gases (carbon dioxide - CO_2, methane - CH_4, nitrogen oxides - NO_x) and ozone - O_3, as well as aerosols, which contribute to the change in the composition of the atmosphere and consequently also influence the energy balance of the Earth.

The primary source of triple- and multi-atomic gases and aerosols are fossil fuels, the consumption of which has been continuously increasing ever since the commencement of the industrial age. Agriculture contributes a share of approximately 20% to greenhouse gas emissions through the emissions of methane (rice production, livestock production, fertilization) and nitrogen oxides (soil treatment, fertilization). The increasing concentrations of the above listed greenhouse gases contribute to modifications in the energy balance of the Earth's surface in such a manner that the latter absorbs a greater amount of energy through radiation than it emits. The result is the global warming of the planet leading to climate change.

Agriculture, weather, climate variability and climate change scales

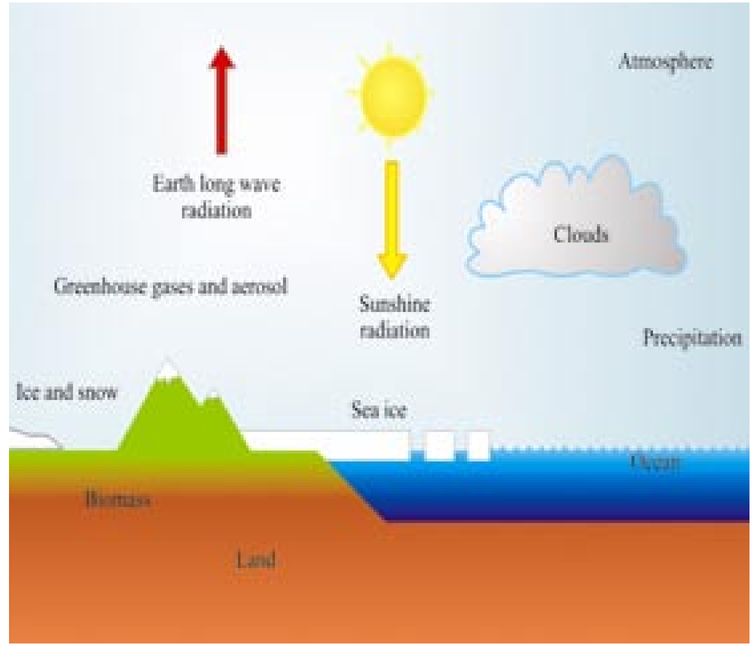
Weather and climate affect agriculture at different time and spatial scales ranging from single agro technical operation to global food production The climate has always changed, driven mainly by the path of the Earth around the Sun, but in a slow, predictable manner. By contrast, the change we have seen recently has been unusually rapid. Emissions of greenhouse gases from human activities are the most important driver of recent climate change. The concentration of CO_2 has increased by 34 % compared with pre-industrial levels, with an accelerated rise since 1950. The total rise in all greenhouse gases since the pre-industrial era amounts to 170 ppm CO_2-equivalent, with contributions of 61 % from CO_2, 19 % from methane, 13 % from CFCs and HCFCs, and 6 % from nitrous oxide. If no climate-driven policy measures are implemented, a further increase to 650/1215 ppm CO_2-equivalent is projected to occur by 2100.



Examples of the range and scales of natural hazards that are observed, detected, monitored and forecasted by WMO networks (Source: DPM programme, WMO, 2004).

World Meteorological Organisation's climate research programmes are advancing our knowledge of natural climate variations, human-induced climate change and their relation to the changing trends in the type, frequency, severity and impacts of hydrometeorological hazards.

Climate change was already recognized as a serious problem at the First World Climate Change Conference. However, it was only in Rio de Janeiro in 1992 when the UN Framework Convention on Climate Change was adopted, coming into force in 1994. The year of 1997, furthermore, saw the drafting of the Kyoto Protocol, a legally binding international agreement setting out specific commitments for signatory states with the ultimate objective to "achieve stabilisation of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous interference with the climate system".

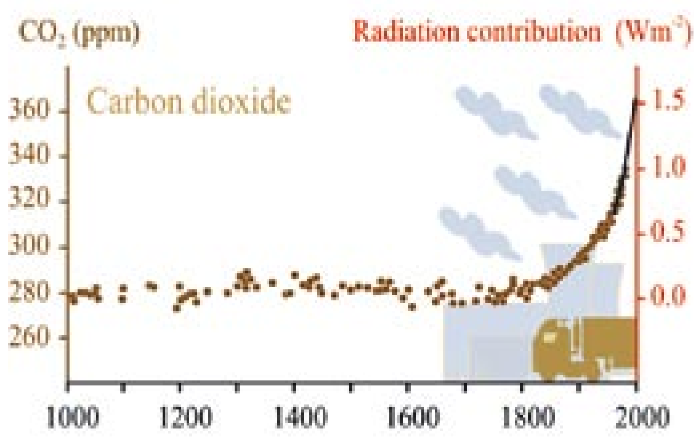


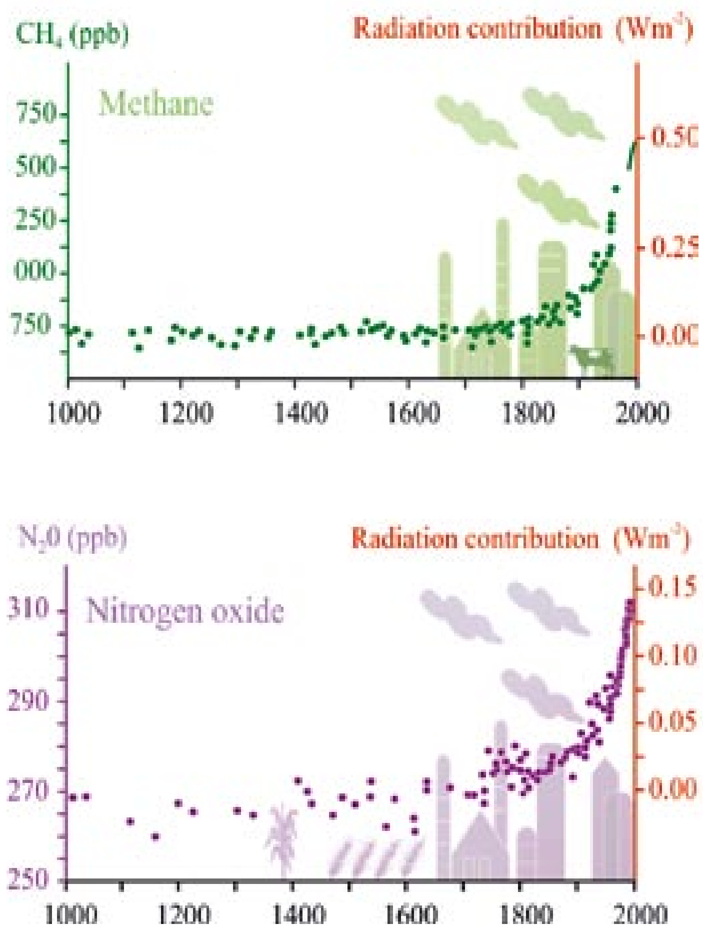
Schematic illustration of the climate system.

It therefore goes without saying that the climate is already undergoing change and that its change will have a considerable impact on mankind. With careful consideration it becomes clearly evident that there is hardly any activity that is not dependent on weather conditions. This dependence is thus crucial for agriculture, however, the same also applies to energy production, water resources, tourism, transport, insurance business, biodiversity, our well-being and health, and so much more. The impact of global warming on mankind will be diverse, in some instances even positive, but mostly it will prove negative. Suffice it to mention only a few of these: global redistribution of precipitation, restricted drinking water supply, increasing occurrences of floods, fires and droughts, endangerment of biodiversity due to the shifts in climatic zones and spreading of certain diseases into new areas.

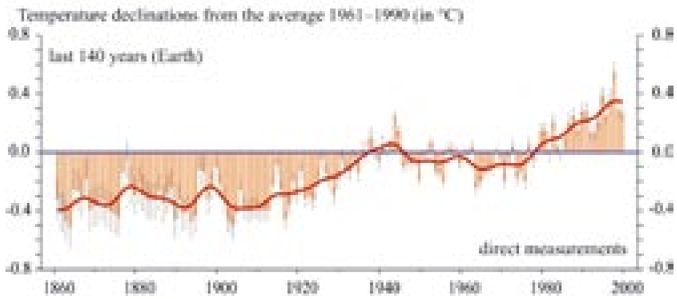
Climate change impacts on agriculture

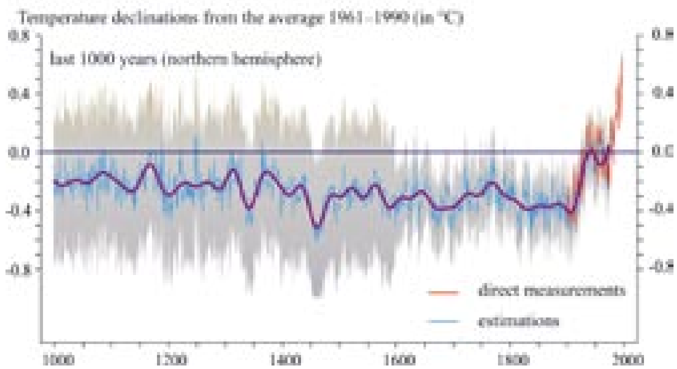
The publication at hand presents a detailed discussion of the impacts that climate change will have on agriculture. The physical effects of climate change and increased CO_2 content in the atmosphere on flora and fauna will occur in vast numbers. Plant production and forest recruitment will be essentially affected by the increased concentrations of CO_2 with their physiological impact, yet altered weather conditions will be the most crucial factor, particularly the direct and indirect impact of increased air temperatures. A decisive impact on agricultural production will also be borne by hydrological balance. According to global estimates, climate change will entail a rise of at least 10% - 20% in agricultural production costs. Studies suggest a considerable increase in various risks associated with agriculture; particularly significant increases will take place in relation to the occurrence of extreme weather events, such as heat waves, droughts, storms and floods. Plant production will require the introduction of certain adjustments, such as: changes in sowing dates, modified cultivars (replacing early varieties with late ones), irrigation or the selection of cultivars that are not vulnerable to drought, and possibly intensified fertilization in order to compensate for a shortened vegetation cycle and potential water stress. In the future, higher air temperatures will lead to more favourable conditions for larger-scale and more rapid development of diseases and pests. For this reason the costs of pest and disease management systems will rise, as well as the costs of overall plant production. In order to better understand the impact that climate change has on agricultural plants a vast body of knowledge is required from various fields of expertise.





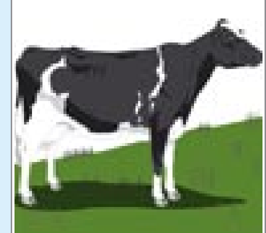
Global concentration of well mixed greenhouse gases in the atmosphere
Indicators of human impact on atmospheric composition in the industrial age: gas concentrations (in ppm and ppb) and their radiation contribution (in Wm^{-2}) in correlation with time (Source: Houghton et al., 2001).





Global concentration of well mixed greenhouse gases in the atmosphere
Indicators of human impact on atmospheric composition in the industrial age: gas concentrations (in ppm and ppb) and their radiation contribution (in Wm^{-2}) in correlation with time (Source: Houghton et al., 2001).

Summary of the likely climate change impacts on different types of agriculture (Adapted from Pittock, 2003).

Crops • increased crop water-use efficiency due to higher CO_2 concentrations but potentially reduced grain quality • reduced water availability due to both reduced rainfall and increased evaporation • reduced crop yield • changes to world grain trading • increased risk of pests, parasites and pathogens	
Horticulture • changes to frost frequency and severity may cause lower yields and reduced fruit quality • damage from more extreme events such as hail, wind and heavy rain • increased risk of pests and disease • warmer conditions may impact on chilling requirements of some fruit cultivars	
Viticulture • higher ripening temperatures may reduce optimum harvesting times • potential changes to phenology and wine quality • warmer conditions may allow new varieties to be grown in some areas • reduced water supply for irrigated crops • investment impacts due to long investment cycles	
Grazing & livestock • increased growth from higher carbon dioxide levels but potentially offset by reduced rainfall and higher temperatures • higher temperatures reducing milk yields • decreases in forage quality • increased rainfall variability reducing livestock carrying capacity • heat stress impacts on productivity and animal welfare • increased risk and rates of salinisation in some areas • increased risk of pests, parasites and pathogens	

OBSERVED TIME TRENDS IN WEATHER CONDITION VARIABLES

Meteorological and phenological data

Meteorological measurements and observations constitute the basis for monitoring, understanding and envisaging likely trends in weather conditions and for all climate-related analyses. In the main part of Europe, the period of instrumental measurements of meteorological variables has been long, lasting approximately 150 years. The meteorological archive in Slovenia dates back to the mid-19th century. For various reasons, the quality of old data is questionable, therefore their use necessitates detailed knowledge and consideration of the existing measuring techniques and instruments. The quality of post-war data, e.g., from 1951 onwards, however, is already comparable with the quality of current measurements. Thus, for conducting trend analyses we prefer processing more recent data. In establishing climate changes we increasingly use phenological data as well.

The investigation of changes is enabled only by long lasting systematic observations focusing on the phenomenon of development phases concerning the start of flowering stage, e.g. in ox-eye daisy *(Leucanthemum ircutianum)*, snowdrop *(Galanthus nivalis)*, dandelion *(Taraxacum officinale)*, spring saffron *(Crocus napolitanus)*, orchard grass *(Dactylis glomerata)*, common plum *(Prunus domestica)*, apple *(Malus domestica)*, silver birch *(Betula pendula)*, common beech *(Fagus sylvatica)*, common elderberry *(Sambucus nigra)*, horse chestnut *(Aesculus hippocastanum)*, goat willow *(Salix caprea)*, common hazelnut *(Corylus avellana)*, lime tree *(Tilia platyphyllos)*, black locust tree *(Robinia pseudacacia)*, common spruce *(Picea abies)*, and common lilac *(Syringa vulgaris)*.

Analysis of trends in meteorological variables

Climatology prioritises secular trends calculated on the basis of longer periods provided, of course, that the latter are available. Where such data are not available our analyses focus on trends for periods in which the data are homogeneous. The analysis of trends in meteorological and phenological variables belongs to the analysis of time series which divides the basic time unit into its components and can thus help us in examining past events or preparing statistical forecasts in relation to future developments. The underlying direction of time series development is a trend, and the simplest function used to describe it is linear function. This connection, of course, does not provide a complete description of the interdependence between meteorological variables and time, since it is only linear and the data fluctuate considerably over time. The trend coefficient and significance are also essentially dependent on the selection of the period under consideration. Climate fluctuations also include the impact of a potential change in micro-location of measurements, changes in measuring equipment, and the impact of urbanization.

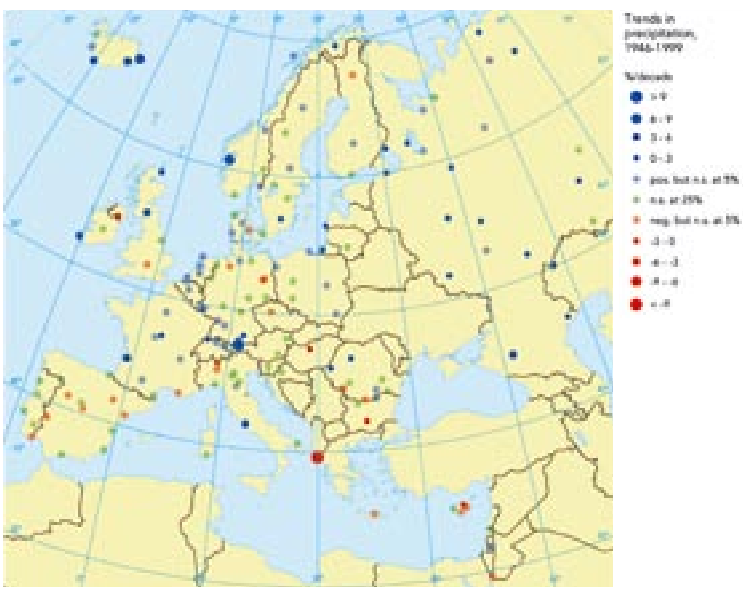
Automatic meteorological station in Lesce.

Phenology is a branch of science studying periodical biological phases (e.g. foliation, flowering, autumn yellowing of foliage, etc...) and reasons for their occurrence taking into account living as well as non-living factors.

Analysis of trends in Europe

Trends in meteorological variables for European monitoring stations for the period 1961-1990 can be found in the Atlas of Climate Trends in Europe showing local-scale variations. In the 30-year period (between 1961 and 1990), average annual air temperature increased by 0.5 to 1°C in most of Europe, except in the extreme south-eastern part of the continent, where the trend is negative. Winters showed the greatest warming (from 0.5°C to 2°C in 30 years) and summers the least (from 0°C to 1°C in 30 years). The statistical reliability of calculated linear trends for average annual air temperature is relatively close to the reliability threshold, although in physical terms it cannot be considered significant. Therefore the calculated linear trends can be interpreted only as a direction of developments being in line with the physical predictions of general air circulation models.

Temperature deviation in Europe, compared to 1961–1990 average (in °C) (Source: European Environmental Agency).



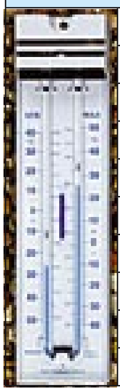
Trends in precipitation in Europe for the period 1946–1996 (Source: European Environmental Agency).

Within the period of 30 years (from 1961 to 1990), average air pressure at sea level rose in central and southern Europe (by 0.5 mb to 2 mb) and dropped in north-western Europe and northern Europe (by -0.5 mb to -2.5 mb). The most significant changes in air pressure occur in winter and autumn periods, when the size of the trend in rising air pressure in central and southern Europe reaches to as much as 4 mb over 30 years, and the air pressure dropping trend at sea level in north-western and northern Europe reaches as much as -7 mb over 30 years. Although the majority of trends are not statistically significant, these results indicate changes in the overall atmospheric circulation, which in our area is reflected in milder and sunnier winters.

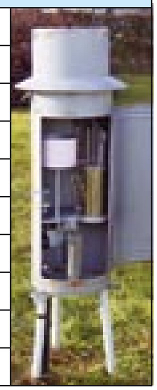
The most ambivalent situation occurs with regard to the estimate of changes in precipitation across Europe during the period 1961-1990, particularly in central Europe, including Slovenia. The annual amount of precipitation increased in western and north-western Europe (from 50 to 200 mm in 30 years) and its easternmost parts (from 50 to 100 mm in 30 years), and decreased in parts of central Europe, thus also around Slovenia (from 50 to 100 mm in 30 years and approximately -10% of annual precipitation, respectively). In terms of seasonal trends there are no appreciable differences between the respective seasons. The statistical reliability of calculated linear trends for annual precipitation is not considered as significant; therefore these trends should be interpreted merely as an approximate direction of development.

Trends in Slovenia

For monitoring stations in Slovenia we have calculated trends for the 50-year period. Average annual air temperature in Slovenia during the last 50 years (1951-2000) has risen by 1.1 ± 0.6°C in a statistically significant manner ($p< 0.05$), with major increases occurring in urban areas (Maribor 1.7 ± 0.6°C/50 years), Ljubljana (1.4 ± 0.6°C/50 years), and lesser increases in agricultural areas (Kočevje and Rateče 0.8 ± 0.6°C/50 years). Due to the vicinity of the sea, the warming trend has been least apparent in Portorož (0.6 ± 0.5°C/50 years). Statistically significant trends at the risk level below 5% are marked with an asterisk or are printed in bold characters. The variations are probably also due to a large share of relocated monitoring stations as well as the influence of the sea in the Primorska (coastal) region. A considerable rise in air temperature is also noted in monitoring stations located in elevated areas where the impact of urbanization is negligible. For instance, at Kredarica (2514 m), where continuous monitoring commenced in 1954, average annual air temperature during the recent 47 years increased by 1.2 ± 0.6°C. Particularly intense rises in air temperature occurred after 1980, while 2000 was recorded as the warmest year in Slovenia since the establishment of the meteorological measurements network. Similarly to other parts of the Northern Hemisphere, Slovenia experienced the most intense warming trend during winter and spring periods, which also results in a reduced number of snow cover days, a gradual decrease in the Triglav glacier extent, an earlier start to phenological phases of plants, etc.



Air temperature trend in a 50-year period (in °C)		Relative change in precipitation quantity in a 50-year period (in %)
+1.7 *	Maribor	-1.5
+1.4 *	Ljubljana	-2.2
+1.4 *	Celje	-7.8
+1.2 *	Novo mesto	+0.9
+1.1 *	Slovenj Gradec	-6.3
+1.1 *	Murska Sobota	+1.6
+0.8 *	Kočevje	-15.7
+0.8 *	Rateče	-21.1
+0.7 *	Postojna	+13.1
+0.8 *	Portorož	-9.0

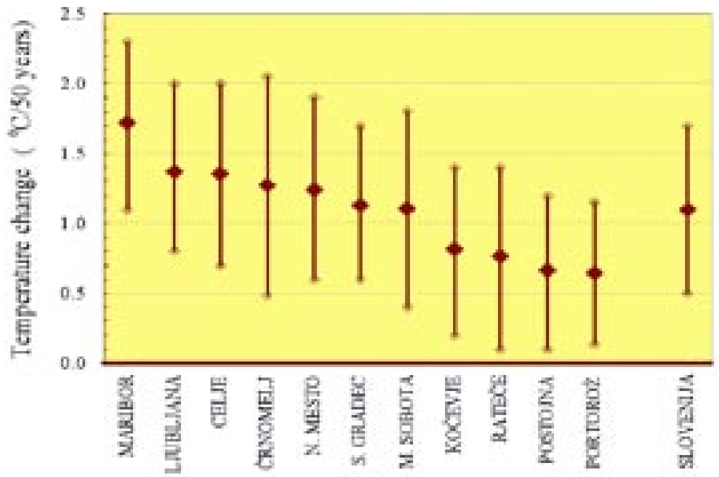


Trends in average annual air temperature (in °C/50 years) and relative change in precipitation (in %/50 years) in Slovenia for the period 1951- 2000.

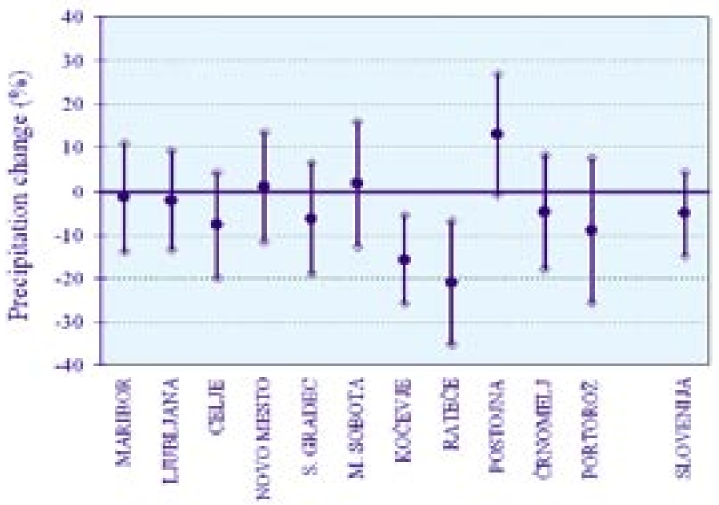
The trends in annual precipitation in most areas of Slovenia are not statistically significant, with the exception of the cities of Kočevje and Rateče, which during the last 50 years recorded a statistically significant drop in precipitation (-16 ± 10% per 50 years and 21 ± 14% per 50 years). So far, no note has been taken of an appreciable change in the precipitation regime despite more frequent summer droughts in the north-eastern part of Slovenia with the exception of the intensity of showers, which is showing a slight growth.

With regard to other weather condition variables, there are two noticeable trends: the decrease in the number of fog days and a trend of extended duration of solar radiation.

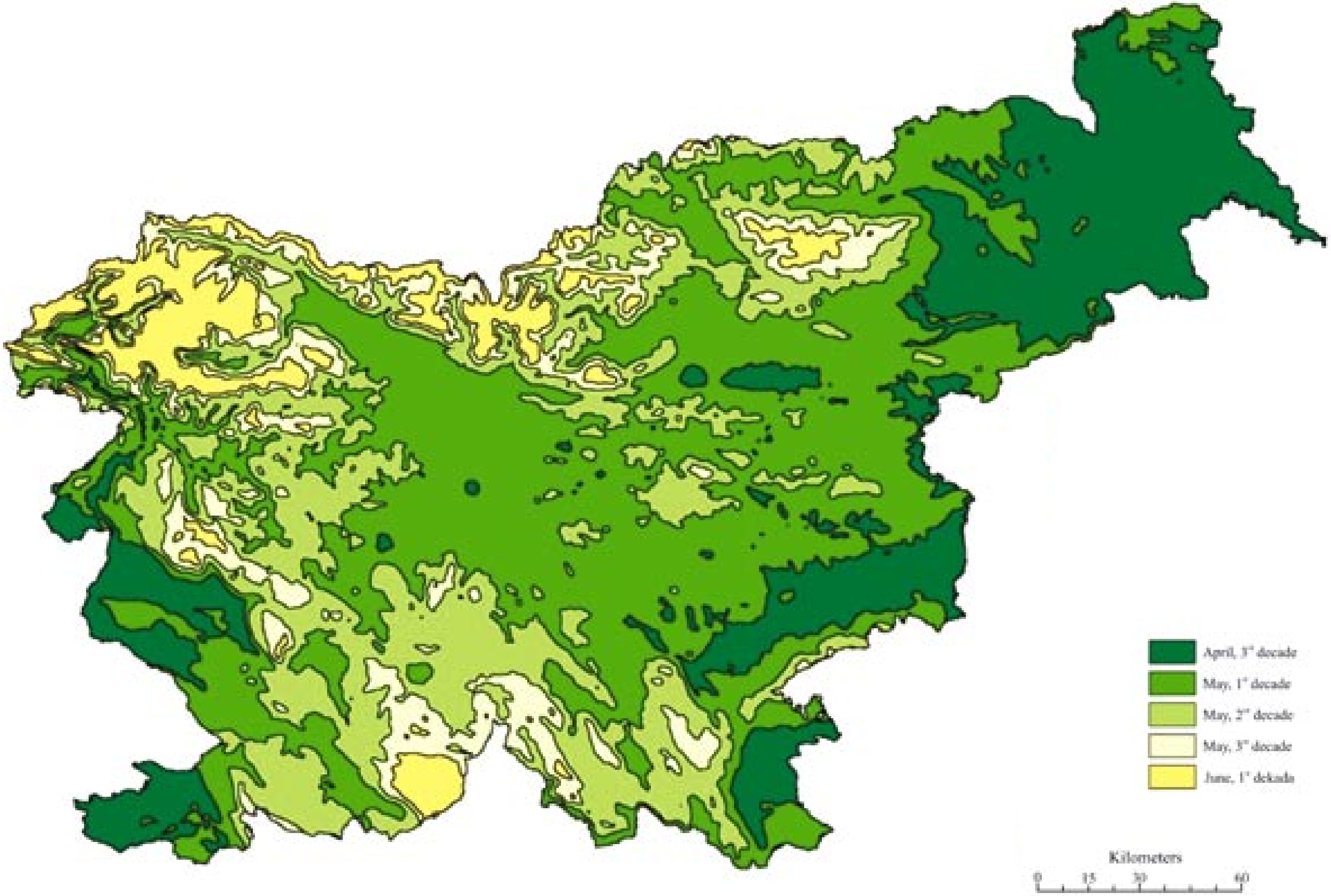
How can we thus summarise climate events recorded in Slovenia during the last 50 years? On the basis of the air temperature and precipitation measurements carried out it may be concluded that in comparison with the long lasting average values, most of the years following 1990 have been excessively warm, and that precipitation is reaching the average values. This phenomenon is, in particular, noticeable during the warmer half of the year (from April to September). Although the trends in precipitation are insignificant, a rough estimate may be made indicating that the most likely development which the climate in Slovenia will follow is that of warmer winters.



Assessment of the change in annual air temperature (in °C) in Slovenian locations in the period 1951-2000.



Assessment of relative changes in annual precipitation (in mm) in Slovenian areas in the period 1951-2000.



Spatial distribution of average occurrence of young off-shoots of common spruce (Picea abies) in the period 1971-2000 in Slovenia.

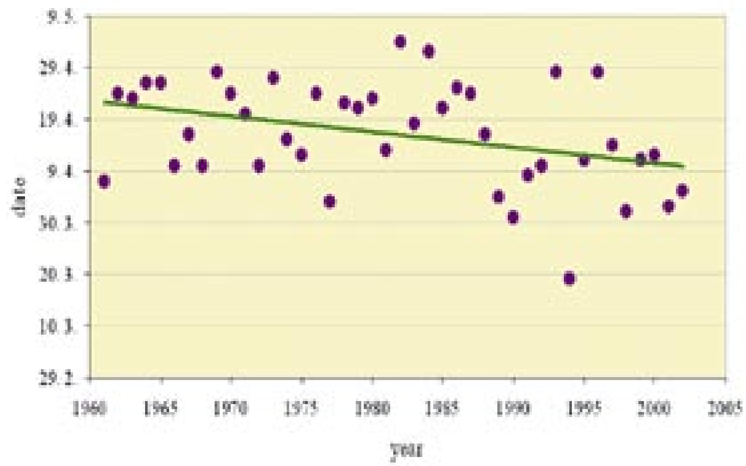
Phenological trends in Europe

The changes in phenological development (seasonal change in animal and plant activity under the influence of environmental variables) from year to year can constitute a vulnerable and noticeable indicator of changes taking place in the biosphere. Numerous indications of the shift in plant and animal phenology have been noticed in Europe as well as in all moderate and cold zones in the Northern Hemisphere. Some studies focus on the qualitative changes (e.g. the number of species with early occurrence), while others prioritise the quantitative change in phenological phenomena. For example, the data as provided by the International European Phenological Garden in Ljubljana show that during the period 1960-2000, the spring phases start 6.3 days earlier (i.e. -0.2 day per year), while finishing 4.5 days later (i.e. +0.15 day per year). Since 1960, average annual vegetation season has been extended by 11 days.

International European Phenological Garden in Ljubljana.

Phytophenological trends in Slovenia and their association with air temperature

Similar conclusions have been drawn in respect of Slovenia. During recent years, approximately half of the spring phenological phases (start of flowering stage, general flowering, foliation, etc) occur earlier in a statistically significant manner, with the remaining half of spring phenological phases not exhibiting significant trends. Foliation starts at significantly earlier stages in silver birch, common beech, common spruce, horse chestnut and lime trees, while autumn colouring starts at significantly later stages in common beech, silver birch and lime trees. On the basis of the data on the commencement of phenological phases involving foliation and yellowing of foliage in silver birch, common beech and lime trees, the analysis of the duration of the period (number of days) elapsing between the occurrences of both phases is also interesting. In more than half of the instances the trend in the length of the period between both phases is positive, which means that in the above mentioned tree species the period of growth is extending. Similar findings also apply to numerous other wild grown herbaceous plant species, grasses, fruit trees as well as forest trees and shrubs, which are commonly recognised as representative of Slovenian flora.



Start of flowering of plum tree (Prunus domestica) in south–eastern Slovenia during the period 1961–2002.

Flowering of plum tree (Prunus domestica).

New pest appearance - cotton bollworms (Helicoverpa armigera). (Source: Phytosanitary administration of Slovenia 2001).

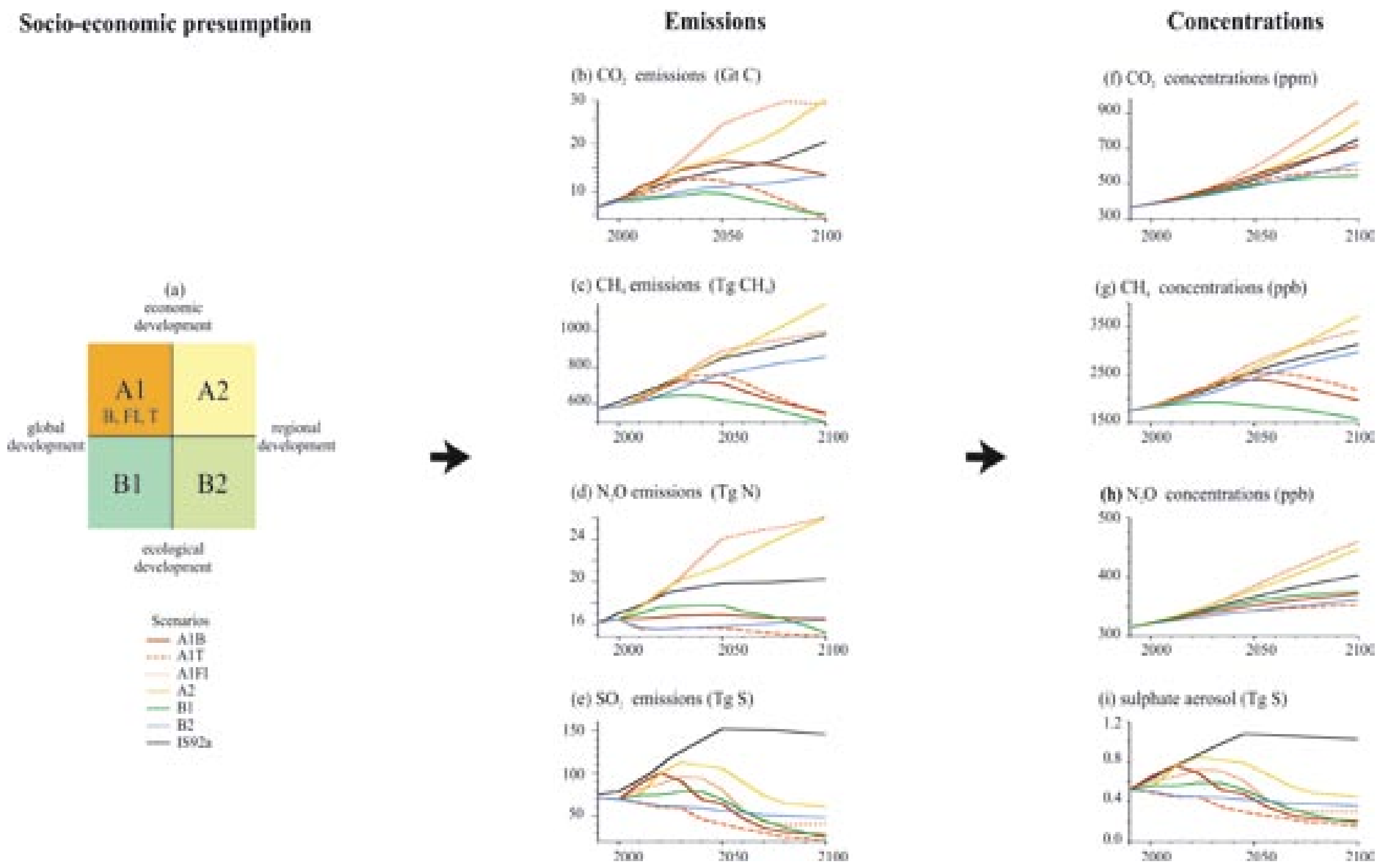
Thus, global warming has as its consequence an earlier start to the vegetation period and more rapid plant development. Since plants differ in their vulnerability to the fluctuating behaviour of climate factors, this can bring to changes in population dynamics where plants that can adjust to altered conditions more rapidly are in a better position to survive.

The change in the onset of phenological phases and their duration also consequently affects the emergence of new diseases, weeds and pests, and stronger outbreaks of those diseases, respectively. These are not currently causing serious damage. With respect to certain pests, higher temperatures may lead to an increased number of generations within one year. Due to warmer winters and springs, the danger of extreme late spring frost is also greater, resulting in failure or loss of agricultural crops. With respect to fruit trees, however, the consequences may be felt for years.

CLIMATE CHANGE SCENARIOS FOR SLOVENIA

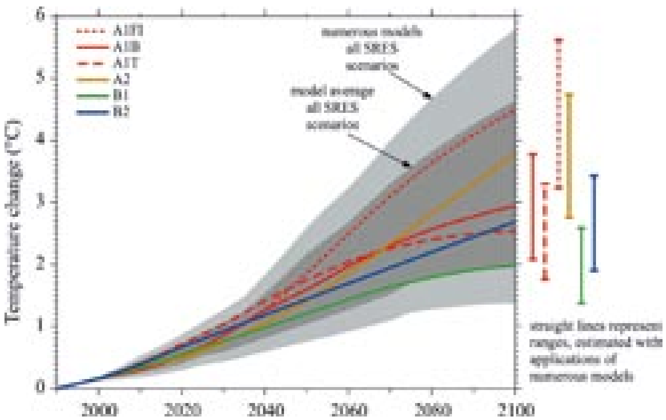
Our future climate

It is an established fact that the climate is changing throughout the entire terrestrial globe and that these changes cannot be entirely attributed to otherwise major and understandable climate fluctuations. The main reasons for these changes have been proven, therefore the responsibility of present generations is to try to eliminate or at least limit them and thus stop the advancement of threatening trends. This responsibility lies above all in the hands of political leadership, although unfortunately, environmental conservation is often a matter of secondary consideration to this group. An essential role in this field, however, is played by those professional fields that are able to define what climate conditions may be envisaged and what the best ways of adjusting to them are. The preparing of climate and adjustment scenarios is especially significant for agriculture, since this line of activity does not have the capability of making swift adjustments.



Emissions scenarios for certain greenhouse gases CO_2, CH_4, N_2O and sulphate aerosols in correlation with time (Source: Houghton et al., 2001).

General circulation models



Envisaged air temperature rise on Earth in the 21st century according to SRES emissions scenarios (Source: Our Future Climate, WMO – No 952, 2003).

General circulation models (GCMs) are the most frequently used tool for investigating climate system responses to changes in atmospheric composition, with their results serving as the basis for drawing up climate change scenarios. GCM models are three-dimensional numeric models where differential equations encompass the primary physical, chemical and biological processes taking place in the atmosphere, oceans, ice and terrestrial surface, as well as their interdependence.

Key input data for GCMs in investigating the climate system response to modified atmospheric composition are the scenarios of future emissions as well as the resulting content of greenhouse gases and aerosols in the atmosphere. The Intergovernmental Panel on Climate Change (IPCC) suggests the use of various emissions scenarios, generally known under the abbreviation SRES (i.e. Special Report on Emissions Scenarios), the future realization of which is equally plausible. The emissions scenarios, roughly divided into four groups (A1, A2, B1 and B2), derive from various presuppositions on future social and economic development. Modelled emissions that these scenarios envisage are presented in the Figure Emissions Scenarios, together with the resulting content of greenhouse gasses and aerosols in the atmosphere and within the scope of expected terrestrial surface temperature changes in the 21st century.

GCMs provide a precise description of the processes taking place on a global and larger spatial scale, respectively; their results are less reliable on a regional scale, since GCMs do not include regional terrestrial surface details, but merely average topography and vegetation. Local climate conditions, on the other hand, are significantly dependent on the processes that take place on a scale below the GCM-based spatial resolution. For this reason the direct use of the results obtained by GCM simulations in local and regional studies on the impact that climate change has on human activities (e.g. agriculture, forestry, energy, and hydro energy) is not considered appropriate. To bridge the gap between larger spatial and regional scales we chose empirical reduction of the scale. The connection between climate variables on a regional scale and climate variables on a larger spatial scale was established with the use of various mathematical models. Empirical models that are based on values measured in the past were then used for projecting the GCM simulation results.

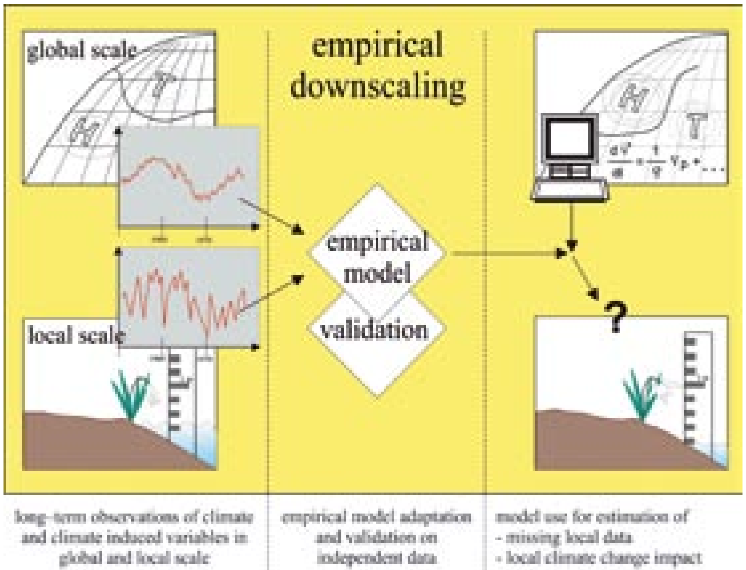
Empirical models are based on values of climate variables on a larger spatial scale (predictors) and climate variables on a regional scale (predicted values) that have been measured and reconstructed, respectively. As predictors, air temperature at terrestrial surface level and air pressure at sea level were used. The predictor fields in this area were connected via empirical models with air temperature and precipitation values based on measurements at meteorological stations. In order to assess future climate change we used simulation results obtained by applying five different GCM models that took into account the A2 and B2 SRES emissions scenarios. Our analysis covered the comparative period 1961-1990.

Selected GCM models

Model	Country of development	Horizontal resolution
NCEP/NCAR	USA	1.9° x 1.9°
CSIRO/Mk2	Australia	5.6° x 3.2°
CCC/CGM2	Canada	3.8° x 3.8°
UKMO/HadCM3	Great Britain	3.8° x 2.5°
DOE-NCAR/PCM	USA	2.8° x 2.8°
ECHAM4-OPYC3	Germany	2.8° x 2.8°

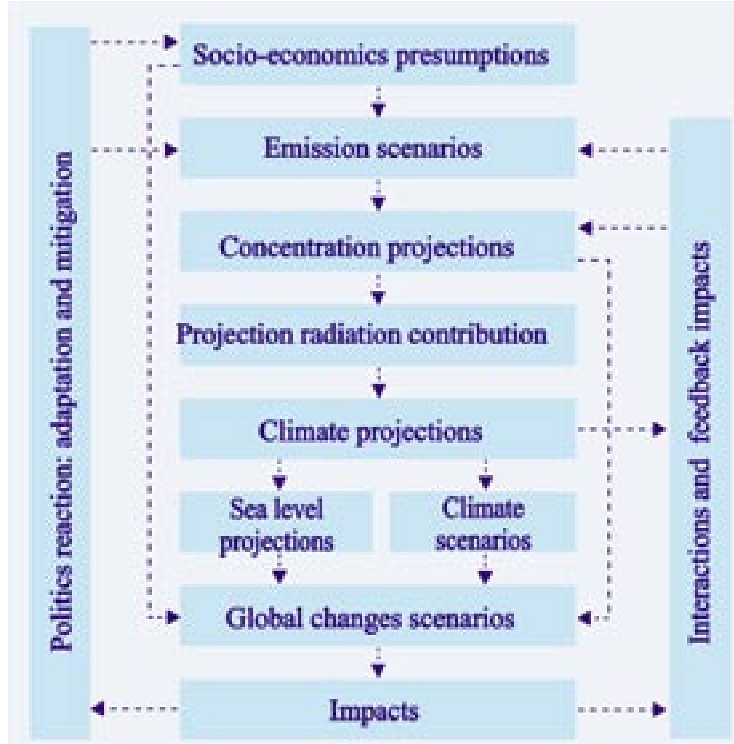
Regional variability of scenarios

Empirical models associating air temperature (T) and precipitation (P) with air pressure at sea level and terrestrial level air temperature in a selected predictor area, were used in conducting empirical reduction of the results scale obtained by simulations with five GCMs in relation to nine selected locations across Slovenia. Projections of GCM results provided a basis for assessing envisaged changes in T and P in the 21st century that are given as deviations from the comparative period 1961-1990. The projections differ for each 30-year period: 1971-2000, 2001-2030, 2031-2060 and 2061-2090.



Schematic illustration of GCM reduction from a global-range into a local-range scale (Source: Heyen, 2002).

The outcome of projecting GCM results leaves no doubt about a rise in air temperature in the 21st century. The envisaged increase in the greenhouse gas and sulphate aerosols content will lead to a rise in air temperature across the entire territory of the Republic of Slovenia with no noticeable differences between respective areas. In respect to precipitation, the reliability of projections is more questionable and the level of their uniformity lower, however, the prevailing trend in changes is negative. This especially applies to the northern, north-western and south-western parts of Slovenia.



Uncertainties encountered in preparing scenarios for the evaluation of climate change impact (Source: Houghton et al., 2001).

The significance of rising air temperatures and falling precipitation can be explained with the data for past periods. The years within the period 1951-2002 for selected monitoring stations were categorized with regard to deviations in air temperature and precipitation that occurred in the warmer half of the year from average values recorded in the period 1961-1990. In view of agriculture and water balance the most critical years were those when air temperature exceeded and precipitation was below longstanding average values. For the majority of monitoring stations in central and north-eastern parts of Slovenia, these years were 1952, 1971, 1983, 1992, 1993, 2000 and 2001. These years also recorded extreme agricultural drought between June and August spreading across a major part of Slovenia.

As the envisaged rise in air temperature to the end of the 21st century exceeds the air temperature variability in the period 1951-2002 and any other period, respectively, that has elapsed since the first measurement of meteorological variables in Slovenia, climate conditions will most likely also reach a state which cannot be predicted on the basis of the established past trends.

On the above stated grounds it is reasonable to conduct studies on the impact of climate change and vulnerability thereto, taking into account various combinations of rises in air temperature and changes in precipitation covering a wide range of possible climate changes. Most reasonable are the interval of air temperature changes extending from +1°C to +4°C with regard to their average value in the period 1961-1990 and the interval of precipitation changes extending from +10% to -30%. Such an extent would cover climate changes in Slovenia within the first half of the 21st century as indicated by projections of GCM results.

The use of various combinations would eventually facilitate an assessment of agricultural ecosystem and agricultural activity vulnerability to potential climate changes.

Uncertainties in preparing scenarios

Climate change scenarios are determined by greenhouse gas and aerosol emission scenarios deriving from presuppositions on future social and economic development of mankind, which causes a considerable degree of uncertainty. What we have to be aware of is that the estimates of changes in air temperature and precipitation presented are essentially based on the SRES A2 and B2 emissions scenarios. In the event of actual emissions deviating from the above mentioned scenarios in the future, appropriate recalculations will be required, such as those done by the IPCC in investigating various possible emissions scenarios. All the above mentioned uncertainties must be taken into account in providing any explanation of climate change scenarios.

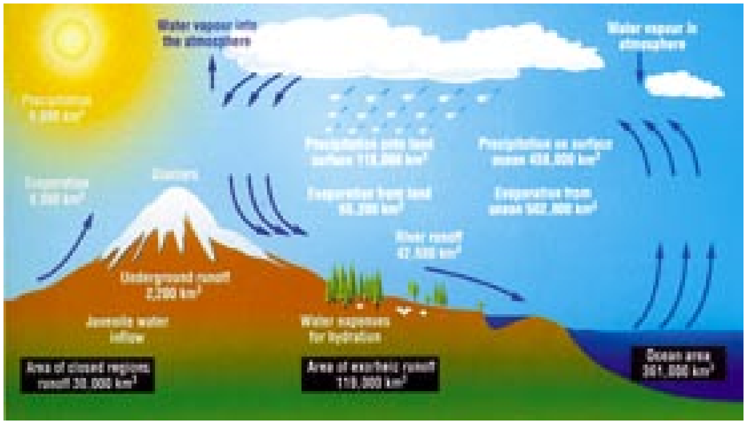
AGRICULTURE VULNERABILITY TO WATER BALANCE CHANGE IN AGRICULTURAL LAND IN SLOVENIA

Water - most vulnerable natural resource

Since water is the most crucial element on our planet, future development will necessitate rational consumption of limited quantities of fresh water. Appropriate management of water resources will only be possible through the use of in-depth knowledge in respect of their origin, quantity and quality. Regular informing, advising and warning of the public at large of the future variability of water resources will also facilitate making the first steps towards improving the current conditions with regard to water consumption in agricultural production.

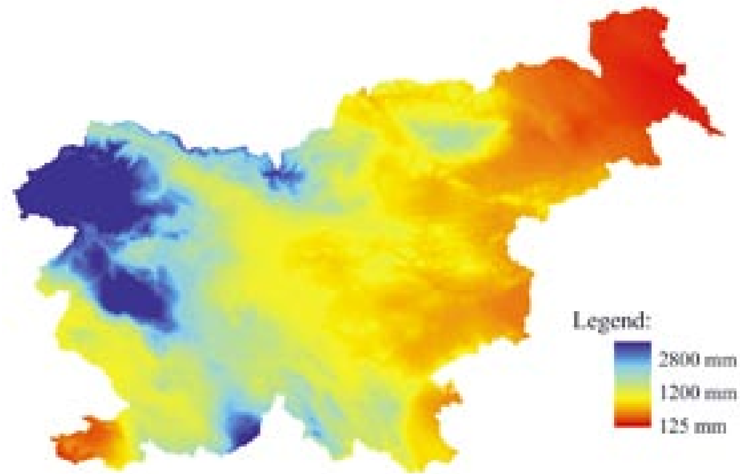
Global water balance

Water balance constitutes a cycle in which water is transferred from the terrestrial surface to the atmosphere and from the atmosphere back to the terrestrial surface, including the water storage in soil. Water is transferred to the terrestrial surface through precipitation and, to a lesser extent, also through condensation (dew), and sublimation (frost). With evaporation from seas, lakes and land, water is mostly transferred to the atmosphere, but a certain amount is also lost. A major challenge for the coming decades will be facing the phenomenon of precipitation shortage during the vegetation cycle in plants. We are already increasingly faced with the phenomenon of the so-called agricultural drought. Drought is not a rare and incidental phenomenon; on the contrary, it constitutes a normal, repeated climatic feature. Long-term periods marked by precipitation shortages may also affect wider areas and cause major social distress, environmental damage and economic loss. One of crucial indicators in establishing the vulnerability of water cycle elements to changes in weather conditions is also determining the changes occurring in available water resources in a particular area. Compared to other European countries, Slovenia is rich in water resources, which is mostly due to abundant precipitation with an annual average amounting up to 800 mm in its north-eastern and even up to 3000 mm in its western parts. Large amounts of water, together with geographical and geological characteristics, decisively determine Slovenia's considerably ramified river network, as well as several major aquifers containing large stocks of groundwater. Yet, just as it true with respect to precipitation, water distribution, as well, varies in both spatial and temporal terms. Conditions may thus vary significantly from one river basin to another. In the case of some river basins in the eastern part of Slovenia with specific runoffs amounting to less than 5 $l/s/km^2$, there is only 20% precipitation runoff, while in the western parts of Slovenia with specific runoffs amounting to 90 $l/s/km^2$, there is even up to 80% precipitation runoff. Due to abundant aquifers, stocks accumulated in groundwater constitute an important source for which dynamic stocks are estimated.



Water cycle and shares of individual components in 1000 km^3 (Source: www.unesco.org, 2000).

Shallow Krka at Podbočje, summer 2003.



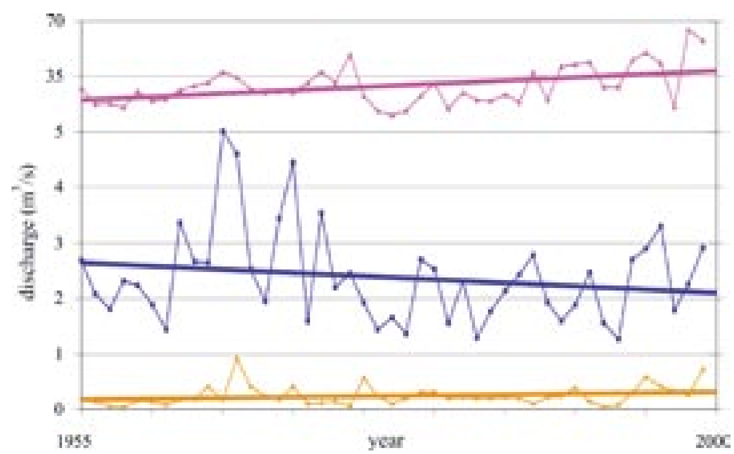
Yearly water balance (precipitation – evapotranspiration) for the period 1991–2002 in Slovenia.

Hydrological state in Slovenia

If we only consider the internal runoff from Slovenia (excluding the inflow from neighbouring countries), annual runoff of potentially available water amounts to 9,350 m^3 per capita. Annually, 32 km^3 of water runs off Slovenia, with water consumption at 1.5% or 0.5 km^3 per year. During the last 40-year period there has been a considerable fluctuation between the highest and lowest quantities of available water. In 1971, we recorded only scarcely half the amount that ran off from the country in 1965, when the amount of 49 km^3 was recorded as the maximum in the period 1961-2000. The drop in the trend path is 0.15 km^3 per year, which means that the amount of available water in the period under study decreased by 6 km^3. Such a decrease of available amounts of water is, of course, not only a consequence of increased water consumption, but primarily the result of the variability of climate conditions particularly those which have an impact on the amount, as well as temporal and spatial distribution of precipitation. The change in precipitation on which river discharges and groundwater levels depend, cause changes in characteristic river regimes - i.e. pluvial, pluvio-nival, nivo-pluvial, nival river regimes. Higher air temperatures and their impact on snow conditions in high-altitude locations will, primarily by lowering and shortening spring excesses in nival regimes, also cause concerns for the provision of adequate amounts of water for agriculture in spring months. Smaller flows from ice thaws will also impede the renewal of dynamic groundwater stocks. However, it is worth mentioning that agricultural areas suffering from water deficits and river basins with the smallest discharges often do not coincide in summer months. Two such examples are the Drava and Mura rivers, whose nival discharge regimes allow them to have the largest amount of water in summer months, when the Slovenian parts of their river basins receive the smallest amounts of precipitation.

Trend paths for period-specific discharges (small, medium, large) show that medium annual discharges in all river basins are decreasing; small discharges show a similar trend, while large discharges decrease only in the catchment areas of the Adriatic rivers and in the Slovenian part of the Drava basin.

In view of the unfavourable trends in all river basins, the drought and failure of agricultural production in 2003 will impose further pressure on water resources by increasing water consumption for the purposes of agricultural production (irrigation), particularly in periods when rivers have smallest discharges and groundwater levels drop the greatest. Let us emphasise that in 2003, small discharges in the majority of rivers dropped below the lowest values in the period under observation, while too many rivers dried up completely.

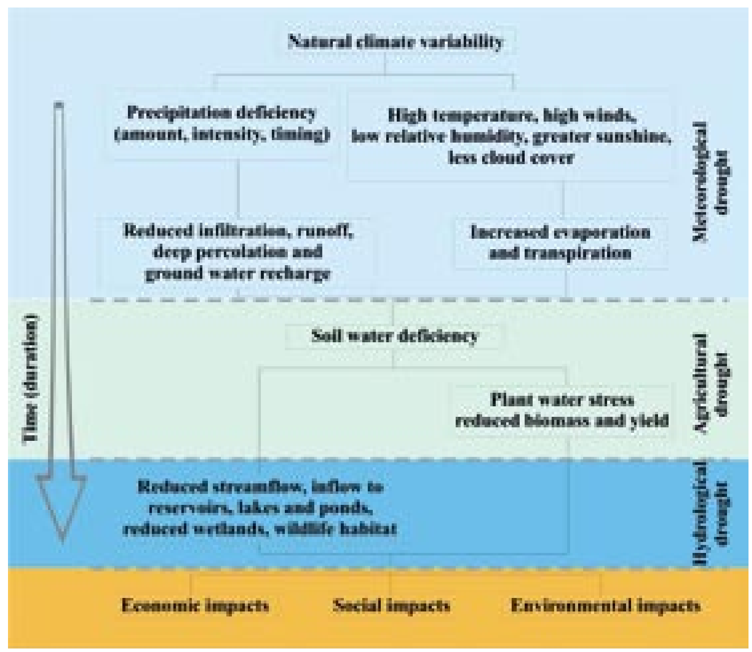


The trend of significant small, medium and large discharges of the Ščavnica river for the period 1955-2000 at the Pristava hydrometric station.

In spite of the fact that the drought in 2003 had catastrophic consequences for a vast number of European countries, it cannot compare with the droughts occurring north and south of the equator (particularly in desert regions of Africa), where the term "severe drought" means a multi-annual period without any precipitation with high air temperatures, leaving behind utter devastation and, what is the greatest tragedy, considerable sections of the population dying of famine. Among the numerous definitions, that which most adequately specifies drought is provided by the European Environment Agency, describing it as a combination of meteorological, physical and human factors.

Causes and consequences of drought

The primary cause of drought is the shortage of precipitation, where the period of shortage is also crucially important, as well as the distribution and intensity of precipitation shortage in connection with the existent stocks and consumption of water. Evapotranspiration, in combination with precipitation, influences the intensity and duration of the phenomenon. Further physical factors influencing the occurrence of drought are the level of natural water stocks (in soil, rivers, lakes, reservoirs, and wetlands) as well as social and economic factors altering water consumption (changes in population, living standards).



Intensification and duration of drought (Source: NDMC, 1995).

In view of the duration of a dry period, three prevailing aspects of drought may be determined:

- Meteorological aspect which is described by a prolonged period with a shortage of rainfall and is frequently defined as a reduced number of days with precipitation in comparison with the selected ("normal") reference period. These are general, regionally-specific definitions of drought, since the atmospheric conditions expressed as the shortage of precipitation vary considerably from region to region.
- Hydrological aspect: the shortage of precipitation reduces the amount of water in rivers and lakes, and lowers the level of groundwater. Hydrological drought occurs later than meteorological and agricultural droughts since it lasts longer, so that the shortage of rainfall is also expressed in hydrological system components, such as water in soil, water courses, and groundwater sources. Water in hydrological stocks (e.g. rivers and lakes) is frequently used for numerous other competitive purposes (irrigation, recreation, navigation, hydro-energy, water and waterside habitats, etc...).
- Agricultural aspect: this aspect represents the inadequate amount of water in soil which plants require for normal development. It is a combination of meteorological and hydrological drought occurring during the intense growth and development period of agricultural plants, i.e. in critical phenological periods; crops fail to some extent or are even completely lost.

There are an increasing number of countries suffering from water shortages. According to data provided by the WMO, in recent years the entire world has recorded utterly catastrophic droughts of extreme intensity and of a long duration. In the recent period the spread of droughts has also intensified in areas where they were never recorded in the past. As to the phenomenon of droughts, we can claim that the shortage of precipitation or its irregular temporal distribution already pose a real problem and risk in Slovenia as well. The patterns of occurrence and duration of droughts are changing. A large part of Slovenian territory falls within the area where agricultural droughts have contributed significantly to crop failure during the last decade. The shortage of water from April to the end of September shows that droughts have affected agricultural plants in a significant part of the rest of the country- within the last 40 years this phenomenon occurred no less than ten times: 1967, 1971, 1973, 1977, 1983, 1992, 1993, 1994, 2000 and 2001. The persistent drought in 2003 was a special case.

In the north-eastern part of Slovenia a negative water balance was recorded as many as 12 times lasting throughout the entire vegetation period.

Quantitative shortages exceeding a period of 100 days clearly show that in the last decade we have been facing the longest and also the most severe water shortages to-date. Extreme situations have occurred in all Slovenian regions. Measures taken in the field of agricultural production require a precise analysis of the current state of agricultural plant water supply and the severity of predicted changes.

Methods of estimating the levels of water shortage in the past

The most important element of this estimate is the cumulative shortage of water representing the difference between the optimum and actual state of humidity in soil throughout the entire vegetation period. In addition to its magnitude, the duration of water shortage is considered equally important. During vegetation time, there are usually several successive periods of water shortage, while in extreme years, e.g. 2003, a shortage may be continuous.

Distribution of water shortage and excess in percentiles.

In the perspective of the magnitude and duration of water shortages in soil the following categories have been determined:

- Moderate shortage with the lower limit at the 75th percentile and the ceiling at the 90th percentile, representing 15% of all shortages within the period 1961 - 2000;
- Extreme shortage exceeding the 90th percentile and representing only the upper 10% of all shortages.

On the other hand, the magnitude and duration of water excess in soil have been subdivided into the following categories:

- Moderate excess with the lower limit at the 10th percentile and the ceiling at the 25th percentile, amounting to 15% of all water excesses within the period under observation;
- Extreme excess as lower than the 10th percentile (i.e. only the lowest 10% of all excesses).

All instances of water shortage and water excess, respectively, between the 25th and 75th percentiles fall within the class of moderate conditions or normal state, where excessive or insufficient amounts of water do not impede the growth and development of agricultural plants. During the period under observation, moderate shortages of water in soil occurred six times and extreme shortages four times in all four regions (central, north-eastern, northern and south-western Slovenia).

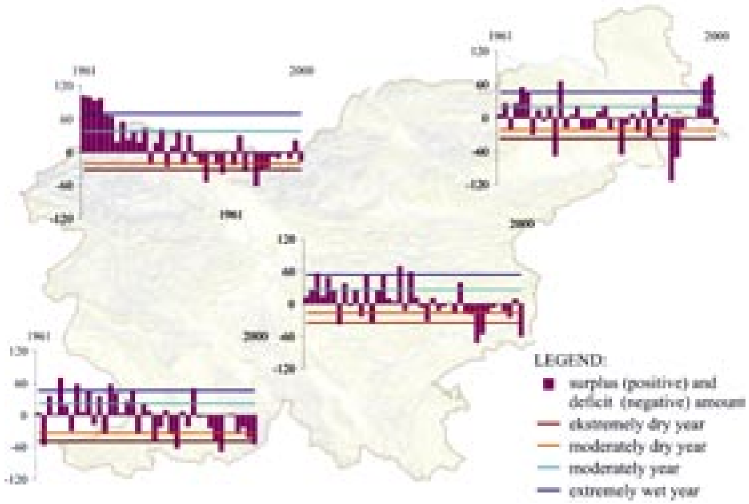
Cross-section between lenght and height of crop water deficiency during the period 1961 - 2000.

	Long and moderate shortage	Extremely long and extreme shortage
central Slovenia	1967, 1973, 1988	1992, 1993
north–eastern Slovenia	1971, 1976, 1977	1992
northern Slovenia	1973, 1976, 1979, 1985, 1986, 1988	1992
south–western Slovenia	1973, 1986, 1992, 1993, 2000	1962

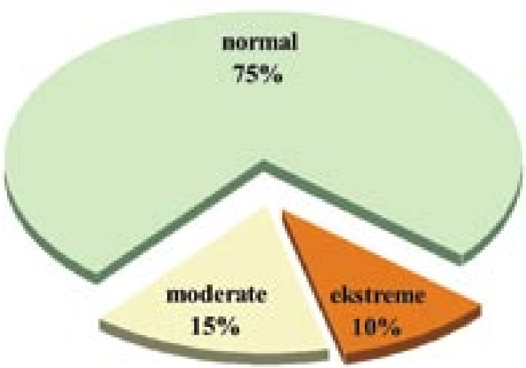
The number of periods with moderate and extreme water shortages was similar in all regions. The differences among regions occur especially in the distribution of years with abnormal shortages. In central Slovenia, thus, moderately and extremely wet years occurred up to 1989, only with the exception of 1967 recording an extreme shortage. The years following that period were mostly marked by moderate and extreme shortages. North-eastern and south-western Slovenia recorded years with high and low shortages, distributed almost evenly throughout the period 1961-2000, however the main part of high shortages occurred in the 1990's, primarily due to the conditions in 1992 and 1993. A significantly increasing trend in water shortages is shown in northern Slovenia. In this area, wet and extremely wet vegetation periods prevailed up to the onset of the 1980's, i.e. periods with moderate and extreme excesses of water in soil. Later, in 1983, 1986, 1990 and 1992, high and extremely high water shortages started. The year of 2003 exceeded all extremes.

Distribution of length of duration of water shortage in soil

A prolonged water shortage in all four Slovenian regions occurred in observed vegetation periods 7 to 10 times, and an extremely long water shortage occurred 4 to 6 times. Most frequently, long and extremely long shortages occurred in the south-western part of Slovenia. For a more precise estimate of the past variability of water shortage in soil, aggregated data on the length and magnitude of shortages facilitate the rank of moderate and extremely long, as well as moderate and extremely severe shortages. In 1992 all regions except south-western Slovenia recorded an extremely severe agricultural drought. The year that falls within this class in south-western Slovenia is that of 1962, while extreme droughts affecting central Slovenia occurred in 1992 and 1993. Years recording moderate shortage differ from region to region, which means that drought in the years concerned was confined to individual regions.



Regionally-based relative shortage of water (in mm) in soil by individual year.



Percentage of years with moderate and extreme shortage of water in soil for the period 1961 - 2000 in Slovenia.

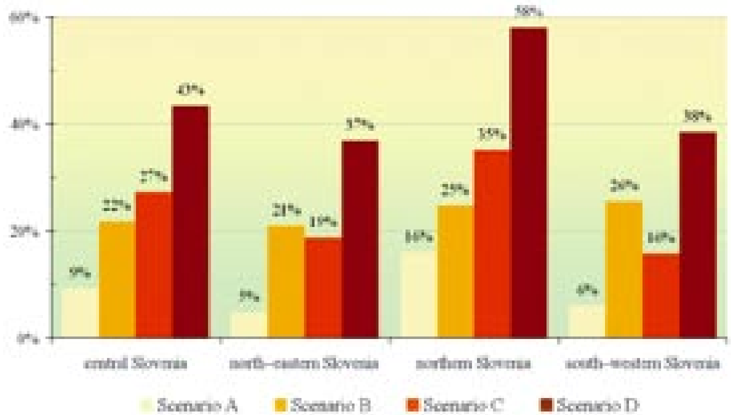
Analysis of trends in water shortage in soil

By calculating a linear trend we analysed the changes in the magnitude of water shortage in soil. The trend was expressed as absolute and relative changes in the shortage over 10 years within the period 1961-2000. The trends in shortages differ; however, all regions have a significant negative sign (implying that shortages are increasing). The most significant increase in water shortage is in northern Slovenia. The recorded trend is -19% per 10 years. Thus, for example, in ten years the amount of usable water contained in shallow soil for agricultural plants during vegetation period, reduced from 460 m^3/ha by 87 m^3, leaving a mere 373 m^3/ha. The trend for this region is statistically significant. Water shortage in soil is increasing the least in north-eastern Slovenia (less than 2% per 10 years). Other regions have negative trends at an approximate average of -6% per ten years.

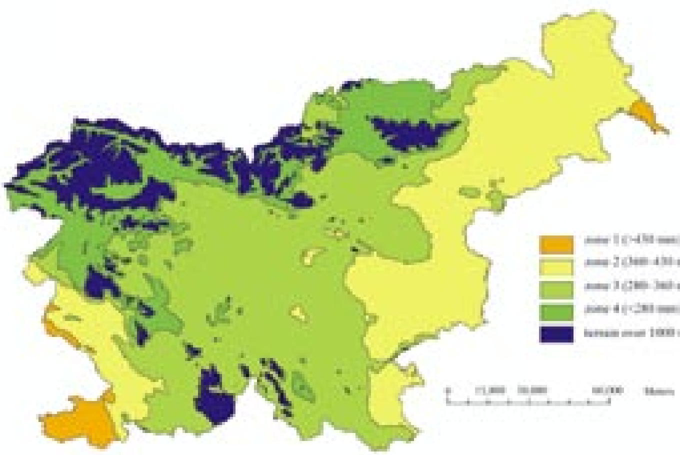
Methodology of assessing the impact of climate change on water shortage in soil

Although it cannot be clearly established how the climate change will affect regional water resources, it is evident that the latter are already today - irrespective of the climate change - very vulnerable. Each further added stress deriving from climate change or increased variability will lead to a rise in competitive water consumption among various sectors. In the short-term, the direct impact of climate changes on water resources will be hidden within natural climate variability. Warmer climate conditions may result in more frequent, sever and longer droughts and intense showers. The existing climate scenarios have been divided into four groups (A, B, C and D). They envisage a rise in air temperature in Slovenia of 1 or 3°C and up to 20% less precipitation in the next 50 years. On the basis of these input data, a rise was calculated in extreme water shortage in soil for the respective regions. It was established that, according to individual scenarios, extreme water shortages in northern Slovenia will increase the most (the worst scenario predicts a 58% increase). In other regions, the magnitude of extreme shortage under scenario D will increase by approximately 40%.

It is precisely the 2003 drought that explicitly showed what consequences of climate change may be expected in the event that the change will take place in both aspects, i.e. frequency and duration.



Influence of various scenarios on the increase in extreme shortages of water in soil.
Legend:
Scenario A: temperature rise at 1°C and unchanged precipitation regime
Scenario B: temperature rise at 3°C and unchanged precipitation regime
Scenario C: temperature rise at 1°C and 20% less precipitation
Scenario D: temperature rise at 3°C and 20% less precipitation.



Spatial shortage of water in agricultural soil in Slovenia from March to June 2003.

EXTREME WEATHER EVENTS AND VULNERABILITY OF SLOVENIAN AGRICULTURE AND FORESTRY

Extreme weather events are unpredictable

Extreme events constitute an integral part of natural climate and weather variability as its everyday features. They are already rare by definition and for this reason they are also difficult to adjust to, since the time between two occurrences of one particular extreme event in a certain area may extend over a period of several years. The predictions and scenarios of envisaged climate changes don't say much about predicted characteristics of extreme events. The general professional public has accepted the hypothesis that the frequency and intensity of extreme events will increase on a global scale; the information collected on regionally- and locally-based changes are still not sufficient. We can conclude that all extreme events observed to-date will continue to occur in the future, whereby we will most likely experience an increase in both their intensity and frequency. We also need to take into account the possible synergic effects of various components of the climate system and environment. Although Slovenia is relatively small, the differences in the magnitude and frequency of extreme values of weather variables in respective parts of the country are noticeable and crucial.

Due to their direct and close dependence on weather conditions, agriculture and forestry fall within the most susceptible and vulnerable sectors to extreme weather events. Damage to plants can be caused by powerful storms with hail, hurricane-like winds and intense showers; sleet and heavy snow are harmful to both forestry and agriculture. Floods, including alluvial deposits on pastures and fields, hydrological drought and fire risks in the natural environment are frequently dependent not only on weather conditions but also on the state of the environment and human interference.

Spring frosts reduce agricultural production

Global climate changes will also affect the frequency and territorial distribution of cold. Plants already respond to changes in air temperature in late winter and early spring periods. Spring flowering phases in certain wild plant species occur, on average, earlier than at the beginning of the 1950's. Also noticeable is the extension of the annual vegetation cycle. Consequently, climate change will also influence the occurrence of frost. In certain areas this will impede cultivation of economically essential fruit cultivars and crops. Global-scale estimates indicate that in view of the current climate variability, each year 5% to 15% of agricultural production is destroyed by frost. Numerous European countries estimate that the number of years with failing agricultural crops will increase by more than 100%. The economic and social consequences will undoubtedly be enormous.

Frost risks in Slovenian agricultural territory

Individual areas of Slovenian agricultural territory vary considerably in the level of frost risks. The frequency of frosts is higher in open basin and flatland areas, but less on slopes and crests as well as in locations where the relief conditions allow good wind circulation. The damage to flower buds in various development phases depends on the duration of cold. Air temperatures below -2°C cause moderate frost, air temperatures below -3°C cause serious frost and air temperatures below -4°C cause severe frost. Most frequent are moderate frosts notably reducing agricultural crops; however, due to the features of gradual flowering, the economic damage is manageable. Economic damage of an extent and magnitude of natural disasters were caused by serious and severe frosts. The recent past recorded two of the most severe frosts: the first occurred in 1997, affecting the entire Slovenian territory, and the second in 2001, affecting the main part of the country. The first caused SIT 5.3 billion in damage (1 EUR = 240 SIT) and the second SIT 3.5 billion in damage. The damage caused after the spring frost in 2003 amounted to nearly SIT 1 billion. The data analysis shows that the frequency of critical minimum air temperature is decreasing, especially when we compare the period 1991-2000 with the preceding 30-year period 1961-1990. Average minimum air temperature is also increasing, yet at the same time the absolute values of minimum air temperatures vary considerably and are non-homogeneous.

The time analysis relating to the occurrence of the last spring day and the first autumn day with air temperatures of -2°C, as well as the length of the period elapsing between both thresholds for the period 1961-2000, has shown a negative change with respect to spring and a positive change with respect to autumn. During the spring period, the last day with air temperatures below -2°C on average occurs 1 to 7 days earlier per 10 years, and the first day in autumn occurs 1 to 6 days later per 10 years, compared to the situation at the beginning of the period under observation. The period elapsing between both these days in question is also longer by 2 to 7 days (in extreme cases even 11 days) per 10 years. The last spring day and the first autumn day with air temperatures of -2°C have shifted towards the winter half of the year. The change is more noticeable in flatland and basin areas as well as urbanized locations and is less noticeable on slopes and crests as well as locations with good wind circulation. Similar results on the extension of warmer periods with the limit value at 0°C are also reported from Canada and the United States.

Frost-related risks arising from altered climate conditions

Altered climate conditions will increase the risk of frost in Slovenian agricultural territory as well. Taking into account air temperature scenarios (A, B), flowering will on average occur 4 to 10 days earlier, provided that average air temperature rises at 1°C, and 6 to 14 days earlier, provided that average air temperature rises at 3°C. The calculations show the most insignificant changes during the flowering period on slopes, crests, locations with good air circulation, and urbanized areas. Provided that average air temperature rises at 1°C, these locations will experience a 5% increase in frost risks. In most flatland and basin locations, however, such risks will increase by 10% to 20%, and in extreme cases even at 30%. In other words this means that the locations where in the past, a fruit grower expected a 10% risk of frost (once in ten years) according to the existing variability, the 10% rise in such risk will result in frost occurring every five years. In respect to more exposed locations, the statistical estimate also shows that frost occurred 3 times in 10 years and in most extreme cases every other year. Insofar as warming reaches 3°C, the flowering phase will on average shift into the period with increased frequency of critical air temperature. The statistical risk of frost will be 20% to 30% greater than the present risk. Thus fruit growers in such locations will have to take into account increasingly more frequent occurrences of frost. According to all scenarios the risk will be highest in basin and flatland locations where the occurrence of frost is already considerable.

Protection of blossoming peach trees against frost by sprinkling, the Vipavska valley, April 2003.

Frosted peach blossoms (Prunus persica), Goriška, March 1998.

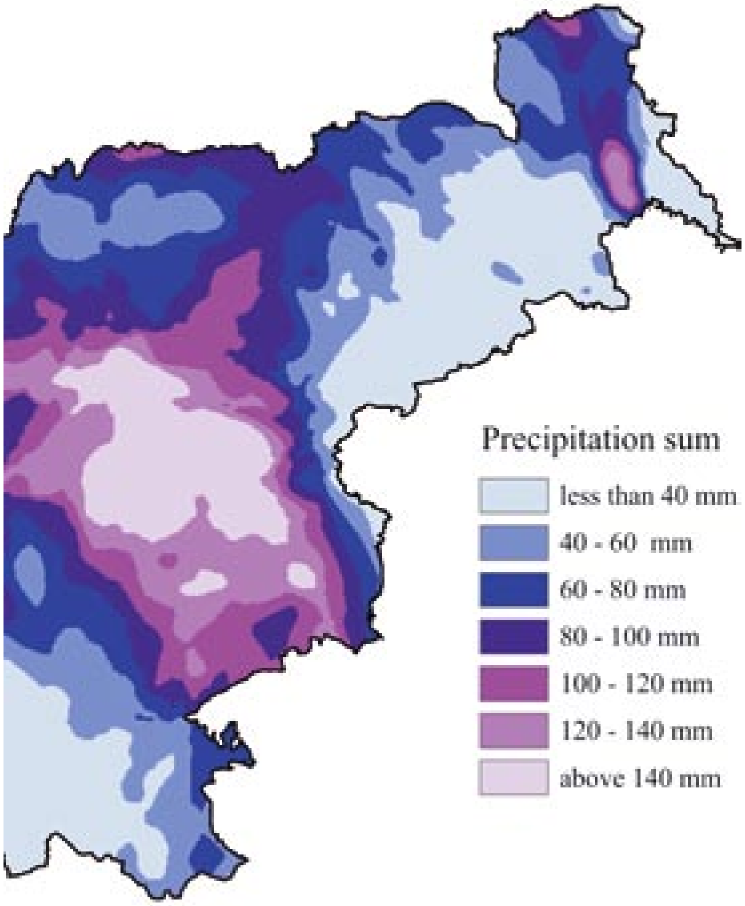
Damage in walnut tree (Juglans regia) caused by frost.

Extreme precipitation

The territory of Slovenia represents the point of contact and interdependence of the Mediterranean, Alpine and sub-Alpine zones, respectively, as well as a continental climate determining a diverse precipitation regime and corresponding precipitation maximums. Showers are divided into those lasting several minutes to several hours, heavy 24-hour and multi-day precipitation. During extreme showers water usually runs off across the terrestrial surface causing torrential floods, while 24-hour and multi-day extreme precipitation may result in larger-scale floods. Torrents and floods are a direct result of heavy precipitation, which may, however, also cause a series of other harmful events, such as soil erosion, landslides and material deposits onto fields and pastures.

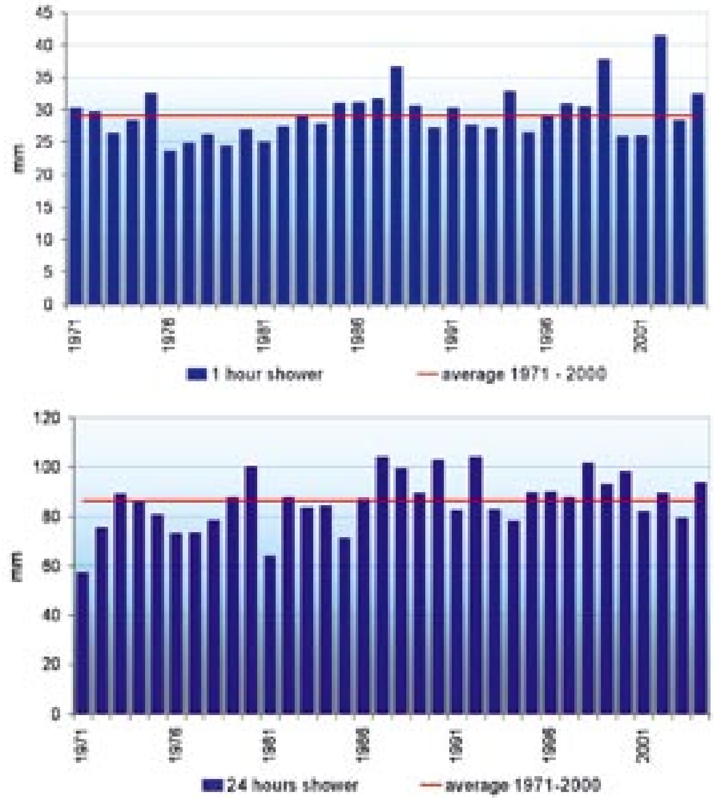
Floods in Sevnica, August 2005.

River Mirna flooded Boštanj , August 2005.



On the 21st of August 2005 in eastern part of Slovenia 2-days precipitation sums exceeded 100 mm and caused huge floods. In some parts the 2-days precipitation sums exceeded 100 years return period.

More than 180 mm of 24-hour precipitation is received only in north-western Slovenia, therefore these events are considered very rare and no trend can be determined. 24-hour precipitation exceeding 150 mm may occur over a much wider part of Slovenia; although a trend is not noticeable, a cycle is clearly evident with maximums occurring at the beginning of the 1960's and on the turn of 1980's and 1990's, as well as with a minimum in the 1970's. More than 100 mm 24-hour precipitation is often measured in north-western Slovenia and very rarely in north-eastern Slovenia; also in respect of these events, the positive trend is not statistically significant. A cycle with a maximum at the beginning of the 1960's, a minimum in the 1970's and the following maximum at the beginning of the 1990's is very noticeable.

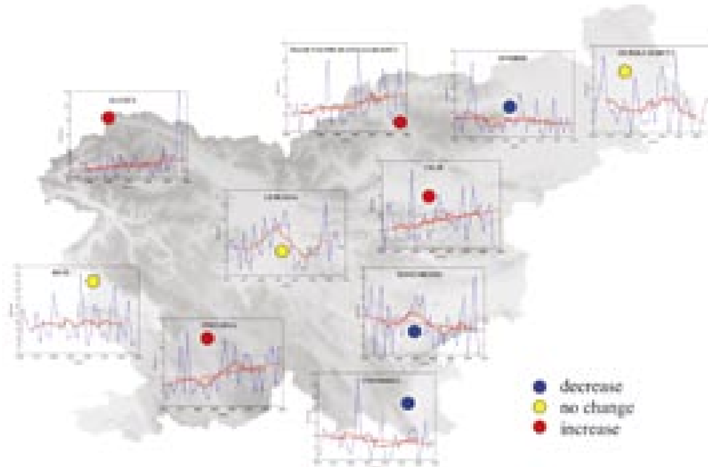


Average amount of rain in 1–hour and 24–hours showers at 40 measuring sites in Slovenia in the period 1971-2004.

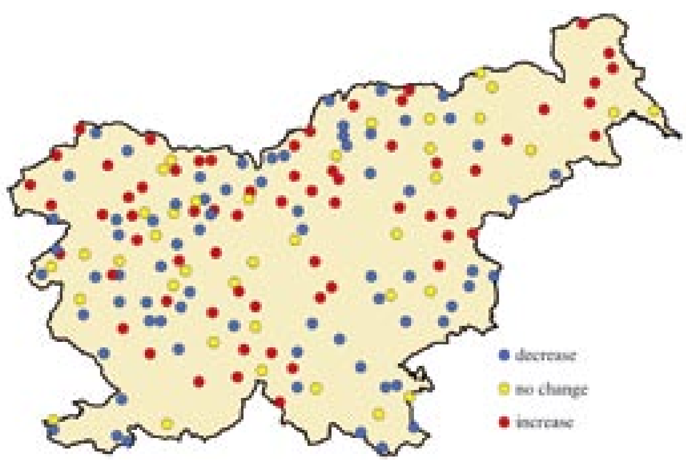
A rise in the share of abundant precipitation of all types means that water availability for vegetation is lower, with the erosive effect of meteoric water being greater. Such a distribution is essentially less favourable for vegetation than more frequent but less intense precipitation. The differences across Slovenia are considerable, particularly in view of the selected threshold for heavy precipitation. The share of most intense precipitation across Slovenia either increases or stagnates; linear trends are not statistically significant; there is a strong prevalence of cyclical changes.

Storms and hail

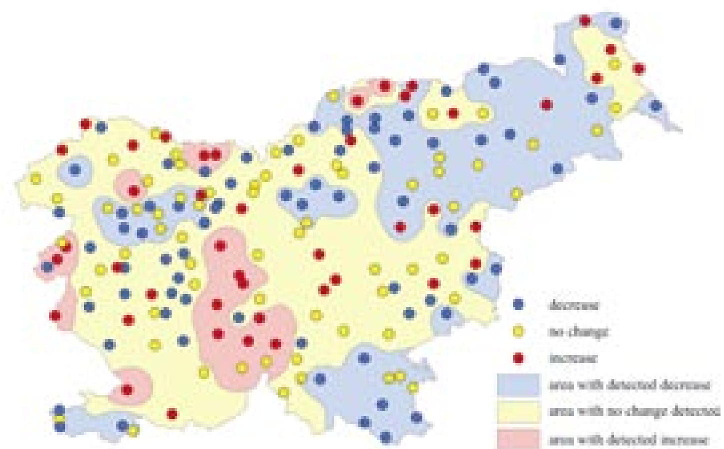
Severe storms with strong winds, heavy precipitation and hail could cause a lot of damage on the crop, especially in the vegetational period, when the energy accumulated in storms and kinetic energy of hail particles is the largest. The risk of severe storms in Slovenia is among the highest in Europe. Spatially homogeneous decrease of storm frequency wad detected in Primorska, Dolenjska and Bela Krajina. On the other hand, the storm frequency had increased in Prekmurje and Goričko. In other parts of the country there is no uniform trend in storm frequency for larger domains. Symmetrically to the storm decrease, the frequency of hail had decreased in the costal region and in Bela Krajina. In the last 14 years less hail was observed also in parts of Štajerska and at the southern edge of Julian Alps. The positive trend in hail frequency was observed in Goriška Brda in central part of Slovenia with Bloška planota in small part of Karavanke and in some parts of Štajerska. Storms are strongly correlated to short-term heavy precipitation. The trends in frequency of 30-minutes precipitation exceeding 12 mm are accordingly correlated to trends in storm frequency. The differences across Slovenia are considerable, in some parts the frequency of heavy rain-showers is statistically significant increasing, in other parts it is decreasing. In some parts, like Ljubljana, Maribor and Bilje, the linear trend is not statistically significant, but a strong prevalence of cyclical changes is evident.



Statistically significant trends for frequency of the 30-minutes showers exceeding 12 mm in the vegetational period (May-September). Trends were calculated for the period 1961-2004.



Spatial distribution of statistically significant trends in storm frequency in the vegetational period (May-September). Trends were calculated for the observational points with homogenous time series in the period 1961-2004.

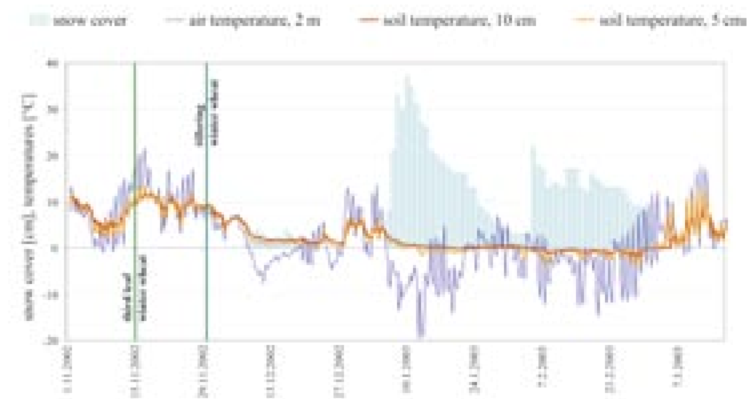


Spatial distribution of statistically significant treds in hail frequency in the vegetational period (May-September). Trends were calculated for the observational points with homogenous time series in the period 1961-2004. The deviation of mean hail frequency of the last 14-years period (1991-2004) from the mean hail frequency in the reference period (1961-1990) is indicated in the background.

Hail completely damaged crop yield, Šentlovrenc, June 2001

Fresh snow

Climate change is also supposed to be manifested in the frequency of days with heavy snowfall in low-lying areas. The differences across the territory of Slovenia are considerable, since the number of days with snowfall and the amount of precipitation also varies significantly between respective regions. In most instances, a falling trend is more or less present; the cycles are notably stressed, especially the minimum at the end of the 1980's and the beginning of the 1990's. Many monitoring stations also record a minimum in the 1970's. The climax at the beginning of the 1980's is noticeable across the entire Slovenia.

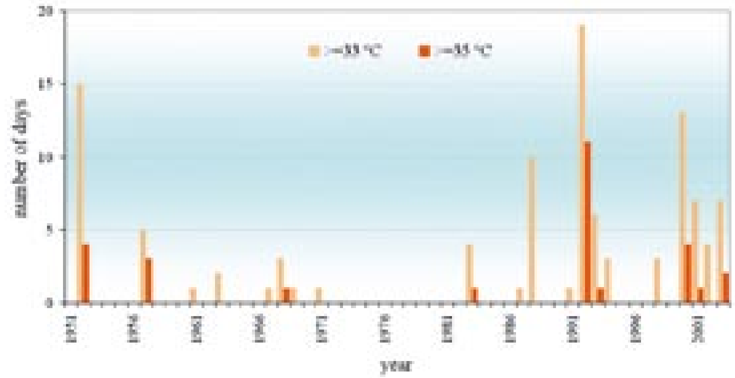


During the vegetation period 2002/2003 winter wheat was protected against low air temperature by snow cover (meteorological station Maribor).

Wind

The possibility of powerful storm is more or less the same across all of Slovenia. Characteristic of storms and short-term showers is extreme intensity which develops within and lasts for a very short period of time, and is mainly confined to a small area. Maximum wind gust speeds in the case of the north-east wind (gale) are comparable with those characteristic of the north foehn wind or hurricane-like south wind. However, strong gales are a common phenomenon to which a part of permanent vegetation has successfully adjusted. Characteristic deformation is often noticeable in trees due to the prevailing direction of wind gusts. Although blowing in strong gusts, gales do not form such vortices as hurricane-like south or north winds, which are appreciably less frequent than gales. The capacity to cause wind damage may be attributed especially to north foehn and hurricane-like south winds. Wind damage can also be caused by storm wind gusts which can spread across the entire territory of Slovenia; they are very limited in their scope and duration, which also applies to the form of vertical storm winds.

Damage caused by strong wind, November 2002.



Number of days with temperature above 33°C and 35°C in Murska Sobota (1951-2003).

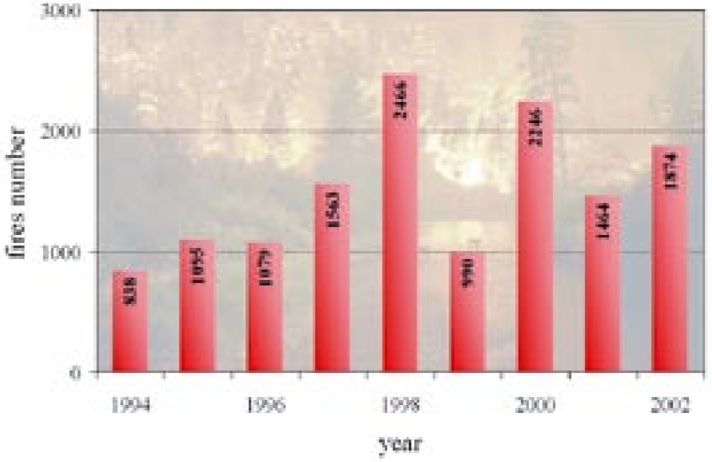
Drought and heat stress by plants coincidence in year 2003.

Extreme air temperature

Within recent years, the first heat waves are occurring already at the end of calendar spring. Air temperatures exceeding 33°C and 35°C are a rare phenomenon in Slovenia; since the beginning of the 1990's there has been a noticeable rise in the number of extremely hot days. During the 1970's the latter were very rare. The differences between respective years are considerable.

Fire incidents in the natural environment

Fire risk in the natural environment depends partly on climate conditions in a certain area, yet the determining factors are the current weather conditions and vegetation development phase. Fire risks in the natural environment are greatest in late winter and early spring (February and March), when the predominant part of natural vegetation is dead and dry, and thus easily flammable. The primary cause of fire incidents is human activity.



Number of fire incidents in the last 9 years (Source: Admiistration for civil protection and disaster relief).

Further climate change will lead to a slight increase in the number of fire incidents, but more likely it will lead to the increase in the extent of areas under fire. In summer, the occurrence of powerful storms will be among the causes of fire incidents, lightning even more so than in the past. Fire incidents will thus also occur in uninhabited, particularly mountainous areas in Slovenia, where higher slope gradients will facilitate the spreading of fire, while the impeded accessibility and water shortage will render extinguishing these fires extremely difficult. In the event of transitional precipitation crown fires can turn into ground-level fires and in favourable weather conditions gradually back into a crown fire again.

Floods

In addition to natural changes in water regimes, the latter are also affected by the changes caused by human interference in the environment. Extreme weather phenomena associated with precipitation are usually followed by extreme hydrological conditions mostly in the form of longstanding large-scale droughts or floods. Hydrological drought usually follows agricultural drought. Due to prolonged precipitation shortage a vast number of watercourses dry out and groundwater levels are considerably reduced due to interrupted inflow. Contrary to droughts, floods in our country are limited to shorter spans of time due to Slovenia's hydrographical characteristics. Floods usually last several days, except in frequently flooded areas in the Carst region and along rivers with lower gradients, such as the Krka and Mura rivers. Due to their frequency and general understanding of their characteristics, agricultural production finds it easier to adjust to them.

Deposited alluvial material on a pasture in the Zgornjesavska valley, August 2003.

Floods in Log by Sevnica, August 2005.

Floods in Razkrižje, August 2005.

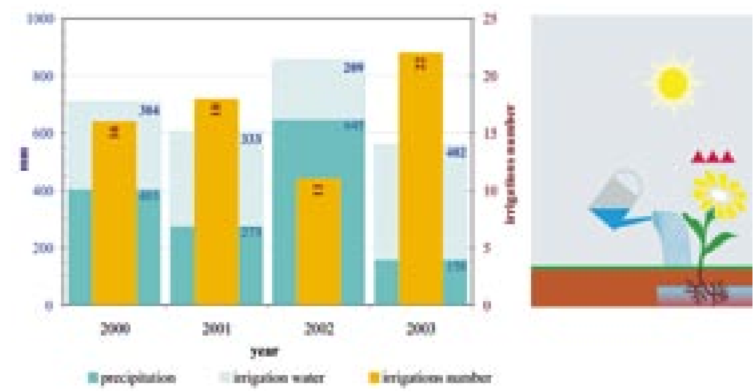
High water trends show that great river discharges in the eastern and western Slovenian regions are increasing and stagnating or even slightly dropping, in the rest of the country's territory. The predictions, however, show a higher occurrence and increase in autumn high waters. In recent periods, local floods that are especially caused by torrents and lesser rivers with great erosive capability are becoming more frequent. Rock material which rivers deposit on agricultural surfaces reduces the possibilities of agricultural land machining.

ADJUSTING TO CLIMATE CHANGE AND DEVELOPING NEW STRATEGIES IN AGROMETEOROLOGY

Agrometeorological monitoring and analysing the state of the weather in respect of water balance has a long tradition in Slovenia. Yet the unchanged trend paths may pose a danger, since they can invoke a feeling that the efforts invested into improvement and further development are not essentially required. The publication at hand presents a few fields which are considered to be among the most crucial for the development of expert knowledge. We will develop the products from these fields (and aspire to develop them, respectively) in subsequent years.

Meteorological support in water management

The best advice to water resources operators with regard to climate change is to start preparing a strategy as well as building a flexible and cost-effective management system. Flexibility enables protection and rapid reaction in ever changing conditions, while a cost-effective system facilitates the population's preparedness to cope with scarce water conditions. By planning and managing water systems the population will be better prepared to cope with the impact of climate changes, irrespective of their scope, and at the same time be better equipped for tackling the consequences of climate variability which are already noticeable.



Optimum quantities of water required for the purposes of irrigation and the number of irrigations of tomato during the vegetation period between 1st May and 15th September in the Primorska region (application of the domestic simulation model IRRFIB).

In the field of regular water supply for agricultural plants the envisaged changes will particularly require actions in the following directions:

- preparation of preventive measures (i.e. agricultural drought monitoring by means of indicators),
- preparation of measures for drought condition management (interdisciplinary approach),
- conducting up-to-date analyses of the climate change impact on Slovenia (new GCM techniques, regional analyses).

How to manage drought conditions in agriculture?

Numerous approaches have been tested in practice to adjust to drought conditions and the change in water supply of plants by means of technological measures and modified farming methods. Estimates show the need for:

- a change in sowing structure and production orientation on farms, including a change in the technology of agricultural production,
- a change in crop rotation necessitating ecological tests of cultivars and the introduction of drought resistant plant species and cultivars,
- improving the state of soil in drought conditions by increasing the humus content,
- setting up irrigation systems where this measure will be considered as economically justifiable and ecologically acceptable,
- planned irrigation by controlling the level of irrigation through irrigation models, with regard to the weather conditions and forecast, as well as by controlling naturally harmonized production of agricultural plants on irrigated land,
- and finally, insuring agricultural production in the event of extreme conditions (i.e. solving the issues regarding mutual insurance and further development of a methodology applicable for the assessment of agricultural droughts and risk insurance in agriculture).

How to adjust to extreme weather events?

Although extreme weather events cannot be prevented, we can prepare ourselves to cope with them in various ways: by selecting less vulnerable species and activities, by selecting less exposed areas, and by trying other means of damage control. Physical protective measures are invaluable in the event of flood hazard (for example: embankments, containment areas, drainage systems, appropriate maintenance of river, stream and torrent beds); drought may be mitigated by water reservoirs and irrigation systems; crops may be protected against hail with protective meshes. Spring cooling, with air temperatures below the critical values causing frost already in the present weather variability, presents an important hindrance in Slovenian agricultural territory.

In extreme cases, vulnerability to frost will increase to such an extent that some areas will be rendered unsuitable for economically justified production of certain fruit plants. Consequently, this will affect social and economic development, especially in crucial agricultural areas where fruit growing represents an important branch of agricultural production and the economy in general.

The wish to preserve agricultural production will require a high level of adjustment. This will include multi-level measures, whereby economic justification of production will constitute a significant adjustment criterion. More crucial than presently will be the decision made either in favour of a change in production orientation or the organization of protection for the existing production orientation. Passive protection against frost will be attributed a greater importance. Elements of passive protection are to be included in year-round technology which will ensure good status and also, indirectly, adequate resistibility of agricultural plants. An important role will also be played by active protection. The application of the sprinkling method in blossoming fruit plants is, as a rule, effective, but past experience has pointed to certain shortfalls related to its technology and management. Active protection requires a suitable water resource. According to the most recent statistical census of orchards there are only 259 ha of orchards in Slovenia that have the possibility of anti-frost sprinkling protection. In examining the spatial distribution of minimum air temperature and frost risks in the very diverse agricultural territory of Slovenia it will be crucial to dispose of an adequately dense network of meteorological and phenological monitoring stations in representative locations. The assessment of frost risks for certain agriculturally crucial plants will serve as the basis for decision-making on insurance eligibility of crops, which will become an important part of the adjustment strategy in modified climate conditions.

The elements of passive protection should be included in year-round technology that will ensure good status and also, indirectly, adequate resistibility of agricultural plants. The decisions on relevant measures will, of course, be difficult, especially because in the absence of clear and precise answers to key issues, such as the changes in the intensity and scope as well as frequency of extreme weather events. The measures will bear multi-layer consequences, both sociological and economic. We must also not neglect the psychological impact of the consequences on farmers affected by extreme weather events and forced into making adjustments. It will be necessary to establish a close inter-connection between short-term, mid-term and long-term measures. Adjustments to modified climate conditions should start with an optimum adjustment to the existing climate changeability and the occurrence of extreme events. Most obvious is the importance of measures targeting the reduction in vulnerability to the existing weather extremes. Short-term measures are based on enhancing the predictability of weather extremes in weather forecasts within a time-span extending from several hours to several days.

The use of a good information system that will enable us to be warned on time of a likely occurrence of an extreme weather event will also be very beneficial. At present this is only possible for events associated with atmospheric conditions on a regional scale, but rapid development of numeric models and super-computers will soon give rise to a higher spatial resolution and thus take into account small-scale events. In the coming years there are also great expectations regarding the development of mid-term and long-term weather forecasts.

The next possibility that, at least in our area, will not be introduced in the near future includes seasonal weather forecasts. Since global predictions of climate changes are still very tentative, especially when we try to apply them in our territory, great care will be necessary in our future monitoring of events occurring across Slovenia as well as taking into account the fact that all regions do not react the same.

Updating the information system

Agrometeorological information, even when obtained according to state-of-the art technology, does not convey a major value if inappropriately presented, evaluated and communicated to all interested users. The updating of communication channels and the introduction of different methods of communicating the information as enabled by modern information technologies should be given greater priority than the development of new products. We are aware that communication is one of the weak points of our agrometeorological service.

Appropriate presentations of agrometeorological products could help us resolve several issues: the determination of the level of affectedness by areas and the agglomeration of the latter into zones would be available at any time, instead of being prepared (usually in haste) on individual requests; by means of information technology any party having adequate expertise and data would be able to contribute to quality monitoring. The result would be a kind of a “consensual product”; the use of appropriate technologies (the most appropriate being the World Wide Web) would ensure suitable access to the broadest possible circle of users.

Studying samples of weather conditions over a broader, continental area

Studying the state of the weather over an extensive part of continental dimensions (the established meteorological term is - synoptic state) is not a new approach in weather analysis; quite on the contrary, it was established with the birth of modern meteorological science in the 19th century. By that time, the improved communication system facilitated an intensified exchange of meteorological data between European cities where measurements were carried out. When entering the data on the chart, outlines were made of recognizable weather systems - cyclones, anticyclones and fronts. Such charts still appear in the media on a daily basis.

The only difference is that now (owing to repeated weather analyses conducted by applying modern computer-based methods and historical data) we have the opportunity to study synoptic states of the weather on the basis of digital data archives for the past period of nearly 50 years. We thus have at our disposal an extensive time series of high quality and (fairly) homogeneous information on past weather conditions.

And where do we see greatest potential usability?

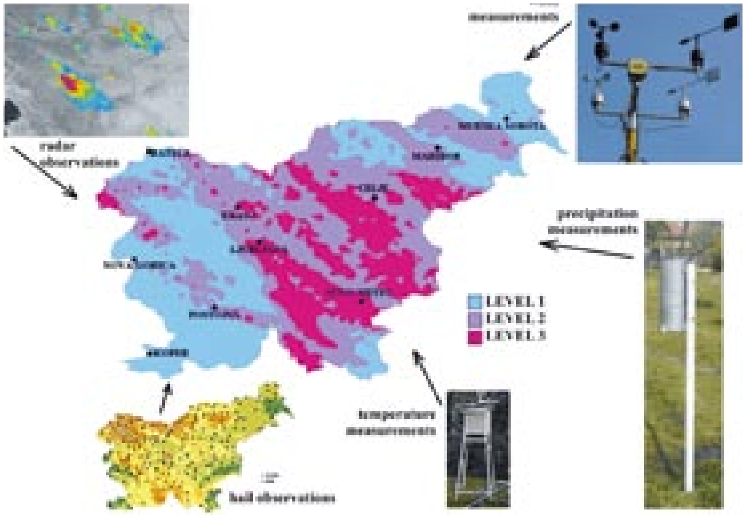
In enhancing the methods applied in past weather analyses. All weather analysis methods "translate", in one way or another, information collected at points where we undertake measurements, to points where measurements are not carried out. The "rules" for such a translation can be adapted to individual (typified) synoptic weather situations. Rather than conducting an analysis with data obtained from the nearest meteorological station (which may also be located at a fairly distant location), we can associate our data with the type of the weather prevailing over the entire continent. This enables us to be less dependent on data obtained from individual locations which may also be less representative for a particular issue under consideration.

Understanding the dynamics of synoptic disturbances in changed global climate conditions will enable the production of a more reliable illustration of the future climate in Slovenia. It is not a question of whether the average air temperature of the Earth's surface will experience an increase in the following decades - there is no doubt about that - the more likely question to be raised is how synoptic weather systems will respond to the increase. What kind of situations will occur more often and when?

The use of data obtained by remote sensing

Remote sensing systems have long been established in daily meteorological practice. Everybody knows the satellite pictures accompanying TV weather forecasts. Many are also familiar with the possibility of tracking precipitation systems enabled by meteorological radar.

In this case, as well, the novelty lies in the approach, the manner of applying the data. Data provided by satellites and radars are (having regard to their shortcomings) increasingly subject to quantitative application in spatial analyses. One such example is the analysis of the consequences of a hail storm, which spreads across the entire country. The key to success is in a suitable data synthesis. The use of data from a point measuring network is usually inadequate owing to insufficient spatial density. On the other hand, merely using measured radar reflections are not sufficiently precise to provide an exclusive basis, without any additional information (on wind gusts, rapid drops in temperature, etc...), for determining the areas affected by storms. The analysis of the consequences of the 2001 storm provides an example that should be applied in further practice.



Schematic illustration of sources in drawing up the chart of areas affected by hail.

Satellite footage (NASA) of the fire in Portugal in 2005.

Similar conclusions are true for meteorological satellites - the products of which are currently used by the Environmental Agency of the Republic of Slovenia for the purposes of weather analyses. These products are not suitable for direct use in meteorological applications relating to the Earth's surface itself. Due to a relatively small number of channels these satellite pictures allow only a clear determination of the highest layer of clouds in the atmosphere (which is crucial in some analyses e.g. extreme precipitation situations). Problems already arise in the differentiation between clear areas and areas overcast with low clouds.

The European intergovernmental organisation EUMETSAT managing the European meteorological satellites orbited the first meteorological satellite of second generation, the so-called MSG. In 2003, Slovenia became a partner country in this organisation, obtaining access to all products including MSG in real time. The MSG project also envisages applicative satellite products, the so-called SAF's. These are products which, together with the numerous channels and by applying the latest methods, also enable a quantitative insight into atmospheric events (quantity of clouds, radiation balance) and soil (surface temperature, soil humidity and snow cover, vegetation type). In the event of a 2007 drought (when it is expected that the system is fully operational), it would be theoretically possible to conduct a water balance analysis primarily with the use of suitable SAF's. In practice, however, it will be more reasonable to use a similar procedure as in the analysis of the storm consequences. The weakness of the MSG-generated data is also a relatively inadequate spatial resolution (10-15 km), which cannot be compared with the LANDSAT satellite resolution (approximately 30 m). The European meteorological satellites, unfortunately, cannot sense such details. A potentially applicable value for the purposes of agrometeorological analyses can thus also be attributed to other satellite systems.

Raising awareness and education

To a great extent, the future of and adjustments to climate variability and change also depends on raising the awareness of citizens who are only beginning to learn about the role of meteorology in such conditions. It is crucial to raise the awareness of users working in agriculture, which is one of those economic activities that represent a source of greenhouse gas emissions.

It is very important that long-term planning of agricultural production includes analyses of climate-related risks as well as climate change and variability impacts:

- agricultural practice methodological recommendations taking into account weather and climate data (climate zoning, microclimate, ecological and integrated agricultural production),
- operational decisions (irrigation management, plant disease and pest management, crop prediction, agricultural practice, etc...).

It is vitally important that decision-makers in agriculture and other economic activities acquire knowledge of the climate change issue, if we are to adopt effective measures for preventing or mitigating the consequences of climate change.

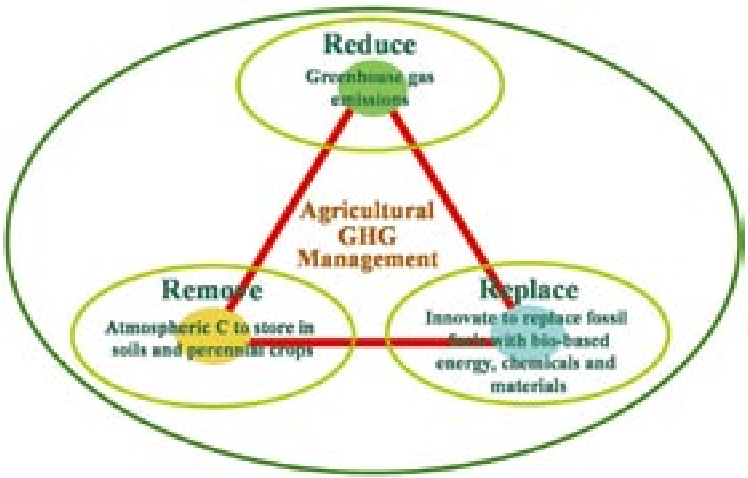
Mitigation opportunities

There is no uncertainty on the need to stabilize GHG concentration in atmosphere. In agriculture there is also the need to initiate mitigation urgently, because agricultural sources of several GHG are very significant. Agriculture can participate either as a source of emission reductions or as a sink for gas emission storage. Gases which are the object of the reduction are in addition to carbon dioxide also nitrous oxides and methane, of which the latter largely stems from agriculture-related sources.

Agriculture has many unique opportunities to manage greenhouse gases. There are several "no-regrets" measures that make economic sense, because they reduce emissions from the agricultural sector or improve resilience of all sectors of agriculture against weather variability. Furthermore they can often be implemented at minimal cost. GHG source-reducing management practices traditionally focus mainly on improving nutrient, feeding and manure management. Such measures include:

- improved fertilizer use, as N_2O released into the atmosphere is a loss and constitutes a symptom of inefficient farming. Needless to say, the same applies to nitrates lost to the water table and surface waters,
- improved ruminant digestion through more efficient feeds or, when feasible, a shift to enzymic digesters,

- development of water harvesting and conservation techniques, as well as other improvements to crop-water management as an adaptation to rainfall variability,
- improved rice farming, as higher yields are accompanied by a relatively smaller loss of methane,
- improved low-impact harvesting in forests, reduction of slash-and-burn agriculture, better soil protection.



Agriculture's opportunities to manage greenhouse gases.

Sink enhancing management practices should improve soil carbon storage (carbon sink) while at the same time improving soil structure increasing water holding capacity. There are possibilities to increase no-till, decrease or eliminate summer fallow, increase hay in crop rotation, improve grazing management, increase permanent cover and shelterbelts. Soil carbon can be enhanced also via less intense tillage, perennials, grass conversions and increasing carbon input to soil (fertilizer, irrigation, more yield). Forest carbon sequestration could be enhanced by conversion of agricultural lands to tree plantations and by better management of existing forests including growth promotion and longer rotations.

In a mitigation world agriculture is still considered as a passive sector, although it could be affected by GHG reduction policies which are largely directed toward other sectors, mostly through higher fuel and fossil prices. Farmers should consider innovations to replace fossil fuels with bio-based energy, chemicals and materials. Agricultural products can be used as feedstock, burning agricultural biomass can offset fossil fuel, growing of alternative energy crops is a way to close the carbon cycle, corn or other cellulose laden products can be converted into ethanol substitution for petroleum and wood can substitute other building products.

Adaptation strategies

Even if society substantially reduces its emissions of greenhouse gases over the coming decades, the climate system is projected to continue to change. Thus, farmers have to prepare for and adapt to the consequences of some inevitable climate change, in addition to taking action to mitigate it. So adaptation strategies are required at national, regional and local level.

Historically, the agricultural sector has proven itself to be highly adaptive to environmental and social changes, with a strong capacity to adapt in a responsive manner. However, to most effectively reduce vulnerability, anticipatory adaptation is necessary. For example, efforts to increase adaptive capacity through diversification and the development of new technologies represent valuable types of proactive adaptation. Anticipatory adaptation is also important with respect to major capital investments by producers and the food industry.

As said before, appropriate adaptations can greatly reduce the magnitude of the impacts of climate change. The wide uncertainties in climate scenarios, regional variation in climate effects, and interactions of environment, economics, and farm policy suggest that there are no simple and widely applicable adaptation prescriptions. Farmers will need to adapt broadly to changing conditions in agriculture, of which changing climate is only one factor. The key questions that farmers should consider are: to what climate variables is agriculture most sensitive, who needs to adapt (e.g., producers, consumers, industry), which adaptation options are worth promoting or undertaking and what is the likelihood that the adaptation would be implemented. Especially important is to find answers to the questions: who will bear the financial costs and how will the adaptation affect agricultural livelihoods.

Adaptation options in agriculture can be classified in different ways. Farm level adjustments and policy responses to climate change can be distinguished from regional and national ones. Alternatively adaptation options in agriculture can be classified into the following categories: technological developments (e.g., new crop varieties, water management innovations); government programs and insurance (e.g., agricultural subsidies, private insurance); farm production practices (e.g., crop diversification, irrigation); and farm financial management (e.g., crop shares, income stabilization programs).

Adjustments and policy responses to climate change

Farm level:

- Changes in land use: amount of farmed area, crop variety and crop location.
- Changes in management: irrigation use, fertilizer applications, control of pests and diseases, soil drainage and control of erosion, land topography, farm infrastructure, crop and livestock husbandry.

Regional and national:

- Changes in regional land-use allocation: changes in land use to optimize and stabilize production.
- Changes in national agricultural policy: to maintain national food security, to maintain equitable regional farm incomes, and support of farm inputs.

Some of the possible adaptations more directly related to climate include:

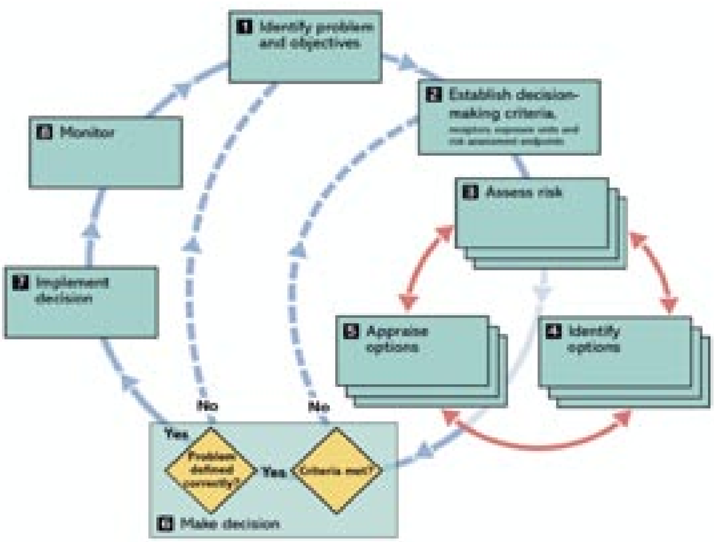
- Sowing dates and other seasonal changes: Plant two crops instead of one or a spring and fall crop with a short fallow period to avoid excessive heat and drought in mid-summer. For already warm growing areas, winter cropping could possibly become more productive than summer cropping. Change varieties grown in a region and look for new sites.
- New crop varieties: The genetic base is very broad for many crops, and biotechnology offers new potential for introducing salt tolerance, pest resistance, and general improvements in crop yield and quality (increase nutrient content in crops).
- Water supply, irrigation, and drainage systems: Technologies and management methods exist to increase irrigation efficiency and reduce problems of soil degradation, but in many areas, the economic incentives to reduce wasteful practices do not exist. Increased precipitation and more intense precipitation will likely mean that some areas will need to increase their use of drainage systems to avoid flooding and water-logging of soils. Climate change should be incorporated into long-term water sharing agreements.

Drip irrigation and fertigation of paprikas in greenhouses.

- Tillage practices: A warmer climate will speed the decay of soil organic matter by bacteria and fungi. Loss of organic matter reduces the capacity of soils to store water and nutrients essential for plant growth. Tillage practices that incorporate crop residues in the soils would likely combat this loss and improve soil quality.
- Pests, pathogens and parasites: Systematically mapping of vulnerability of plants and animals to endemic and exotic pests, pathogens and parasites is needed. Select animal breeds and plant varieties resistant to pests, pathogens and parasites already present and strengthen quarantine measures.
- Optimal strategy in forestry between high growth (e.g., dense stands with high leaf area) and risk aversion (e.g.,

sparse stands with low leaf area) for particular sites and particular trees.
- Use near-term climate predictions: Accurate six-month to one-year forecasts could possibly reduce losses due to weather variability. Develop warnings prior to planting of likelihood of very hot days and high erosion potential.
- Other management adjustments: Virtually all components of the farming system from planting to harvesting to selling might be modified to adjust to climate change.

Adaptation to climate change will not be a smooth process or free of costs. It is reasonable to expect that mistakes will be made and costs will be incurred along the way. Farmers are neither so foolish as to continue doing what they have always done in the face of climate change, nor so omniscient as to perfectly understand what will need to be done and to carry it out most efficiently. In reality, we are more likely to muddle through, taking adaptive actions as necessary, but often not doing what may be needed for optimal or ideal adaptation. Some adaptations to climate change and its impacts can have negative secondary effects. For example, an increase in the use of pesticides and herbicides is one adaptation to increased insects, weeds, and diseases associated with warming. Runoff of these chemicals into groundwater, rivers and lakes could threaten drinking water supplies, coastal waters and waterfowl habitat.



A framework to support good decision-making in the face of climate change risk (Source: Willows and Connell, 2003).

Additionally, adaptation is an on-going process rather than a one-shot instantaneous occurrence. A climate adaptation strategy represents a combination of measures and options chosen to meet a particular risk. Setting up an effective strategy requires several iterative processes including identifying climate sensitive system components; assessing risk; identifying potential options for adaptation and deciding on and implementing adaptive measures. Willows and Connell suggest that an objective of climate change risk assessments should be to identify no regret climate adaptation options. These are climate-sensitive decision areas where no apparent uncertainty exists as to the best adaptation option to implement. Such an option is anticipated to deliver benefits under any foreseeable climate scenario, including present day climate.

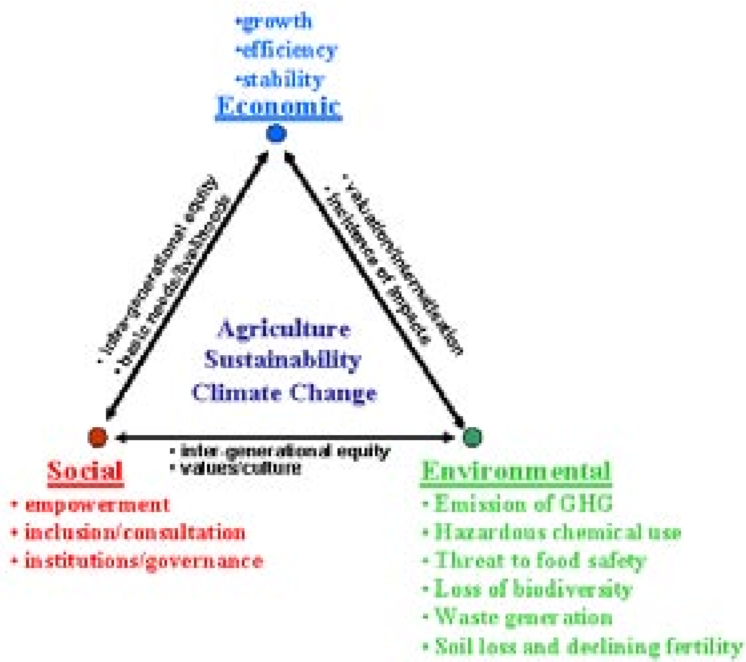
To provide a flexible approach to decision-making under climate change the decision-making framework has to be circular involving several stages. Feedback and iteration are important, so that the problem, objectives and decision-making criteria can be refined, and further options identified to better reduce and manage climate change risks. Iteration is important to achieving robust decisions.

Farmers should also recognize the fact that adaptation to climate is itself not risk-free. There is danger to underestimate the risk associated with climate variability and climate change, which may lead to choices that fail to deliver appropriate levels of adaptation. Alternatively, the climate risk may be overestimated, resulting in over-adaptation and perhaps the unnecessary use of resources. There is also a risk that the adaptation option will not deliver the benefits anticipated, due to uncertainty in future climate.

Sustainable agriculture and climate change

Sustainable development and climate change are two vitally important and interrelated challenges facing us in the 21st century. Our ability to develop more sustainable will determine the speed and degree of climate change we experience. And as the climate changes the choices available to us to develop sustainable will change. Climate change is with us today, but its main impacts are expected to occur in the future. Not only the climate system, but also socioeconomic systems, is characterized by important inertia.

The work of the Intergovernmental Panel on Climate Change (IPCC) is also focused on the sustainable development and climate change interconnections and is seeking answers to important questions: how future development patterns will affect climate change; how climate change impacts, adaptation, and mitigation will affect future sustainable development prospects; and how climate change responses might be better integrated into emerging sustainable development strategies. Development, equity, and sustainability were found to be integral elements of sustainable development. According to sustainable strategy agriculture sector is considered responsible for: emission of greenhouse gases, hazardous chemical use, threat to food safety, loss of biodiversity, waste generation and soil loss and declining fertility. Sustainability rests on the principle that we must meet the needs of the present without compromising the ability of future generations to meet their own needs.



Key elements of sustainable development and interconnections (modified after Munasinghe and Swart, 2005).

Sustainable agriculture integrates three main goals: environmental health, economic profitability, and social and economic equity. A variety of philosophies, policies and practices have contributed to these goals. People in many different capacities, from farmers to consumers, have shared this vision and contributed to it. The economic domain is geared mainly toward improving human welfare, primarily through increases in the consumption of goods and services.. The environmental domain focuses on protecting the integrity and resilience of ecological systems. The social domain emphasizes the enrichment of human relationships and achievement of individual and group aspirations.

Usually it is believed that pursuing sustainable development and climate change mitigation can be mutually reinforcing. That climate change mitigation can have ancillary benefits or co-benefits which will contribute to the sustainable development goals and that sustainable development creates conditions in which climate change mitigation can be effectively pursued. Therefore, *stewardship of both natural and human resources* is of prime importance. Stewardship of human resources includes consideration of social responsibilities such as working and living conditions of laborers, the needs of rural communities, and consumer health and safety both in the present and the future. Stewardship of land and natural resources involves maintaining or enhancing this vital resource base for the long term. It is important to point out that *reaching toward the goal of sustainable agriculture is the responsibility of all participants in the system,* including farmers, laborers, policymakers, researchers, retailers, and consumers. Each group has its own part to play, its own unique contribution to make to strengthen the sustainable agriculture community.

Slovenian goal should be sustainable agriculture capable, also in the long term, of producing wholesome and safe foods and other high-quality products without impairment to the resource basis or negative impacts on nature's ecosystems. Agriculture should use management practices that promote agricultural efficiency and make economic sense, measured in terms of profit, land stewardship, and long-term sustainability on the landscape. Management practices that promote environmental health, measured in terms of air, soil and water quality, and preservation of biodiversity and wild spaces on the landscape are important, as well.

CONCLUSION

While much progress in understanding the climate change issue has been made, uncertainties continue to exist about aspects of the climate change science, and regarding societal developments that will affect the extent of future climate change and societal vulnerability. The high probability of at least some global warming, given the inertia in the climate and agricultural systems, means that some adaptation will be necessary.

Although warmer temperatures, longer growing seasons and elevated CO_2 concentrations are generally expected to benefit agriculture in northern latitudes, factors such as reduced soil moisture, increased frequency of extreme climate events, soil degradation and pests have the potential to counteract, and potentially exceed, these benefits. Some regions could experience net gains, while others may see net losses. Regional variations will result from several factors, including the nature of climate change, the characteristics of the farming system/ organization, and the response of different groups.

Appropriate adaptations have the potential to greatly reduce the overall vulnerability of agriculture to climate change. These adaptations will require the participation of several different groups, including individual producers, government organizations, the food industry and research institutions. Unfortunately adaptive capacity is not equally distributed worldwide. For agriculture the vulnerability of the developed countries is substantially lower than the vulnerability of developing countries. The two main reasons for their greater vulnerability are their sensitivity and exposure and their lower adaptive capacity. Developing countries have a far larger proportion of their economies in agriculture. They also face more adverse impacts.

Developing countries also have greater vulnerability to climate change because they have less economic resources, technology, information and skills. It is reasonable to expect that adaptation would be less effective in coping with adverse effects of climate change. The challenges posed by climate change demand also that multilateral environmental agreements are more strongly integrated and harmonized. The measures proposed by such agreements can only be addressed by being set within broader national and global development policies. This means integrating environmental issues within the agenda of trade, debt and global poverty.

- **It is most likely to be impossible to avoid climate changes.**
- **Timely adjustments are more effective and cheaper than last-minute adjustments.**
- **Climate changes will probably occur faster and in greater extremes than is envisaged by the current estimates.**
- **Better adjustments to the existent climate variability and extreme weather events can deliver instant benefits.**
- **Indirect benefits deriving from immediate adjustments are also guaranteed by the replacement of older inadequate policy and practice measures with new ones enabling better adjustments to climate change.**
- **If the adjustments are made in time, climate change may also bring new possibilities and not only risks.**

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