OcCC

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Extreme Events and Climate Change

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Editorial

Kathy Riklin

Floods, extreme storms and dangerous avalanches have caused repeated concern in recent years. Has the weather got completely out of hand?

In 2000, the The Advisory Body on Climate Change (OcCC) discussed the possibility of a connection between the increased frequency of these events and climate change, and considered what action was needed. At the suggestion of the former president of the OcCC, Gian-Reto Plattner, it was decided to prepare a report on the theme to be addressed to the wider public, members of the media and decision makers. The present publication presents a scientifically founded review of the most important results and meteorological phenomena. What are the conclusions to be drawn from the knowledge gained and what measures should be taken?

In game theory, the 'minimax' theorem is often mentioned. In games, the objective is to determine the optimum stake for each separate strategy in order to minimize the maximum gain of the opponents. Here, we are concerned not with a game but with a battle against the supposed moods of nature. In our case, the sums betted are very large and the playing board spans the entire globe. Under the minimax rule, a strategy must be selected for which the maximum possible damage is as small as possible. For this reason, political decisions should be based on the minimax rule. Also, we are concerned here – other than in game theory – with long-term damage that is to be minimized.

In the coming decades, scientists will continue to deliberate on and research the exact causes of climate change. Nonetheless, decision makers are called on to take precautionary measures here and now. The OcCC offers clear and unmistakable recommendations on page 7 of the report. The building of avalanche barriers, stonefall shelters, retention basins and dams will not suffice. Direct measures of this kind to minimize the damage are of course essential. However, it will primarily be necessary to adopt measures that are effective not only in avoiding climate change, and in providing protection against extreme events, but also have a positive influence in other spheres. This is the only conceivable way to ensure that 'spaceship earth' will remain inhabitable into the distant future. Over and above that, so-called win-win situations will arise in the short term from the measures taken. This is the case, for example, for the economical use of fossil heating and motor fuels and for the promotion of renewable energies.

Switzerland's signature to the Kyoto Protocol on 9 July 2003 represented an important political step. Now, deeds are called for. The political parties and the leaders of industry and commerce must now be reminded of their promises. The situation is crucial. Words must be followed by deeds. The present publication reviews the risks at hand.

Dr. Kathy Riklin, National Councillor
President of the OcCC

Extreme events and climate change – status of knowledge and recommendations of the OcCC

Members of the OcCC

The term extreme events refers to infrequent weather and natural events that depart heavily from the average. Extreme events can result in very extensive damage. The term natural catastrophe is used where the capacity of the local population to deal with the damage is exceeded. The present report addresses the most important categories of extreme events in Switzerland and their relationship to climate change, namely to temperature extremes, drought, frost, forest fires, heavy precipitation, hail, floods, mass movements, avalanches and winter storms.

In one sense, extreme events and natural catastrophes can be seen as a normal aspect of the Alpine climate. Landslides and floods have actively formed the landscape over thousands of years, and this includes the characteristic structure of our mountain valleys and rivers. Indeed, even today's modern infrastructure cannot provide complete protection from extreme events. Thus our civilisation must often content itself with treating high-risk occupied areas on a separate basis, mitigating the negative consequences by timely measures and the provision of immediate assistance to the victims.

From the human standpoint, the damage unleashed by heavy storms in Central Europe in past decades is very extensive. The Swiss reinsurer, Swiss Re, for example, estimates the losses to the national economy caused by the Lothar and Martin storms at 31 billion CHF, those caused by flooding and landslides in October 2000 in Switzerland, France and Italy at 9 billion CHF, and those from flooding in Europe in July and August 2002 at 23 billion CHF (2002 prices). These figures underline the severity of extreme events in the Alpine region and in Europe as a whole. Should the character and frequency of extreme events shift as a result of climate change, this could have very serious consequences.

Current knowledge

The relationship between climate, extreme events and the extent of damage is extremely complex, and calls for a very broad range of interdisciplinary research. On the basis of current knowledge, the following general conclusions may be drawn:

- Over the past century, the global average temperature rose by 0.6 ± 0.2°C. This temperature increase is attributed mainly to human activity. Climate simulations for the 21st century predict a faster increase in the average global air temperature at the ground of 1.4°C to 5.8°C. The entire water regime will be affected by these changes, and marked changes in the precipitation pattern are expected.
- The probability and geographical distribution of extreme events will alter gradually with the change in climate. The extent and character of the changes will differ depending on the location and character of the extreme events. It is not at present possible to give a quantitative assessment of these effects.
- At present, natural catastrophes are observed to occur more frequently. This could either be accidental, the result of natural long-term climate change, or of climate change from anthropogenic causes. For fundamental reasons, it is difficult, or may even be impossible, to identify or exclude a statistically valid trend in the frequency of rare extreme events. Indeed, it may not prove possible to positively identify long-term changes in the frequency of extreme events until their extent has become very considerable and extensive damage has been caused.
- In contrast, statistical predictions are possible for trends in 'intensive' events. It can be shown, for example, that heavy precipitation events (which do not usually lead to damage) have become more frequent since the beginning of the last century. Also, the volume of precipitation in winter has increased substantially in almost all parts of Switzerland since the beginning of the last century. Although these results cannot be applied directly to extreme events, they do point to substantial changes in the hydrological cycle over the last 100 years.

- Our present knowledge of meteorological processes suggests that the frequency and intensity of certain extreme events (heatwaves, heavy precipitation and floods in the winter months, drought to the south of the Alps in summer and in the inner Alpine valleys, and landslides) will increase with the change in climate. This anxiety is corroborated by calculations using climate models. In distinction, the frequency of days with frost and very cold periods will decrease.
- Future trends in the threat arising from extreme events will be determined not only by climatic factors but also by social changes. In the past, the increasing concentration of buildings and communal infrastructures in many areas – not least in exposed locations – has demonstrably had its effect on the losses incurred. Future changes in land use may lead to magnification – or possibly to attenuation – of the purely climatic factors.

Recommendations of the OcCC

The OcCC has identified a need for action from the part of political bodies, administration, commerce and research, on measures to protect against extreme events and combat anthropogenic climate change, and to ensure the integrity of communication.

The planning and implementation of measures must be based on a dynamic assessment of the hazard situation and take into account the need for ecological, economical and social sustainability. Priority should be given to those measures that are effective not only in combating climate change and in providing protection from extreme events, but also have positive (win-win) repercussions in other areas, and allow sufficient room for manoeuvre when they are in place (flexibility).

(a) Protection measures against extreme events

Even in the absence of climate change, there is an evident need for action to provide protection against extreme events owing to the increasing concentration of assets and their higher vulnerability, and the societie's enhanced need for protection. In recognition of the changing climate, hazard patterns, protection objectives and accepted residual risks should be periodically reviewed and solutions permitting the greatest possible flexibility sought. In the middle term, new assessment and planning methods must be developed that are able to quantify the risks under changing climatic conditions.

There is an increased need for action to provide protection from those events for which qualitative predictions of future trends are available today:

- Heavy precipitation, floods and landslides.
  Current knowledge of meteorological processes and the results of simulations point to an increase in the intensity of heavy precipitation and faster runoff in the winter months. This circumstance must be taken into account in risk assessment, planning of protection measures (reforestation, protection structures and retention areas) and in development planning. Also, the changes anticipated during the period in which the measures are in place must be considered. The same is true for the assessment of zones threatened by landslides.
- Heat waves.
  Higher temperature extremes are likely to occur as a result of climate change. It may be expected that higher mortality will result from the more frequent occurrence of extremely high temperatures. Structural measures (e.g. sun shading, insulation and greening) can increase the level of comfort and energy efficiency. Rivers, lakes, vegetation and fauna are subject to additional stress through higher temperature extremes.
- Permafrost.
  The increase in temperature will lead to receding permafrost. Slope stability will be reduced in the affected areas. Slopes and the buildings on or near them must be monitored.
- Frost.
  The frequency of days on which frost occurs is likely to decrease with the change in climate. Since the effects of this are dependent both on temperature and vegetation cover, it is not at present clear how these will change. In general, under the assumption that sowing and planting times remain the same, the risk of frost damage is likely to decline.

No assessment is at present possible of future trends in drought, forest fires, föhn, winter storms, hail or avalanches. It will be important to follow research developments carefully in these areas.

(b) Measures to combat anthropogenic climate change

Considerable uncertainty exists concerning the relationship between climate change and extreme events, and on their future variation, direction and extent. Decisions taken under uncertain conditions should be based on the so-called 'minimax' rule. This requires the strategy giving lowest possible maximum damage to be chosen.

Measures to combat the causes of anthropogenic climate change should be vigorously pursued and coordinated at national and international level between research, administration, commerce and political bodies. From the scientific standpoint, the long-term need is to reduce global greenhouse gas emission to the 1900 level. The Kyoto Protocol represents a major step in coordinating international measures. It is planned to fulfil Switzerland's reduction commitment through implementation of the CO_2 and energy laws, and by additional measures.[1] These are designed to achieve a reduction in CO_2 of 10% below the 1990 level by the year 2010. In view of the anticipated effects of climate change, it is essential for Switzerland to press for effective climate protection objectives in the negotiations on procedures to be adopted following the initial commitment period foreseen in the Kyoto Protocol. Among other countries, Switzerland stands to benefit from the measures implemented to combat climate change.

In Switzerland, measures going beyond the CO_2 and energy laws are needed to combat anthropogenic climate change and to establish low-emission lifestyles and industrial processes. Thus in order to foster sustainability in general and to ensure that investments are compatible with climatic needs in particular, the processes and commercial relationships in private enterprise need to be made more transparent. This may be aided by suitable legislative provisions. Partnerships between government and private enterprise (or industry) need to be established and promoted, thereby ensuring that climate protection measures and adaptation strategies are implemented. 'Clean' technologies and particularly renewable energies will need to assume a central role in future.

(c) Communication

Measures against anthropogenic climate change and for protection against extreme events must be planned on a long-term basis, but at a time when only qualitative forecasts of the future climate are available. The promotion of awareness on the part of the public, political bodies and the business sector is therefore crucial. Political leaders and the media will play a decisive role in achieving this.

In reporting on climate change and extreme events, note that extreme events do not represent reliable climate indicators. For this, better indicators are available, e.g. temperature increase and melting Alpine glaciers. There is a danger that the coupling of extreme events and climate change in the public mind could lead to dramatising the climate problem at times when extreme events are frequent, and to trivialising it at times when few extreme events occur.

Although an increase in the frequency of certain extreme events (e.g. heavy precipitation and floods) is consistent with the forecasts of climate models and with our physical understanding of the processes involved, this does not allow individual extreme events to be causally attributed to climate change.

(d) Research

Adequate knowledge is available today enabling measures to be taken to combat climate change and to protect against extreme events. Of course, research will continue in future to increase our knowledge and diminish the uncertainties.

In handling extreme events, integral analyses involving the natural, social, engineering and economic sciences are called for. Reliable measurement networks are of central importance in early diagnosis and analysis. They form the backbone of warning systems and provide the data basis for the detection of long-term changes. Careful system analyses of observed events can help to show which processes led to the event, whether the necessary conditions for similar events are present, and whether the change in climate may alter the probability of similar events occurring. Analytical models and computer simulations are also becoming of increasing importance internationally for short-term forecasts and issuing warnings. These instruments are also applicable in estimating and quantifying the dangers arising under future climatic conditions.

Research projects in progress in Switzerland and abroad (e.g. NCCR-Climate and EU research projects) are leading to a better understanding of climate change and extreme events. Notwithstanding these efforts, the relationship between climate and extreme events is still only partly understood. The thrust of future research must be aligned with the latest report of the Intergovernmental Panel on Climate Change (IPCC)[2,3,4,5] and take the local situation and particular structures of the Alpine region into account.The central objective is to forecast the negative effects on society and the economy at an early date, and to propose suitable measures to combat them. The newly-gained knowledge should be constantly introduced into the ongoing planning and decision-making processes. It is essential for Switzerland to continue to actively participate in international research programmes and to foster the discussion between science, political bodies, the business sector and the administration.

1 For example the SwissEnergy programme for the promotion of renewable energies and of measures to increase energy efficiency.

2 IPCC, Climate Change 2001: The Scientific Basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, U.K., 881 p., 2001.

3 IPCC, Climate Change 2001: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, U.K., 1032 p., 2001.

4 IPCC, Climate Change 2001: Mitigation. Contribution of Working Group III to the Third Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, U.K., 752 p., 2001.

5 IPCC, Climate Change 2001: Synthesis Report. Cambridge University Press, Cambridge, U.K., 397 p., 2002.

Introduction

Roland Hohmann and Christoph Frei

The term 'climate' is always applied to the average weather, and this is characterised in turn by average meteorological values. Extreme events are episodes during which the weather departs substantially from the long-term average and from the fluctuations typical of particular locations and times of year. Extreme events are an integral part of the climate of a region, and have a decisive influence on the landscape and the conditions of life. They can, however, cause serious damage to communal facilities and commercial plants. It is therefore essential for society to have a knowledge of their frequency and intensity. This is needed for planning purposes and for the provision of protection measures.

The recent past has seen a multitude of extreme events in Switzerland. A small selection of these are listed here:

- In 2003, a heatwave brought Switzerland the warmest June since temperature measurements began in 1864. The long-term average monthly temperature was exceeded by 6°C.
- Following heavy precipitation in the Cantons of Grisons, Uri and Ticino in mid November 2002, mud avalanches caused serious damage. The villages of Schlans and Rueun presented a scene of destruction.
- In October 2000, almost 500 mm of rain fell within two days in October 2000. On 14 October 2000, the barrier above the village of Gondo broke. The resulting landslide with earth flow destroyed parts of the village and claimed 13 lives.
- In December 1999, the hurricane Lothar passed over Western Europe, causing extensive damage in France, Germany and Switzerland. Switzerland mourned 13 deaths. Forest damage totalled 12.7 million m^3 of timber.
- In July 1999, an large storm system with embedded thunder cells traversed Central Switzerland and the Alpine foothills from West to East. Over 500 communities reported hail damage in agriculture.
- In early 1999, in the course of three precipitation periods that followed each other at short intervals, over 300 cm of snow fell over large areas of Valais, northern Grisons and in lower Engadine. As a result, a total of some 1200 avalanches causing damage in the Swiss Alps occurred.

Extreme events and the damage they cause are a painful blow to the local population. They are also the subject of extensive media coverage. In the knowledge that global temperatures are rising, the question as to the relationship between extreme events and climate change is posed time and again. Have extreme events become more frequent as a result of climate change?

Climate change and its consequences are set out in detail in the latest Assessment Report of the *Intergovernmental Panel on Climate Change* (IPCC[1,2,3,4]). In the course of the 20th century, the global average temperature increased by approx. 0.6°C, and continental precipitation in central and high latitudes of the northern hemisphere increased significantly. The greater part of the temperature rise over the past 50 years is probably attributable to human activity. It is anticipated that during the 21st century, the rise in the global temperature will accelerate and the precipitation will alter significantly, and to a degree depending on the region.

The global change in the climate will also influence the frequency and intensity of extreme events. There are indications that the frequency of extreme events could react extremely sensitively to climate change. This is attributable partly to physical feedback mechanisms. A further part is played by statistical effects, by virtue of which the frequency of the extremes could be affected more strongly by climate change than that of 'normal' weather phenomena (Fig. 1 illustrates the statistical sensitivity in the case of temperature extremes). This anticipated high sensitivity, taken in conjunction with the vulnerability of modern civilisation, calls for scientific forecasts of extreme events and an assessment of their significance to humans and the environment.

The present report reviews the current status of knowledge on the relationship between extreme events in Switzerland and global climate change as seen by the members of an interdisciplinary expert panel. The analysis addresses the causal chain extending from global climate change via changes in extreme weather

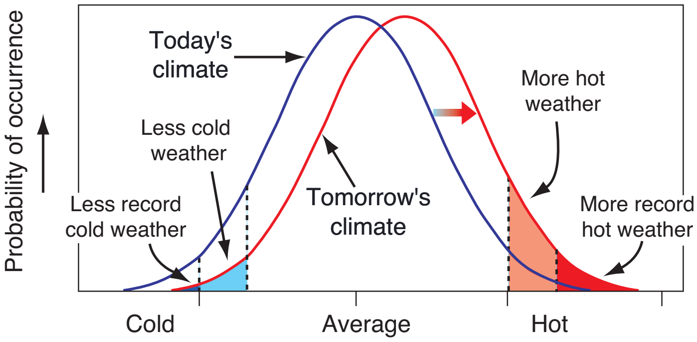

Fig. 1 Hypothetical influence of climate change on the frequency of extreme events for the example of temperature extremes.[1] The blue line shows the statistical distribution of today's temperatures. Whilst average temperatures are frequent, extremely cold (blue areas under the curve) and extremely hot (red areas under the curve) weather is seldom. The changing climate causes the average temperature and the entire temperature distribution to be shifted to the right (red line). The effects of this shift are particularly marked where the frequency of extreme events is concerned, extremely hot weather becoming much more frequent, and extremely cold weather much less frequent. For average temperatures, the relative changes are less pronounced.

conditions in the Alpine region through to changes in the resulting damage and to the economic consequences. The report seeks to adopt a differentiated approach in which aspects of natural science, possible effects on the habitat, and non-climatic influences on the level of risk (e.g. changes in use and the value of assets at risk) all play a part. It is addressed to political decision makers, the authorities, the media and the public.

The report is divided into two main parts. In the first part, the terminology used is defined, the scientific methods described (where necessary for an understanding of the results) and some of the scientific principles referred to later explained. The second part reviews current knowledge on those categories of extreme events of greatest relevance to Switzerland (i.e. temperature extremes, frost, drought, forest fires, heavy precipitation, hail, floods, mass movements, avalanches and winter storms). Where possible, and as far as this seemed reasonable, a common scheme was adopted in all sub-chapters covering the sensitivities of the respective category, conclusions drawn from changes in the past, and future perspectives.

A summary of the main results and the recommendations is given at the beginning of the report.

In total, 24 authors collaborated in the report. The contents were assessed by 7 professionals. The members of the OcCC reviewed and adopted the text at their meetings on 27 February and 28 May 2003.

1 IPCC, Climate Change 2001: The Scientific Basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, U.K., 881 p., 2001.

2 IPCC, Climate Change 2001: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, U.K., 1032 p., 2001.

3 IPCC, Climate Change 2001: Mitigation. Contribution of Working Group III to the Third Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, U.K., 752 p., 2001.

4 IPCC, Climate Change 2001: Synthesis Report. Cambridge University Press, Cambridge, U.K., 397 p., 2002.

Part 1

Scientific basis

1.1. Extreme events, natural hazards and natural catastrophes: a terminology

Roland Hohmann, Christian Pfister and Christoph Frei

Extreme events are rare events that deviate heavily from the statistical mean. They are not necessarily associated with damage. Natural catastrophes are events whose consequences cannot be dealt with by the local community. They do not necessarily result from extreme events. Natural hazards are natural processes and situations that threaten the community and the environment.

For our purposes, events will be designated as extreme if they depart markedly from an average value or trend, and are therefore exceptional. The definition of extreme events is thus based on statistical criteria. Extreme events often have negative consequences on humans and the environment. Examples of extreme events in Switzerland are the winter storms Vivian (1990) and Lothar (1999), the extreme floods in the Cantons of Uri (1987) and Valais (Brigue 1993 and Gondo 2000) and the freezing spell in 1963 when the largest Swiss lakes last froze over.

A comparison with long-term measurement series permits the rareness of an extreme event to be quantified. The rareness is expressed in terms of the return period. An event that occurs statistically every 10 years has a return period of 10 years. The present report does not define a general limit for the return period beyond which an event would be classified as extreme. One reason for this is that a meaningful discrimination would depend on the type and frequency of an event and on the size of the area chosen.

- *Type and frequency of events*
  In Switzerland, earthquakes occur more rarely than floods. An earthquake that occurs on average every 300 years is not classed as an extreme event. Furthermore, it does not result in extensive damage. A flood at intervals of 300 years is, however, an extreme event, and the probable damage is very extensive.
- *Chosen geographical area*
  Statistically speaking, an event that would be classed as extreme in the locality may be quite 'normal' for the region as a whole. In relation to Switzerland, for example, the maximum windspeed recorded during the Lothar storm was an extreme event with a return period of 20-100 years. In relation to Europe, however, it was simply a major event with a return period of significantly under 10 years.

Whilst science judges particular events on the basis of critical limits, society judges them on the basis of the material and immaterial damage arising. For example, whilst little attention is paid to an avalanche falling in an uninhabited mountain valley, should an avalanche devastate a housing area resulting in the loss of human lives, it is classed as a catastrophe.

A common characteristic of natural catastrophes is the helplessness of the local inhabitants. These do not have the resources to deal with the situation, and are dependent on assistance from outside. Examples of natural catastrophes of this sort in Switzerland are the floods of 1987 and the avalanche winter of 1951.[1] Natural catastrophes are not, however, caused by extreme events alone. They can result from events extending over a large area or occurring at short intervals. An example of the former is the occurrence of extensive bands of hail, and of the latter when melting snow and heavy precipitation coincide in spring, as was the case in May 1999.

In the connotation of the 'risk society'[2], which has developed since the early 1970s, the term natural catastrophe has been questioned on the grounds that such events must be seen as resulting partly from human activity. In the public mind, the boundaries between natural and 'technological' catastrophes have become blurred. Nature, society and technology are seen as being interrelated.[3]

In recent times, the term natural hazards has become established in the natural sciences.[4] Natural hazards comprise all processes and influences arising in nature that can endanger people and/or material assets (e.g. tornados, earthquakes, avalanches, floods and locust swarms).[5] Natural hazards therefore carry the threat of disaster, and this can be avoided under certain conditions by preventive measures. A natural catastrophe, on the other hand, is a disaster that has actually taken place.

1 Pfister C., Am Tag danach. Zur Bewältigung von Naturkatastrophen in der Schweiz 1500–2000, Haupt Verlag, Bern, 263 S., 2002.

2 Beck U., Risikogesellschaft. Auf dem Weg in eine andere Moderne. Suhrkamp, Frankfurt/M., 1986.

3 Müller U., W. Zimmermann, P. Neuenschwander, A. Tobler, S. Wyss und R. Alder, Katastrophen als Herausforderung für Verwaltung und Politik. Kontinuität und Diskontinuität. Zürich, 1997.

4 Kienholz H., Naturgefahren – Naturrisiken im Gebirge, Schweiz. Zeitschrift für Forstwesen, 145/1, 1–25, 1994.

5 BUWAL, Begriffsdefinitionen zu den Themen Geomorphologie, Naturgefahren, Forstwesen, Sicherheit und Risiko. BUWAL, Eidg. Forstdirektion. Bern, 1998.

Extreme event:	**Event departing markedly from the average values or trends, and that is exceptional. Mostly, the return period substantially exceeds 10 years.**
Natural hazard:	**The threat of disaster arising from a natural process or influence.**
Natural catastrophe:	**Natural event whose consequences cannot be dealt with by the local population without help from outside.**

1.2. Observed climate change and future trends

Urs Neu

Extreme events are closely associated with changes in temperature and precipitation, and with the frequency of events. IPCC predicts that the average global temperature at the surface will increase by 1.4-5.8°C between 1990 and 2100. Winter precipitation in central and high northern latitudes will probably increase. Intensive precipitation will most probably become more frequent.

"An increasing body of observations gives a collective picture of a warming world and other changes in the climate system." This conclusion is drawn by the Intergovernmental Panel on Climate Change (IPCC) in its Third Assessment Report (TAR).[1] The report demonstrates that the temperature increase observed over the past 50 years is principally attributable to human activity.

Climate change in the 20th century

The observed changes in the global climate during the 20th century are described in the report of Working Group I of the TAR[1] (see box, p. 18).

Extreme events are closely associated with changes in temperature and precipitation, and with the frequency of events. The average global air temperature at the earth's surface rose in the course of the 20th century by 0.6 ± 0.2°C. Globally, the 1990s probably represented the warmest decade, and 1998 the warmest year, since instrumental measurements began in 1861. The daily minimum values of air temperature over land rose between 1950 and 1993 by an average of 0.8°C. In numerous regions in central and northerly latitudes, frost-free periods have become longer. Since 1950, extremely low temperatures have become rarer and extremely high temperatures somewhat more frequent.

During the 20th century, precipitation over most land areas in central and high latitudes of the northern hemisphere has increased by 0.5-1% per decade. In the second half of the 20th century, the frequency of heavy precipitation events probably increased by 2-4%. Possible reasons for this are changes in the moisture content of the atmosphere, and in large-scale storm and thunderstorm activity. The land area affected by severe drought or floods increased slightly in the course of the 20th century.

The intensity and frequency of tropical and extra-tropical storms show no significant global trends in the 20th century. Predictions of changes in storm activity are not at present possible. No systematic changes in the frequency of tornados, or days with thunder or hail events, are evident in the limited areas analysed.

Climate trends in the 21st century

Future climatic variations may be approximately assessed using complex meteorological models. When applied retrospectively, the models are increasingly able to reproduce climate fluctuations observed in the past, so that increasing trust is now

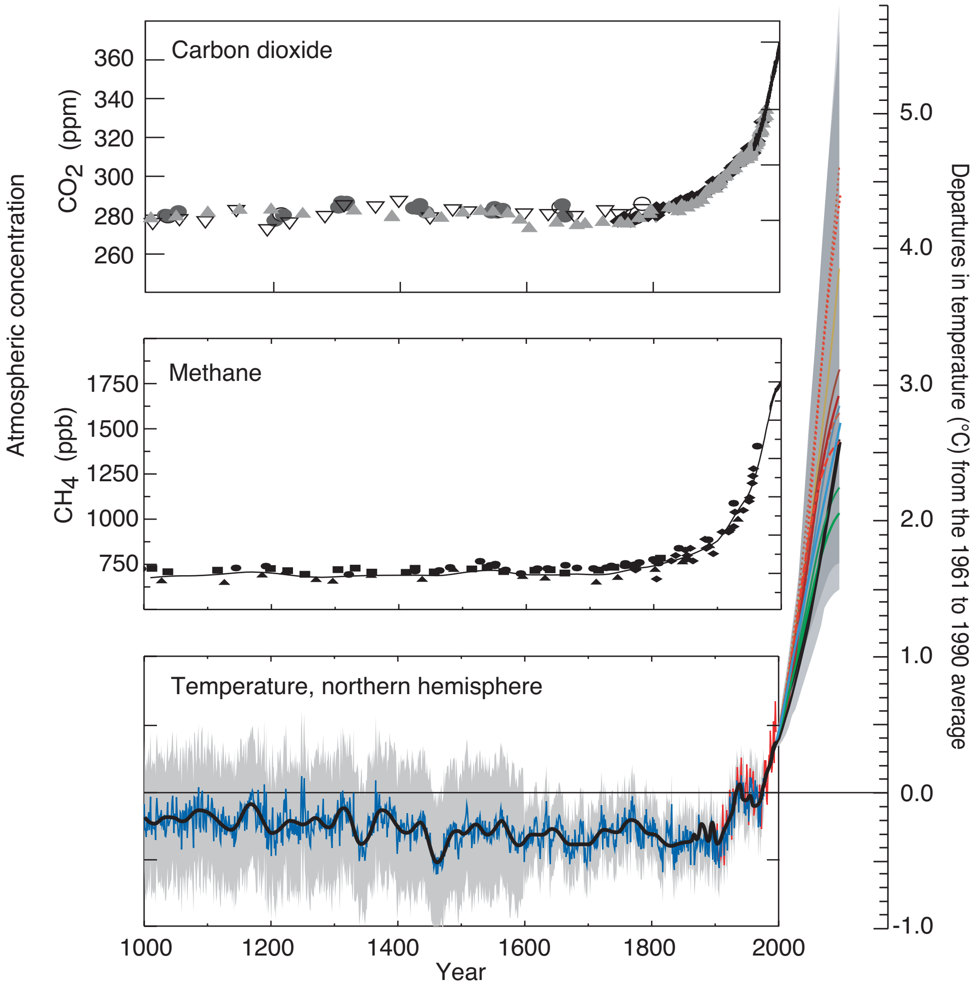

Fig. 2 The concentrations of the greenhouse gases carbon dioxide and methane have heavily increased since the beginning of the 20th century, and depart markedly from the values in the pre-industrial era. At the same time, the surface air temperatures in the northern hemisphere have increased. Climate simulations for the 21st century predict a temperature increase of 1.4°C to 5.8°C (grey area). The temperature increase will be much steeper than was observed over the past 1000 years.[1]

placed in them. In order to assess future developments, so-called emission scenarios[5] are used that specify the emission of the principal greenhouse gases and aerosols in relation to hypothetical changes in population, technology and the economy. Future trends in climate elaborated in the TAR are based on a large number of simulations and studies comparing the different analytical models.

In the period 1990-2100, the simulations show a rise in the average global surface temperature of 1.4-5.8°C. The increase in temperature will proceed significantly faster than in the 20th century (see Fig. 2), and will be above the average particularly over the continents and in high northern latitudes in winter. In general, a tendency towards higher temperature maxima, an increasing number of very hot days, higher temperature minima, less very cold days and those with frost, and lower daily temperature fluctuations above most land masses, are expected. Furthermore, the average global concentration of water vapour in the atmosphere will increase during the 21st century. Winter precipitation will probably increase in the northern hemisphere in central and northerly latitudes, and in Antarctica. In addition, larger fluctuations in precipitation are expected from year to year, and intensive precipitation events may become more frequent. The dry summer periods over the continents are expected to extend, and in central latitudes, the likelihood of drought in most inner continental areas is expected to increase.

Meteorological models are not yet sufficiently fine-mesheds to assess small-scale phenomena potentially having a substantial influence on the environment and society. Thus, for example, geographically confined phenomena such as thunderstorms, tornados, hail and lightening strikes are not simulated in the models.

IPCC reports

The Intergovernmental Panel on Climate Change (IPCC) brings together the available scientific and socio-economic information on climate change, and on methods for its mitigation and for adaptation to its consequences. It was appointed in 1988 by the World Meteorological Organisation (WMO) and the United Nations Environmental Programme (UNEP). Since 1990, the IPCC prepared a series of reports that are now standard works of reference frequently consulted by political decision makers, researchers and other experts (www.ipcc.ch).

The Third Assessment Report (TAR) comprises the reports of the three working groups of the IPCC (Working Group I: The Scientific Basis[1]; Working Group II: Impacts, Adaptation and Vulnerability[2]; Working Group III: Mitigation[3]) and the Synthesis Report[4]. Some 2500 scientists collaborated in preparing the TAR. The reports do not claim to represent the truth as such, but rather aim to present the present status of knowledge in the form of a consensus among the scientists involved. Attention is expressly drawn to any controversy existing on particular issues.

1 IPCC, Climate Change 2001: The Scientific Basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, U.K., 881 p., 2001.

2 IPCC, Climate Change 2001: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, U.K., 1032 p., 2001.

3 IPCC, Climate Change 2001: Mitigation. Contribution of Working Group III to the Third Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, U.K., 752 p., 2001.

4 IPCC, Climate Change 2001: Synthesis Report. Cambridge University Press, Cambridge, U.K., 397 p., 2002.

5 IPCC, Special Report on Emissions Scenarios. Cambridge University Press, Cambridge, U.K., 514 p., 2000.

1.3. Extreme events in Switzerland

1.3.1. Classification of extreme climatological events

Heinz Wanner

The principal extreme events in Switzerland may be classified based on their relationship to characteristic weather conditions. The horizontal transport of air masses, and with these the large-scale wind currents, are responsible for the occurrence of extreme values of temperature, humidity and precipitation. In winter, large-scale pressure differences are responsible for storms and thunderstorms, and in summer, more local effects such as soil moisture and atmospheric stability are important. Floods result from the interaction between the atmosphere, surface characteristics and the topography.

A possible approach to the classification of extreme events is to analyse the weather conditions accompanying them, together with the way an event is manifested and its effects in a particular area. The extreme climatological events occurring in Switzerland may be classified as summarised in Tab. 1. As the extreme events affect areas of varying size, their geographical extent is also given. Events consequent on these such as avalanches and landslides have not been included. Needless to say, a schematic representation of this kind has its limitations, since in the case of extreme events, quite different processes are often involved that may reinforce one another, or, when following one another at short intervals, have a cumulative effect. Although this enables specific cases to be grouped, a more precise analysis very often reveals individual differences.

The climate in any particular region is determined by the interaction of large-scale air currents (i.e. atmospheric circulation), local topography and surface characteristics. The climate in Switzerland is determined to a large extent by the westerly airflow over the Atlantic and Europe. The state of the ocean surface (e.g. regarding currents, surface temperature and distribution of floating ice) also plays an important role through its influence on the principal migration paths of the low-pressure areas (storm tracks). Also of great significance is the land-sea distribution (Atlantic Ocean, Mediterranean Sea and Eurasian Continent) and the topography of the Alps. The altitude and form ('crescent') of the latter modify the direction and characteristics of the air masses. In this way, extreme events such as intensive downhill winds (e.g., föhn), inner Alpine droughts (in Valais) and cyclone formation on the lee side of the Alps (lee or Genoa cyclones) are generated.

For the arising of extreme temperatures and precipitation (Tab. 1, upper part), the horizontal displacement of the air masses (advection), which is driven by the large-scale circulation, is decisive. In this, it is important to know where the air masses originate from, how their temperature and humidity change on their journey to Switzerland, and how fast they traverse Swiss territory. The long-term influence of natural factors (sun, volcanoes), anthropogenic influences (greenhouse and aerosol effects, and surface changes) and incidental fluctuations in the climate system on continental and regional circulation patterns and on the frequency of extreme temperatures and precipitation is still unclear.[1,2]

Depending on the time of year, either the large-scale pressure differences (particularly in winter) or more local effects such as atmospheric instability and ground humidity (particularly in summer) are important in the development of storms and thunderstorms (Tab. 1, middle part). Air masses can store energy either directly in the form of sensible heat or indirectly in the form of humidity. The energy stored in water vapour is released again on condensation. This so-called latent heat of condensation is an important source of energy for hurricanes, and these can only occur above warm surface water at a sufficiently high rate of evaporation. In Switzerland, direct and indirect heat flows are significant both on the large scale (in particular for storms arising over the West Atlantic) and regionally (in the case of summer thunderstorms).[3] Winter storms such as the Lothar hurricane result from very complex phenomena.[4]

The situation is particularly diverse in the case of floods (Tab. 1, lower part). These result from the interaction between the atmosphere, sur-

Table 1: Classification of the most marked climatological extreme events in Switzerland based on characteristic weather constellations.

Extreme event	Winter	Summer
Weather elements:		
Temperature	**(a) Cold and dry** Persistent cold air current as a result of the continental Siberian surface anticyclone. *frost and drought damage* ***Scale: semi-continental***	**(b) Hot and dry** Influence of heat and drought in the subsidence zone over the Azores high-pressure area impinging on the continent. *heat and drought damage* ***Scale: semi-continental***
Precipitation	**(c) Cold and humid** Persistent north-westerly current *heavy snowfall, avalanches* ***Scale: regional***	**(d) Cold and humid** Low-pressure areas drifting from the North-West to the South-East *damage to vegetation* ***Scale: regional to semi-continental***
Storms/ thunderstorms	**Strong pressure gradients, partly containing secondary vortices** *storm wind, gusts, hurricanes* ***Scale: regional to semi-continental***	**Weak pressure gradients, heat lows, thunderstorms** *heavy rain, hail, gusts* ***Scale: local to regional***
Floods	**Northern Alps:** Tendency towards persistent south-westerly, westerly and north-westerly flow situations with tracks of the low pressure systems lying to the South. Advection of warm and very humid air that rises under extreme convection conditions leading to heavy and persistent precipitation. May be combined with temperature increase, melting snow, and in rare cases with blockage effects at the Alps. (Occurrence: hot months, spring and autumn, predominately in spring to early summer) *massive flooding of valley and lake country* ***Scale: regional to semi-continental*** **Southern Alps and inner Alpine region** Combination of inflow of air masses, extreme upward airflow (induced both by air mass movement and Alpine topography) and subsequent rainfall. Southern Alps: predominant southerly Alpine inflow (particularly for low-pressure areas passing to the South), often in conjunction with the phenomenon of high-tropospheric 'streamers'. Inner Alpine region: also in conjunction with stationary low-pressure troughs. (Occurrence: cooler months, spring and autumn, predominately in autumn) *massive flooding of valley and lake areas* *Inner Alpine: triggering of extreme hydro and geomorphologic events causing damage such as mass movements and debris flows.* ***Scale: local to large-scale regional***	

face characteristics and the topography. In mountainous areas, an important role is also played by rising air masses and subsequent precipitation from these, resulting both from large-scale movements and from air currents in the entire troposphere. Of somewhat lesser importance is the triggering of precipitation through air rising on collision with the Alpine topography.[5] Long-enduring and heavy precipitation can saturate the ground with water, and in some cases lead to regional or large-scale floods when combined with melting snow in the Alpine region. In central European areas to the north of the Alps, the migration paths of the low-pressure areas must be considered. Deviations of these to the south occur especially with negative North-Atlantic Oscillation (i.e. when the North Atlantic is warm and the South Atlantic cold), leading to long-enduring south-west to north-west flow situations.[2] In some cases, cold cut-off lows occur that remain for days above a region, leading to extensive precipitation periods. In addition to the lee-side formation of low-pressure areas already mentioned, particular attention must be paid to low-pressure areas south of the Alps that migrate slowly from the Atlantic via the Mediterranean towards the eastern fringe of the Alps and then on to Poland.

1.3.2. A calendar of the last 500 years

Christian Pfister

Our capacity to identify trends in extreme anomalies from instrumental measurements is limited owing to the short periods over which data have been recorded and also to the rareness of these events. To extend the available data base, recourse may be had to historical documents.[6] The most conclusive information on extreme events is available for the period from approx. 1100 to 1800. In fact, for this period, natural disasters can only be identified through reports in historical documents: the more extraordinary and the more extreme an event, the more numerous and exhaustive the available reports.

Contrary to 'natural archives' such as the tree rings, which only permit conclusions on anomalies for certain parts of the year, documents from 'human archives cover all seasons and calendar months. The documents cite the date, and often the hour, of the events. To express the magnitude of an anomaly, observers often made use of easily identifiable natural indicators, and today these may be quantified and calibrated on the basis of analogous events. Following a very cold March and April, cherries, for example, blossom three weeks too late. On current knowledge, this corresponds to a general temperature deficit of 5°C.[7]

Single documents only cover a limited period of time, are heterogeneous, and mostly contain gaps. Alone, they are usually not quantifiable and cannot therefore be statistically evaluated. To obtain conclusive results, as many reliable sources as possible must be brought together. In this way, the data may be checked and complemented. In Switzerland, approximately 40 000 individual observations from some 350 sources were brought together for the period 1500 - 1864.[6,8] In the period following 1550, reports on the weather and/or observations of natural indicators are available for 99% of all months.

Monthly temperature and precipitation data are assigned to a seven-part intensity index. The resulting index series are then compared with those of neighbouring regions. These carefully prepared index series correlate almost as well as instrumental measurement series.[9]

Based on the classification of extreme events given in Chapter 1.3.1, a selection of extreme anomalies in Switzerland is shown below for the last 500 years.[6] In this chapter, the time series are characterised based simply on periods with frequent or less frequent reports of extreme events. Whether the fluctuations shown are incidental, or whether they indicate real changes in the probability of occurrence, cannot be decided owing to the rareness of the events (cf. Chapter 1.4).

Cold and dry in winter

Between 1496 and 1566, no cold or dry anomalies occurred, and in the subsequent 110 years they were very seldom (Fig. 3). Between 1676 and 1895, their frequency rose. One to eight cold and dry months with a persistent cold air current from the Siberian ground anticyclone were identified in all decades of this period. For people living in the 18th century, full ice cover of Lake Bienne was not exceptional. Between 1895 and January 1963 (complete freezing over of Lake Zurich), the cold and dry months became much

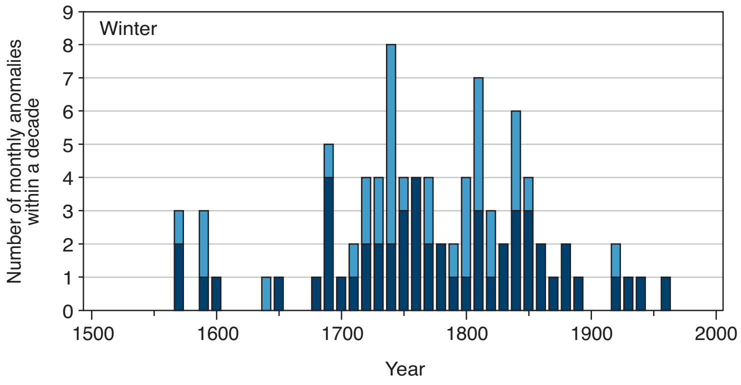

Fig. 3 Frequency of cold (dark blue) and cold-and-dry (light blue) months in winter (November-March/April) from 1496-2000 (10-yearly sums).

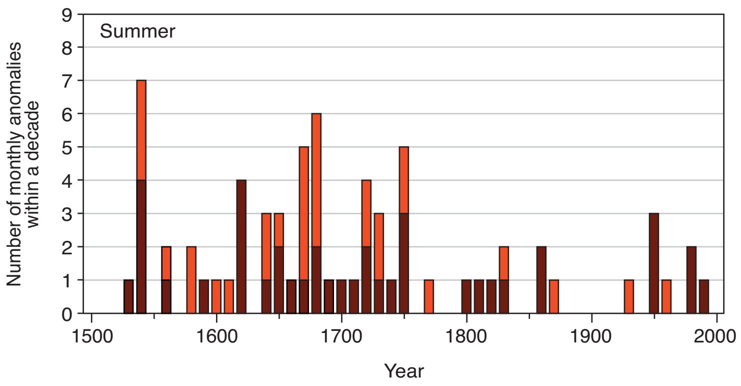

Fig. 4 Frequency of hot (dark red) and hot-and-dry (red) months in summer (April-September) from 1496-2000 (10-yearly sums).

less frequent, and since then have ceased altogether (as of March 2003).

Cold and wet in winter

It is known that several days of intensive northwesterly weather may lead to a large number of avalanches causing losses. However, such weather conditions are not apparent from the average monthly figures for temperature and precipitation. Therefore the above index series do not represent an adequate statistical tool.

The winters in which avalanche damage occurred are fairly evenly distributed over time, and do not occur more frequently in the 20th than in previous centuries.

Hot and dry in summer

Hot and dry months were significantly more frequent prior to 1730 than afterwards (Fig. 4). Between 1718 and 1728, every second summer was significantly too dry. Although there was no century-wide meteorological extreme in these years (as for example in 1540 and 1947), the cumulative effects of the events in 1718/19 and 1723/24 were equivalent to this. In these years, consecutive dry summers interspersed by a lack of rain in winter and the early part of the year occurred.

In the 20th century – with the exception of the decade 1946-1955 – hot and dry months occurred relatively infrequently during the vegetation period.

Cold and wet in summer

Prior to 1880, when the Swiss economy gained access to the international transport network, cold and wet summers and the resulting damage to vegetation led to price increases, supply shortages and occasionally to famine (e.g. 1816/17). Between 1576 and 1635, cold and wet summer months were particularly frequent, and the glaciers grew. Since then, extreme events of this kind have become rare.

Storms in winter

In the 20th century, the statistical tendency in the northern Alps shows a reduction in the number of storm days, and a diminution in the duration of wind strengths between 7 and 9, in the winter months.[10]

Between 1500 and 1960, whilst most of the storms occurred in December, the most extreme amongst them occurred in January and February. Also, there were repeated periods without heavy storms (Fig. 5). Between 1600 and 1900, the Central Lowlands were affected every century by a record storm. These storms all arose in winter from westerly directions and devastated forests, buildings and infrastructure over large expanses. In the 20th century, three record storms were recorded in the space of only 33 years: in February 1967, February 1990 (Vivian) and

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December 1999 (Lothar). As events of this kind are very rare, no long-term statistical trend can be identified.

Floods north of the Alps

In the Central Lowlands, most of the floods occur in early and midsummer when the melting rate of snow in the mountains is large and the highest rainfall occurs over substantial parts of the catchment area.

Up to 1882, the Rhine in Basel overflowed its banks on average every 10 years (Fig. 6). This frequency dropped in the course of the next 120 years. Between 1882 and 1992, extreme floods were entirely absent. However, this development cannot be attributed solely to meteorological and hydrological factors, since the runoff conditions altered in the course of the last 120 years by virtue of structural intervention.

Floods in the central Alps and to the south of the Alps

In the four Cantons of Valais, Uri, Ticino and Grisons, two periods of low flooding frequency (1641-1706; 1927-1975) and two periods of high flooding frequency (1550-1580; 1827-1875) may be identified in the course of the last five centuries (Fig. 7). Long-term fluctuations in the frequency of flooding have also been identified in the Pyrenees and in Germany.[11] These are the result of natural climate variations and have no identifiable connection to human activity.

Contrary to the average values pertaining in the 20th century, the number of extreme floods occurring in the inner and southern Alps has increased over the last 15 years (August 1987, September 1993, October 2000), whereby, however, the frequency of these events still lies within the range of previous occurrences.

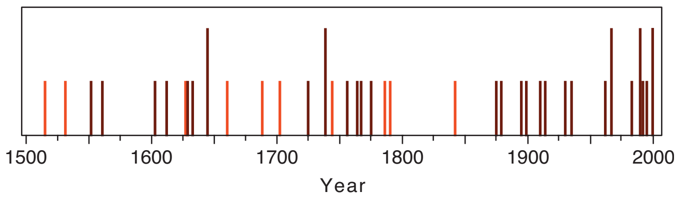

Fig. 5 Heavy (short bars) and extreme (long bars) winter storms in Switzerland over the last 500 years. In some cases (orange), the historical data are indecisive.[6]

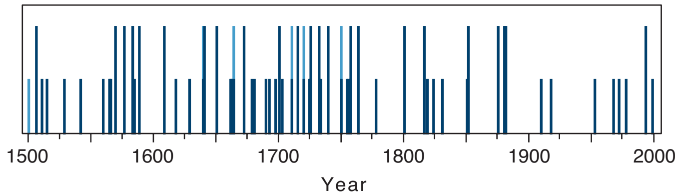

Fig. 6 Heavy (short bars) and extreme (long bars) flooding of the Rhine at Basel over the last 500 years. In some cases (light blue), the historical data are indecisive.[6]

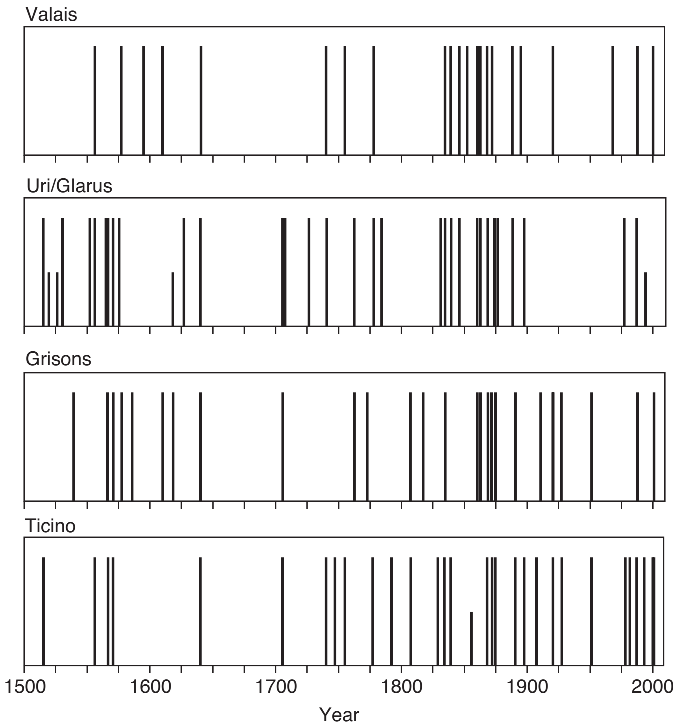

Fig. 7 Heavy (short bars) and extreme (long bars) flooding events in the four cantons in the region of the St. Gotthard Pass, i.e. Valais, Uri, Ticino and Grisons, over the last 500 years. Extreme floods are defined as those that caused damage in at least two Alpine valleys and/or in neighbouring countries.[6]

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1.4. The identification of trends has its limitations

Christoph Frei

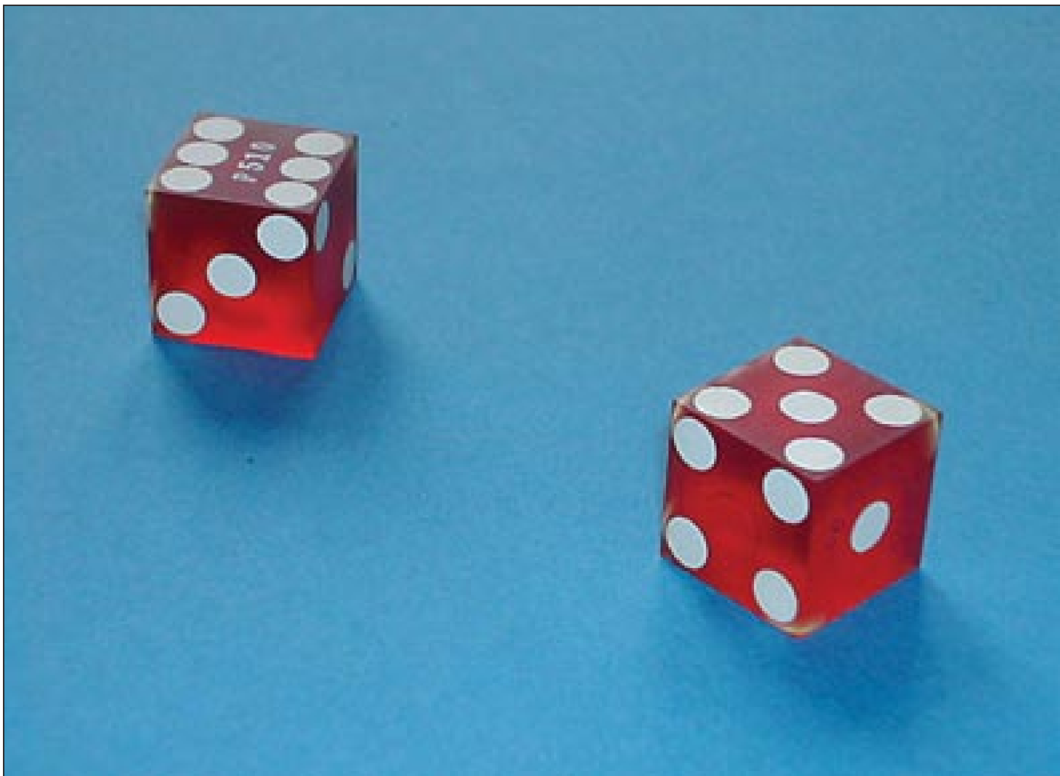
For extreme events, the identification of trends meets with fundamental limits. The more seldom an event, the more difficult it is to establish a trend. Small changes in the frequency of very rare events are masked by natural climatic variations. The apparently more frequent occurrence of extreme events in recent years could either represent a real trend or be incidental. Thus extreme events are unsuitable indicators for assessing global climate change.

With its avalanche winter, Whitsun floods, summer thunderstorms with hail, and the Lothar winter storm, 1999 was an exceptional year seen in the context of the previous 30 years. In 1999, Switzerland suffered a record number of climate-related natural catastrophes of national importance. Is this an unnatural concentration of events – or perhaps even a sign of global climate change? What can the long-range instrument recordings tell us about this?

The most extensive series of climatic measurements in Switzerland go back to the early 19th century (e.g. Great Saint Bernhard Pass up to 1818). Coordinated meteorological measurement networks with substantially comparable measurement equipment were built up in the second half of the 19th century. Uninterrupted measurement series are available from these on a daily basis for some 100 stations at which the precipitation, and for 30 stations at which the temperature, was measured.[1,2] The data basis is less satisfactory for other observed quantities. Thus 100-year measurements of windspeed only exist for three stations (Bern, Basel and Zurich). Also, the numerous instrumental changes and those in the location of stations make it difficult to eliminate non-climatic effects (homogenisation) from the data.[3] However, in recent years intensive processing has enabled high-quality data series to be prepared for Switzerland. These dispose of the necessary temporal and spatial resolution, enabling long-range variations and trends in extreme events resulting from temperature and precipitation conditions to be examined.

Despite the generous data basis, the identification of trends in extreme events meets with fundamental limitations. These are given by the infrequency of the events and by the concomitant statistical uncertainty. To identify a trend, an assessment must be made as to whether the sequence of events observed results from a systematic change (i.e. signalises a trend) or from incidental causes (i.e. 'background' fluctuations of the climate). The rarer (extremer) the events, the more uncertain the distinction between signal and background fluctuations. The situation is comparable to that of a dice player who is required to decide whether his/her dice are loaded using only a few throws.

The limits of identifiability of trends in extreme events may be estimated theoretically. Thus for events with a return period of one year, a trend could only be identified if the probability of the event occurring during the century had



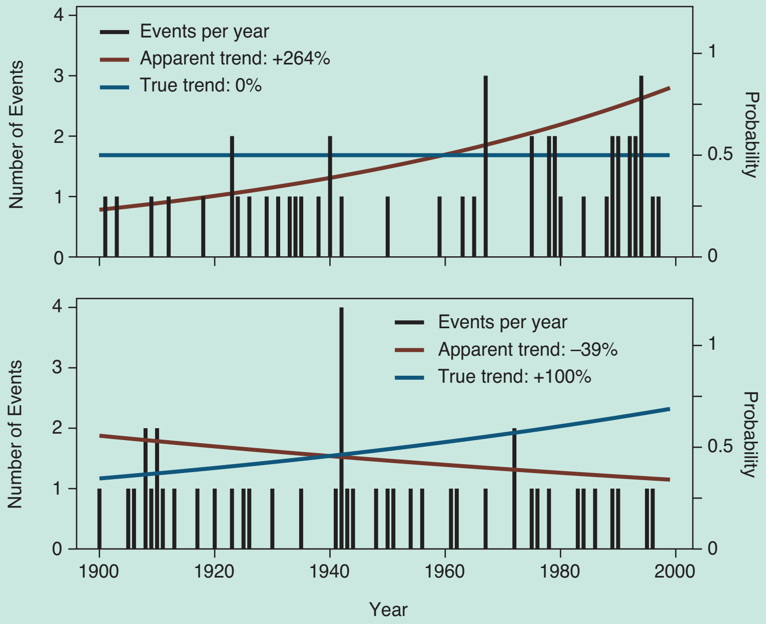


Fig. 8 Artificially generated time series of events in the 20th century. In the upper figure, constant probability of an event occurring was specified (blue line). The random bunching of events at the end of the century feigns an increase in probability of over 250% (red line). The opposite effect is shown in the lower figure, in which doubling of the probability of an event was specified (blue line). The chance distribution of the events leads to the erroneous conclusion of a decrease in the probability of an event by 39% (red line).

Concealed, delusive or true trend?

Owing to the infrequency of extreme events, trends may only be established very imprecisely. In fact, chance bunching of such events at the beginning or end of an observation period can feign a trend that is in reality nonexistent ('delusive' trend). In contrast, a real trend can be masked to such an extent by chance variations that statistical analysis of the measurement series is unable to identify it (concealed trend).

Fig. 8 illustrates possible false conclusions from trend analysis. The figure shows artificially generated time series of extreme events over a 100-year period (number of events per year shown in black, referred to the left-hand ordinate). In the top example, it was specified in generating the series that the probability of an event (blue line, right-hand ordinate) is constant, i.e. that no real trend exists. On average, one event occurs every two years. However, the calculated trend for the data sequence shown (red curve) implies an increase in probability of greater than 250% over the 100 years. This 'delusive' trend results from the chance bunching of events at the end of the period. The same would apply if random bunching had occurred at the beginning of the time period, leading to the erroneous conclusion of a declining trend.

In the bottom example, it was specified in generating the time series that the probability should double over the 100 years (blue curve). However, the sequence of events so generated hardly reproduces this requirement owing to the fact that, contrary to the 'true' trend specified, a chance bunching of events has occurred at the beginning of the period. The statistical analysis of this time series in fact shows a decrease of approx. 40% (red curve). Here, the 'true' trend is concealed and is therefore not identified. The more seldom the events examined, the lower the chance of identifying a real trend.

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at least doubled.[4] For events of the severity of those in 1999, with return periods from 10 to over 100 years, changes of several times would be necessary. Weaker trends are concealed by background fluctuations of the natural climate.
The problem of identification may influence both scientific research and the public debate on the relationship between climate change and extreme events in several ways:

(a) The apparent concentration of extreme events in recent years could either indicate a real trend, or simply be a delusive trend resulting from random factors. For statistical reasons, precise conclusions cannot at present be drawn on these very rare events.

(b) Extreme events are unsuitable indicators of global climate change. Though the attention given in the media to the climate problem whenever extreme events occur suggests a relationship, this can neither be proven nor disproven. There is therefore a danger that in periods with frequent extreme events the climate problem will be dramatised in the public mind, and in periods with less frequent events be seen as harmless (possibly unjustifiably).

(c) Conclusions on trends during the measurement period are based on an assessment of intensive events not necessarily leading to damage. Thus for intensive precipitation having an average return period of 30 days, a significant increase in winter and autumn of 20-80% was found.[4] In the northern part of the Central Lowlands, this is clearly distinguishable from the random fluctuations. However, the results for intensive events cannot simply be applied to extreme events. Furthermore, the trends alone do not represent proof that the climate change is of human origin: this may also be attributable to natural long-term climate variations. They cannot therefore be simply extrapolated into the future.

(d) Predictions on future changes in the probability of very seldom extreme events are of very limited use, at least at the regional level. Even fairlysubstantial future changes can be masked by the random component. A possible increase in the risk following from global climate change will not necessarily manifest noticeably in the decades to come. Irrespectively of this, technical measures for protection against higher risks can have useful effects within shorter periods. As an example, the measures taken in Brigue following the floods of 1993 proved very effective in autumn 2000, when flooding again occurred.

(e) The isolated analysis of long-term observations is not sufficient to gain a deeper understanding of the relationship between climate change and extreme events. Rather, scientific progress must be sought in a better understanding of the climate mechanisms, to which numerical climate models are making an important contribution.

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1.5. Regional climate scenarios

Christoph Schär, Heini Wernli and Christoph Frei

Global climate models covering the relevant processes in the atmosphere, the oceans, the ice shields and the land masses may be used to define average climatic conditions. The effects of global climate change are felt, however, at the regional and local levels. Whilst the global average temperature increase is certainly an excellent indicator of global warming, it provides a poor basis for assessing the consequences of climate change. To provide explicit data on the frequency of extreme events in the various regions, regional climate scenarios are required

Extreme events in the Alpine region result from a whole series of processes and events within the climate system. Thus the effects of climate change on the frequency of extreme events are very difficult to assess. The following questions are critical: how does atmospheric circulation react to the warmer climate and how do the migration paths of the low-pressure areas change? How does the frequency of the relevant large-scale weather patterns change and what influence does this have on extreme events? What influence will the rise in humidity that is associated with atmospheric warming have on the future precipitation regime and on the frequency of storm depressions? How does this affect the geographical and seasonal distribution of heavy precipitation and droughts? How does the rising snowline affect the runoff in rivers and lakes, and how does it affect the frequency of floods and low water? All of these factors, which apply on quite different geographical scales, must be taken into account in generating regional climate scenarios.

Global climate models

Today, a wide range of analytical models is used in climate research.[1] Depending on the problem at hand, they may include different components of the climate system (atmosphere, oceans, ice shields, land surface) and cover different regions (whole earth, continents, regions). Common to all these models is a three-dimensional computational grid, to which the physical equations of the atmospheric and oceanographic currents are applied, and then used to predict future developments.

The first global climate models were developed when high-performance computers became available for weather forecasting purposes in the 1960s. Originally, they were restricted to simulating atmospheric circulation. For climate calculation purposes, these models were gradually extended by additional components of the climate system (oceans, ocean and continental ice, land surface and biosphere). Further, the calculation of climate-relevant processes (e.g. cloud formation) was constantly improved.

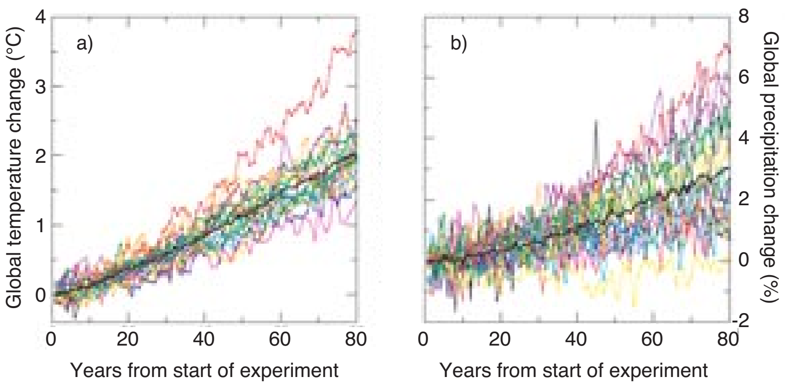

Fig. 9 Comparison of global coupled climate models for a greenhouse gas scenario assuming an increase in the greenhouse gas concentration of 1% per year.[1] The results show changes relative to the average for 1961-1990 for (a) global ground temperature and (b) global precipitation.

Global climate models are applied to scenarios describing trends in atmospheric greenhouse gas and aerosol concentrations, permitting the long-term effects on the global climate to be estimated. At present, the results obtained from the climate models are still subject to large uncertainty. This is illustrated in Fig. 9 for a greenhouse gas scenario, in which several different coupled climate models are compared. An equivalent annual average increase in

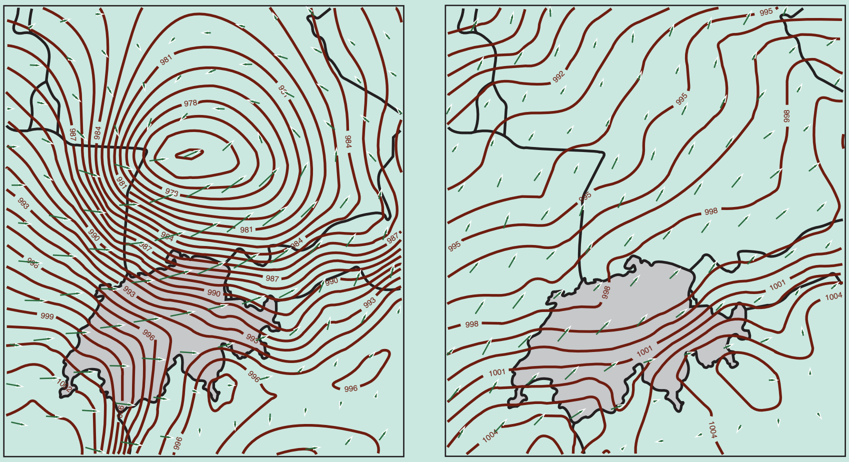

Fig. 10 Sensitivity experiment on the Lothar storm.[2] The figure shows the reduced pressure at the ground (red lines spaced at 1 hPa) and winds at the ground (green arrows) for a simulation including all precipitation processes (at left) and for a simulation excluding condensation of water vapour (at right). The sensitivity experiment shows that the Lothar storm depression was caused to a large extent by precipitation processes.

Lothar – a process analysis

Our knowledge of the key processes and causal chains leading to extreme events is still very incomplete. Further progress may be made through detailed case studies of individual weather events, sensitivity experiments with computer models, field experiments and detailed analysis of trends and fluctuations of the relevant climatic elements. An example of the use of sensitivity experiments on a weather model is illustrated in Fig. 10. Experiments of this sort permit specific analysis of selected causal chains. The present case investigates how the condensation of atmospheric water vapour influenced the low-pressure Lothar storm. This involved a so-called control simulation (Fig. 10, at left) that describes the phenomenon of interest as precisely as possible. Finally, the simulated processes can be modified experimentally. In the present case, the condensation of water vapour was suppressed. A comparison of the experiment (Fig. 10, at right) with the control simulation shows the major role the condensation and precipitation processes played in generating the storm. Thus for the simulation in which condensation was suppressed, the storm depression does not occur. This demonstrates that the precipitation processes in the atmosphere may potentially have a large influence on the frequency of storm depressions. However, no scenario-type conclusion on the frequency of storm depressions is drawn, since this would also depend on numerous other factors.

Heini Wernli

CO_2 of 1% was assumed. Where the global air temperature at the ground is concerned, the calculations show good agreement between the various models. However, in the case of global average precipitation, the scatter is very large. The predicted consequences for sub-global areas (e.g. individual continents) and for the frequency of extreme events (e.g. floods and droughts) are subject to even greater uncertainty.

Because of the extreme calculation times required by the ever more complex analytical models, global scenarios will be restricted in the next few decades – and despite the availability of modern super computers – to a relatively coarse calculation grid. At present, the highest possible numerical resolution for coupled atmospheric and oceanographic models is around 300 km.

Estimating regional effects using concatenated models

Though the causes of the climate problem are of global extent, their regional effects can differ sharply. Thus global average values are not adequate to quantify the potential hazard at the regional level. Thus, for example, although average global precipitation is not expected to change by more than a few percent (see Fig. 9b), seasonal and regional changes of up to ten times this value are expected. Moreover, in some regions (e.g. in Mediterranean areas), the global models show a decrease in precipitation (that is, contrary to the global increase), and this could possibly have a wide-ranging influence on the frequency of summer droughts.

It is clear from this that high computational resolution is essential for estimating the influence of human activity at the regional level. This can either be achieved with high-resolution atmospheric models, with regional climate models, or using global climate models of variable resolution.[3,4,5,6] Concatenated models are often used in order to encompass multiple phenomena of varying horizontal scales. This procedure is described as 'numerical regionalisation'. An example is shown in Fig. 11. This permits calculations of wide-scale climate change to be refined, and – in the present case – to calculate hydrological circulation at the regional level. The case shown comprises a total of five models, namely two global climate models, two regional climate models and one regional runoff model. The last of these is used to simulate the runoff hydrology in the Rhine catchment area to estimate changes in the probability of large-scale flooding.

The precision of models connected in this way depends on that of each individual model. A fine-mesh model cannot correct errors in the wide-scale model 'driving' it, but merely refine the continental climate patterns of the latter. To simulate extreme events, which often depend on small-scale effects and are influenced substantially by the topography, high-resolution techniques are of central importance.[8,9] Thanks to their higher resolution, regional models are better able to represent critical events such as heavy precipitation and storm depressions than the global models. The technique of numerical regionalisation was applied to various categories of extreme events, such as heavy precipitation[10] and hurricanes[11]. The process knowledge necessary for establishing the models is refined and monitored by field experiments, case studies, theoretical analyses and laboratory experiments (see box: Lothar – a process analysis).

Statistical regionalisation

The time expenditure involved in spatially refining climate scenarios using regional or high-resolution global climate models is very great. Thus in meteorological science, in addition to the numerical models, alternative methods of regionalisation are used. These are subsumed under the term 'statistical regionalisation' and are based on a quantitative model of the relationship between regional climate variables (e.g. precipitation in Davos) and large-scale properties of the atmosphere (e.g. distribution of air pressure in Europe and over the North Atlantic). This relationship is determined empirically, i.e. based on past meteorological observations, and then applied to predictions of the future climate obtained from global climate models. The mathematical formulation of the models is based on statistical methods or a combination of statistical and numerical procedures.[12,13]

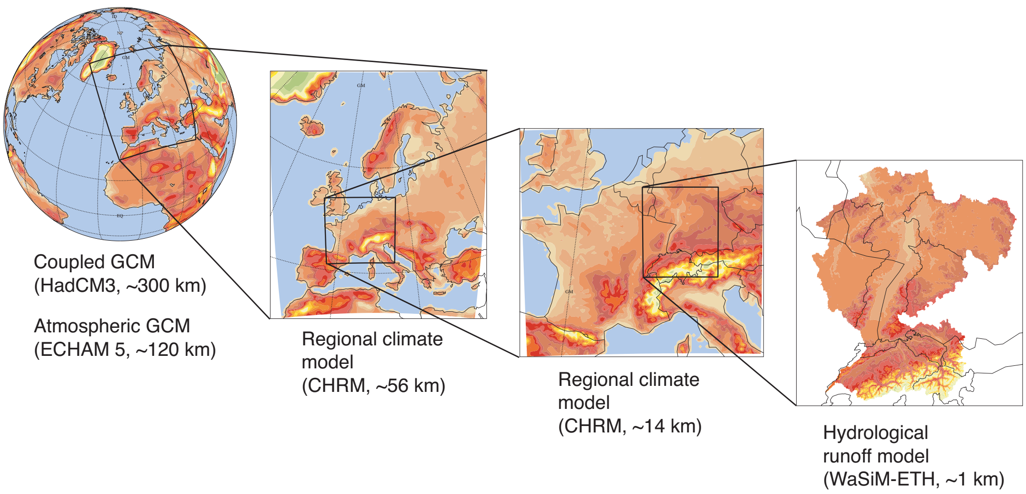

Fig. 11 Concatenated models for the simulation of regional climatic effects.[7] These comprise several coupled models with increasingly fine horizontal resolution. Note the improved representation of the topography achieved with this method.

The simpler mathematical formulation of the statistical methods permits the regional climate scenarios to be derived with comparatively small computational effort. These procedures are therefore used mainly for estimating the uncertainty of scenarios (e.g. by application to a large number of different global climate models[9]) and for regionalisation to very small scales (e.g. application to the results of regional climate models).

A statistical formulation of this kind can only function correctly when the empirical relationships used remain unchanged. Statistical and numerical climatic regionalisation represent techniques that complement one another. By comparing the results of both methods, useful information on their reliability, and finally of the plausibility of the regional climate scenarios, may be gained. In addition to application to average climate variables, various statistical procedures have been developed in recent years for the regionalisation of extreme events.[14,15,16]

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Is the global hydrological cycle accelerating?

The hydrological cycle is driven by the short-wave (solar) and long-wave (atmospheric and terrestrial) radiation flux at the Earth’s surface. The resulting energy yield is termed 'net radiation balance'. This is input directly to the climate system to heat the atmosphere (approx. 20%) and evaporate water (approx. 80%). Therefore the energy balance at the Earth’s surface depends more on vapour transfer than on heat transfer. This leads via condensation processes to warming of the lower and central troposphere.

An increase in the atmospheric greenhouse gas concentration leads primarily to a rise in the radiation energy impinging on the Earth’s surface. Since this energy is consumed mainly by vaporisation, it leads both to global warming and to global humidification of the atmosphere. This is termed 'acceleration of the hydrological cycle'.[1] An acceleration of the hydrological cycle could have a major influence on weather systems, the distribution of precipitation and the occurrence of extreme events.

The most important parameters involved in the atmospheric hydrological cycle are evaporation and precipitation. Owing to the fact that the atmosphere only absorbs small quantities of water in the form of water vapour, cloud droplets and ice crystals (on a global average, the atmospheric water content amounts to a manometer head of 26 mm water), the global average evaporation is equal to the global average precipitation. An acceleration of the global hydrological cycle would thus affect evaporation and precipitation to the same extent.

Observations of the hydrological cycle over the last 100 years

The long-term observations of precipitation and evaporation are restricted almost entirely to land-based measurements using totalisers and evaporation pans. The oceans, which account for 71% of the Earth’s surface, are thereby under-represented.

Observations are available for the past 100 years from thousands of totalisers in all continents. They show a slight increase (1%) in the average global precipitation on the land since the beginning of the last century.[2,3] The increase in precipitation is particularly marked in central and high latitudes of the northern hemisphere (between 40°N and 80°N), where precipitation on the land has increased by 8%.[4] The increase particularly affects the Alpine region.[5] Contrary to this, decreasing precipitation was observed in the subtropics.

As opposed to measurements of precipitation, long-term observations of evaporation are restricted mainly to stations in the former Soviet Union and in North America. However, the evaporation pan used for this does not record the real evaporation but merely the hypothetical evaporation above a surface saturated with water.[6] The real evaporation is heavily influenced by local factors (water content of the ground, vegetation), and it is therefore questionable whether measurements using evaporation pans are suitable for determining global evaporation. Over the past few decades, they mainly (but not exclusively) show a decrease in total evaporation.[7] The discrepancy between the measured global increase in precipitation and the decrease in the evaporation is referred to as the 'evaporation paradox'. Various attempts have been made to explain this paradox, for example as being an inherent feature of the measurements[8,9], or as a consequence of increasing cloud cover or aerosol concentration[10,11].

Results of climate simulations

In accordance with the above-mentioned physical processes, most global coupled climate simulations indicate an acceleration of the hydrological cycle. Most of the scenarios contained in the latest IPCC report show an increase in global average precipitation as a result of the increase in greenhouse gases.[12] For all models and all categories of scenario, the results show an increase in precipitation in the tropics and in central and northerly latitudes. In the subtropics, they tend to show a decrease. These results are qualitatively consistent with the hypothesis of an accelerated hydrological cycle, and the regional differentiation of the increase in precipitation accords with the precipitation trends over the past century. The large deviation between the various models shows, however, that certain mechanisms of the hydrological cycle are still not fully understood and are not therefore adequately represented in the climate models.[6] Owing to the energetic dominance of evaporation over warming, an acceleration of the hydrological cycle must be expected for increasing greenhouse gas concentration, at least in the longer term. This is also supported by observations and simulations of the present-day climate. Although there are significant deviations between the various sources, there is a clear correlation between the net radiation balance at the Earth's surface and the global average evaporation.

Christoph Schär and Atsumu Ohmura

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1.6. Extreme events from the human standpoint

1.6.1. Influence on risks and losses

Armin Petrascheck

In the natural sciences, natural events are assessed on the basis of physical parameters. From a human standpoint, however, the question of losses dominates. Losses arise from a conflict between forms of land use and natural processes. In Switzerland, the extent and frequency of the losses is influenced at present much more by anthropogenic factors such as changes of use and economic growth than by the comparatively slow process of climate change.

Risk

While the term danger signifies the likelihood of suffering losses, the term risk includes both the potential losses and the probability of their occurrence. A high level of risk is usually understood to mean large-scale losses at very low probability of occurrence. For natural dangers at the local level (e.g. floods, avalanches, landslides and rock falls), whilst the likelihood of their occurrence remains uncertain, the extent of the losses can usually be satisfactorily assessed. Where the risk of atmospheric warming is concerned, the situation is precisely the reverse. Here, the likelihood of occurrence is very high and the extent of losses very uncertain or unknown.

Losses as a result of dynamic factors

Losses result from a conflict between a natural event and anthropogenic land use . The more intensive the arising impact, and the more vulnerable and valuable the land use, the greater the losses. The question of human influence on the natural event itself is treated in Chapter 1.6.2.

For losses to occur, the natural dangers involved must accord with certain criteria. As an example, the chain of interactions leading to losses through floods is shown in Fig. 12. Since there are many different dynamic influences active along the road from the precipitation to the losses, it is not possible to find a direct relationship between the size of losses and the size of the natural event. Climate change affects the hydrological risk factors, i.e. particularly the meteorological input and the condition of the catchment area. Interventions in the catchment area (e.g. retention measures) or in the river bed (e.g. raising of the runoff rate), may diminish the danger of flooding. However, such interventions may also amplify the danger through the creation of obstacles (e.g. bridges), as shown by the examples of Poschiavo (1987) and Brigue (1993). Classical protection structures are intended to prevent flooding. However, they do not provide complete protection, as shown by the floods of 1987, 1993, 1999 and 2000. Relying on the effectiveness of the protection measures, structures were erected for decades in risk areas, thereby increasing the loss potential (cf. Chapter 1.6.3).

The loss potential may also be reduced without altering the form of land use. The Cities of Cologne, Regensburg and Passau are examples of how economic growth is possible in areas subject to frequent flooding, provided that the form of use and building structures are designed to take the hazard into account. When an event occurs, losses can be prevented or limited by emergency measures. Thus, for example, in October 2000 the River Kelchbach in Naters could be kept within its banks by provisional measures of the fire brigade.[1]

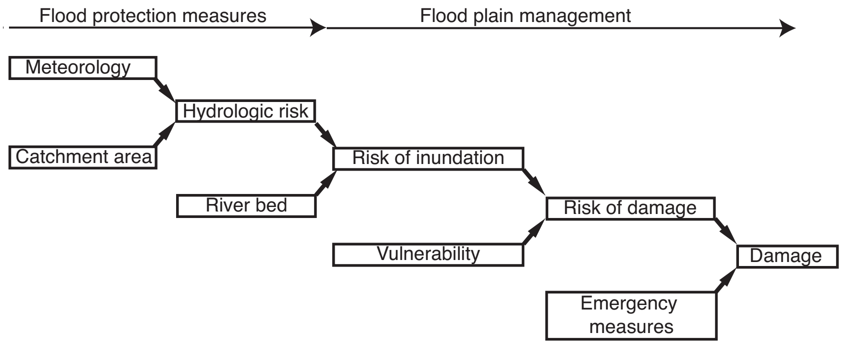

Fig. 12 Causal chain for flood damage.[3] The process leading from the precipitation event to the damage involves many dynamic parameters. The intensity of the natural event cannot therefore be derived from the damage occurring.

A positive example of the interaction of different prevention measures is provided by the avalanche winter of 1999.[2] The land area affected and the number of avalanches are comparable to those during the winter of 1951, so that the two events may be regarded as similar. Despite the significantly larger number of buildings erected since 1951, and despite the larger number of persons, cars and roads, the number of deaths declined from 98 to 17, and the number of buildings damaged from 1300 to 720. Thus today's higher damage potential was more than compensated for by combined protection policies involving avalanche barriers, implementation of hazard zones, alarm systems and emergency measures.

Human factors

Economic growth is a significant cause of increased losses. In Switzerland, some 40 billion CHF are invested each year in buildings and civil engineering. Built-up areas are expanding continually (urban areas, roads and tracks), though not quite so fast as in the 1970s (Tab. 2). The average dwelling space per inhabitant is growing by almost one square meter per year. Owing to the additional assets created, though the natural hazards have remained unchanged, the losses incurred are increasing.

Table 2 Annual increase in residential areas (in ha) in Switzerland.[4]

Period	Residential area	Roads	Tracks	Total
1972–83	+1220	+1000	+680	+2900
1978–89	+1685	+250	+470	+2400
1984–95	+1620	+130	+350	+2100

The influence of economic growth on the losses incurred may be excluded by the choice of a suitable reference parameter, for example the gross domestic product or the total insured assets. In 1868, heavy floods affected Switzerland causing material losses of 14 million CHF in the currency in circulation at the time (Fig. 13). In connection with the floods of 1987, the losses amounted to 1200 million CHF.[5] However, when seen in relationship to the strength of the national economy, the losses in 1868 were very much more severe. Stated in relation to the national income, the losses incurred in 1987 corresponded to a production of 2.2 days for the whole of Switzerland, and those in 1868 of 4 to 6 days. Fig. 13 shows how the losses in the various economic sectors have changed between these two years.

However, economic growth cannot entirely explain the changes in the pattern of losses. In 1994 and 1999, losses were incurred due to flooding in the Reuss valley in the Canton of Aargau. The average losses per building rose between 1994 and 1999 from 4500 to 9200 CHF (based on 61 and 87 buildings respectively in 12 communes). The reasons may be traced to the increased vulnerability of assets and reduced tolerance to losses on the part of the population.

Natural catastrophes overburden local communities

From the standpoint of natural science, natural events are assessed on the basis of their physical characteristics, for example peak discharge in the case of flooding, volume in the case of rock ava-

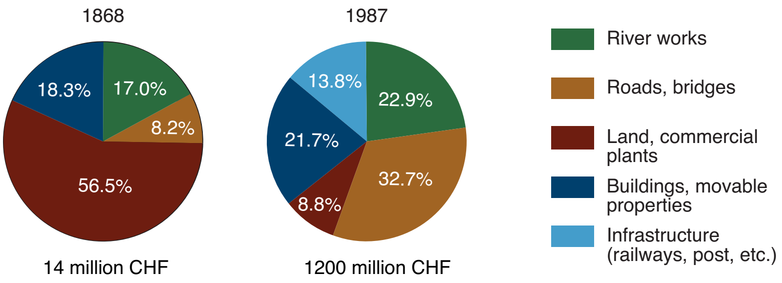

Fig. 13 In 1868, serious floods caused material losses of 14 million CHF in the currency of the day (or at least 1400 million CHF at today's prices). The floods in 1987 caused losses of 1200 million CHF. In the course of social development, not only the extent but also the type of damage alters.[5]

lanches and range of area affected in the case of snow avalanches. From the human standpoint, the losses predominate. The catastrophe statistics cite the number of mortalities, the extent of material losses and the triggering event, but – with the exception of earthquakes – contain no information on the intensity of events. Thus, for example, in the heavy storms of October 2000 in Valais, the debris flow in the village of Fully, with a volume of approx. 350000 m^3, devastated agricultural land and cultures. In Gondo, an earth flow with a volume of almost 10 000 m^3 was held back by a barrier intended for protection against rock fall, which could not withstand the pressure and then collapsed. Ten houses were destroyed and 13 persons lost their lives.[1] The losses incurred in Fully will soon be forgotten. By contrast, Gondo entered the statistics as a natural catastrophe.

According to the civil-defence definition, a catastrophe is an event that exceeds the capacity of the local population to deal with it (cf. Chapter 1.1). Therefore the extent of material losses does not provide a clear picture of the severity of a catastrophe. In 1997, the village stream devastated the village of Sachseln causing losses of some 100 million CHF. This was a natural catastrophe, and the media published detailed reports. By contrast, losses of some 70 million CHF caused a year later by a hail storm in the Canton of Lucerne were hardly noticed. In the latter case, the losses were distributed among a larger community, so that no-one's livelihood was endangered. As in the comparison of losses due to floods in 1868 and 1987, these must be seen in relationship to the economic capacity of the communities affected. Seen from this standpoint, and despite the rising losses, Switzerland may be said to have become safer in comparison to previous centuries.

A significant motor of change leading to higher losses, and to more frequent catastrophes, may be traced to the concentration processes in the business sector. The increasing intermeshing of industry, the reduction of stocks and the concentration of production at a few sites have led to a shift in the risk profile, as shown schematically in Fig. 14. Though the total risk (represented by areas F1 and F2 in Fig. 14) remains constant, the number and extent of the catastrophes increases for system B.

This situation is made worse by the cost consciousness associated with economic calculations. In weighing up the 'certain' costs of risk-reducing measures against the 'possible' costs of the losses, which may be incurred, the risk is – at least verbally – accepted. Thus although it is known that Lake Maggiore overflows its banks at more or less regular intervals, the shore area is intensively used owing to its attractiveness, but unfortunately in a way that takes no account of the hazard. Thus in October 2000, the insured losses to buildings and moveable property amounted to 160 million CHF, i.e. almost as much as in Valais (180 million CHF). However, in Valais the losses occurred at unexpected places, and the dynamic effects of the debris flows and raging water made self protection more difficult. Precisely the same areas (i.e. Upper Valais and Lake Maggiore) had already been hit by heavy storms in 1993. In Valais, the lessons had been learned, and by virtue of the protection structures that were already in place, and with the help of a careful hazard analysis using mobile equipment, the resulting losses could be reduced. At Lake Maggiore, no precautionary measures were apparent, and the material losses were significantly higher than in 1993. It seems here that the risk is generally accepted.

Climate change as additional factor of uncertainty

The extent and frequency of losses are influenced much more heavily by the dynamic changes in the economy than by the process of climate change (that, till now, has taken place comparatively slowly). In deciding on the use to which a site is to be put, the opportunities and

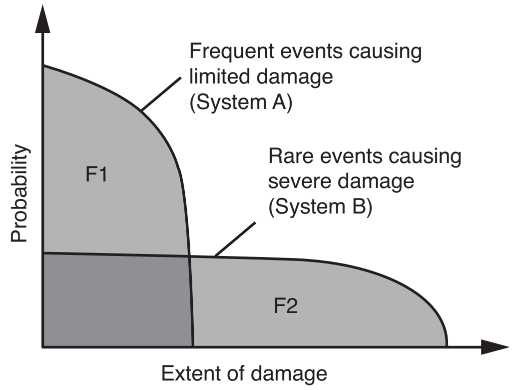

Fig. 14 Change in the risk profile. As a result of concentration processes in industry and commerce, the tendency is for events with limited damage and high probability (system A) to shift to less frequent events with much higher damage (system B).[6]

risks are weighed up, whereby personal or historical experience plays a major part in assessing the risk. Short-term cost benefits are given greater weight than existing natural hazards, or those that may arise in the future.

Natural catastrophes tend to occur when in vulnerable areas the intensity of the impact of the event significantly exceeds the customary level, or when new dangers arise at locations previously regarded as secure. This represents perhaps the greatest danger of climate change, since thereby the system is altered. In a sensitive system such as the Alpine region, small changes may have very large effects. The opposite effect, namely that certain locations become more secure, is hardly of economic benefit, since these are either not utilised or have already been secured by protective structures.

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1.6.2. Trends in losses from floods, landslides and avalanches

Christoph Hegg and Franziska Schmid

Avalanches, floods and landslides claim human lives and cause material damage in Switzerland every year. There has been no obvious trend in their occurrence over the last 30 years. The trend in the losses depends primarily on the rare extreme events. The extent of the losses may be diminished by protection measures. However, precise quantification of the effectiveness of protection measures is not possible.

Trends in casualties

Avalanches, floods and landslides lead to casualties every year in Switzerland. Over the past 30 years, at least 200 deaths were registered, which amounts to an average of about 7 per year.[1,2,3] About 60% of these are attributable to avalanches and 40% to floods and landslides. These figures do not include the well over 600 casualties occurring in connection with tourist activities outside of the so-called secure areas. This figure includes casualties to cross-country skiers and others skiing outside the secure areas (approx. 20 per year) and the 21 victims of the canyoning accident in Saxetbach on 27 July 1999.

The division of casualties as between avalanches, floods and landslides in the last 30 years varies considerably and shows no obvious trend (Fig. 15). Rather, the years with very high losses are clearly distinguished from the remainder. Thus in 2000, for example, storms claimed a total of 20 victims, 13 of these in Gondo. Luckily, there were no such extreme events in other years. Over 30 years ago, the number of victims claimed by extreme events had been significantly higher than more recently. In the avalanche winter of 1951, 98 victims were claimed, and in the floods of 1868, 50 persons were killed. Other natural catastrophes, for example the rock avalanche in Goldau in 1806, which engulfed 500 persons, can lead to significantly higher casualties.

Trends in total financial losses

The financial losses caused by extreme events can be assessed by various means. The damage to insured objects (as discussed in Chapter 1.6.3) offers a possible basis for this. However, public authorities in Switzerland do not usually insure their property, so that these figures do not provide a complete picture of the total losses incurred in any particular case. In the following therefore, variations in the total direct losses over the last 30 years in the case of floods and landslides are discussed. The data are taken from the storm damage database of the Swiss Federal Institute for Forest, Snow and Landscape Research (WSL), which among other data contains systematic estimates of the incurred losses. In addition to data from local authorities and insurances, the estimates are based on a review of all newspaper articles published in Switzerland on this theme.[1] Indirect damage such as loss of business through blocked access roads was not included, as this is hardly ascertainable.

The yearly losses shown in Fig. 16 deviate by more than 2 orders of magnitude. This is mainly attributable to the fact that the major part of the losses is caused by extreme events. Thus the 5 largest events over the last 30 years (07.08.78, 24.08.87, 24.09.93, 15.05.99, 15.10.00) were responsible for over two-thirds of total financial losses. Only one-third of the losses are attributable to the remaining just over 1300 events. Thus the trend in the losses depends primarily on that of the rare extreme events. At present, little is known of the causes and distribution of these. In most cases, they result from exceptional precipitation events.

The graph for accumulated losses since 1972 displays no marked trend (i.e. neither upwards nor downwards) in the losses due to floods and landslides. Both at the beginning and at the end of the time interval shown, a larger number of events causing particularly high damage are seen. This information is insufficient to derive trends for longer periods, or to identify weaker trends, since these are masked by the large scatter (cf. Chapter 1.4).

The magnitude of the losses resulting from an exceptional precipitation event depends on numerous factors and incidental circumstances. Moreover, the influence of protection measures cannot be neglected. An impressive example of this is provided by the dam in Visp, which was raised following the floods in September 1993 at a cost of only a few 100 000 CHF. In October 2000, the dam protected extensive industrial installations from flooding, avoiding losses that would probably have run into the billions. Had the maximum water level in the Rhone been only a few centimetres higher, the installations would have been flooded, showing that there is no linear relationship between the causing event and the losses incurred. Rather, it is characterised by threshold values such as represented, for example, by the height of a dam.

It is not possible to quantify the effects of the protection measures realised over the past

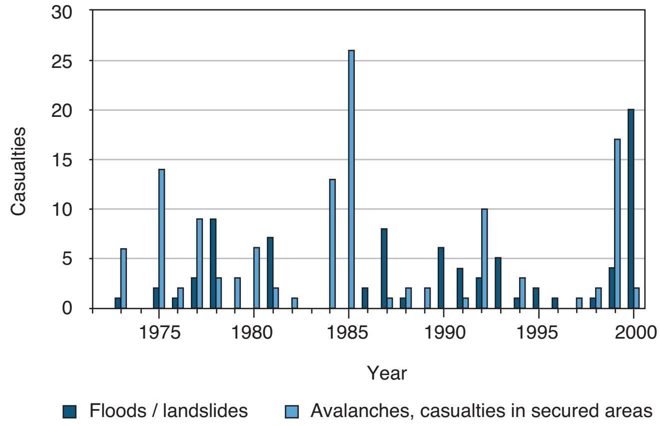

Fig. 15 Number of casualties in Switzerland over the last 30 years caused by avalanches, floods and landslides. The distributions display no obvious trends.

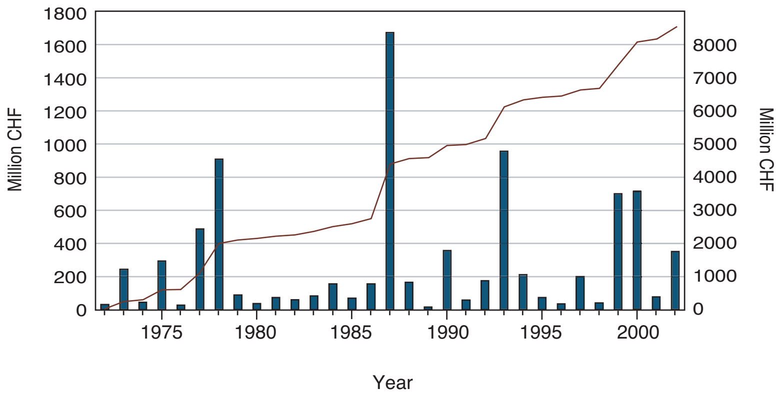

Fig. 16 Direct damage caused by floods and landslides in Switzerland. The columns are referred to the left-hand ordinate and show the annual losses inflation-adjusted to the end of 2000. The curve shows the accumulated total losses since 1972 and is referred to the right-hand ordinate.

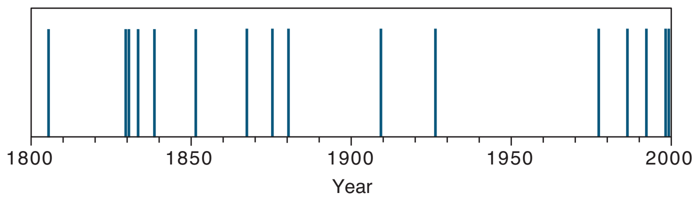

Fig. 17 Flood catastrophes in Switzerland in the last 200 years.

few decades, or in previous centuries, on the extent of the losses incurred in Switzerland as a whole. These may only be determined for precisely documented individual cases, for example with the aid of cost-benefit analyses, in which factors such as maintenance and the failure of protection measures can also be taken into account. It is therefore hardly possible to predict how an increase in heavy precipitation in conjunction with these and the other factors mentioned in Chapter 1.6.1 might affect future financial losses.

1 Hegg C., D. Gerber und G. Röthlisberger, Unwetterschaden-Datenbank der Schweiz. Int. Symposion Interpraevent 2000 – Villach/Österreich. Tagungspublikation, Band 1: 37–48, 2000.

2 Röthlisberger G., Unwetterschäden in der Schweiz. Eidg. Forschungsanstalt Wald Schnee Landschaft, 346, 51 S., 1998.

3 Laternser M., M. Schneebeli und R. Wüthrich, Die neue SLF-Schadenlawinendatenbank. Bündnerwald 51, 1, 35–39, 1998.

1.6.3. Loss trends in elemental loss insurance

Dörte Aller and Ewa Kozlowski

The extent of building losses is not only affected by factors which modify risks and hazards, but also by national economy factors. The evolution of the building losses of the public building insurance companies (PBI) since the beginning of the 1980s shows an increasing variability in the damage events in Switzerland. The exceptional losses of 1999 point out the enormous loss potential of natural hazards.

The evolution of losses from natural hazards is often used as an indicator of climate change. Whilst climate change is certainly an important factor influencing the losses, it is not the only one. The costs of damage are determined not only by risk modifying factors.Economic development also plays a role. (cf. Chapter 1.6.1). The building losses reported by the 19 public building insurance companies (PBI)[1] in Switzerland will be used as an example to discuss the various influencing factors. Building losses resulting from fire have been covered by the PBI since the first half of the 19th century, while elemental losses[2] were not included until the late 1920s[3].

Data availability

Figures for elemental losses on buildings are available from all 19 cantons with a PBI for the last 30 years (Fig. 18). Since it is compulsory to insure all buildings with the respective public building insurance company, virtually all building losses are registered.

The figures exclusively refer to building losses.[4] To enable a comparison of the statistics of the last 30 years, the building losses are put in relation to the total sum insured. The resulting ratio is called the ‘loss quotient’. The total sum insured is regularly adjusted to the index of building costs and, in addition, building valuations are periodically reviewed. Therefore, the use of the loss quotient provides a certain basis for comparison.[5]

Factors influencing the costs of damage

The size of the costs of damage is not only dependent on the extent of the damage but also on economic factors (Fig. 19). The costs are either insured or have to be paid by the owners themselves.[6]

The extent of the damage depends not only on the severity of the event, since an extreme event does not necessarily result in extensive damage (e.g. if it occurs in an uninhabited area). On the other hand, an event which is only slightly above average can cause extreme damage should it occur in a densely populated area with a large number of sensitive, high value resources (cf. Chapter 1.6.1).

The factors which influence damage may be divided into two categories: those which modify risks and hazards and those which influence costs.

Hazard and risk modifying factors

Hazard and risk modifying factors influence the frequency and extent of the damage. Climate change affects the intensity and return period of natural events.

- The hazard in a particular area resulting from average and severe gravitational events can be limited by protective structures such as dams and snow supporting structures. Where extreme events are con-

cerned, there is always a residual risk (cf. Chapter 1.6.2).
- Action undertaken by fire services before or during an event can limit the extent of the damage.
- The effective damage is influenced by the vulnerability of the building to natural hazards. This includes:
  - building in hazard areas, e.g. in flood plains.
  - the inclusion of vulnerable constructional designs, e.g. low-lying openings in flood plains.
  - inappropriate use of buildings in areas subject to natural hazards (e.g. use of the cellar as a living space in flood plains).
  - use of insufficiently robust material, e.g. illumination domes not designed to withstand hail.

It cannot be denied that the exploitation of exposed areas and the use of more vulnerable building techniques and materials has contributed to the increase in basic loss potential.

Cost modifying factors

These factors modify the extent of the insured losses via commercial and national economic mechanisms such as:
- general insurance conditions, e.g. alteration of the deductible.
- the sum insured, e.g. where this is changed from current market value cover to replacement value cover.
- the behaviour of policyholders, e.g. where a back yard is cleaned by professionals rather than by the owner.

By indexing with the total sum insured – taking inflation and the increase in the value of assets into consideration – the comparability of the long-range data can largely be assured. It is more difficult to take changes in the general insurance conditions and the behaviour of the policyholders into account.

Since it is hardly possible to quantify the various factors individually, no attempt is made here to list them in order of importance.

Long-range data on building losses

In Fig. 20, the loss quotient for the period 1972 – 2002 is shown. The year 1999 stands out immediately. The series of results from 1972 – 1998 (cf. Fig. 18) gives no direct indication of the

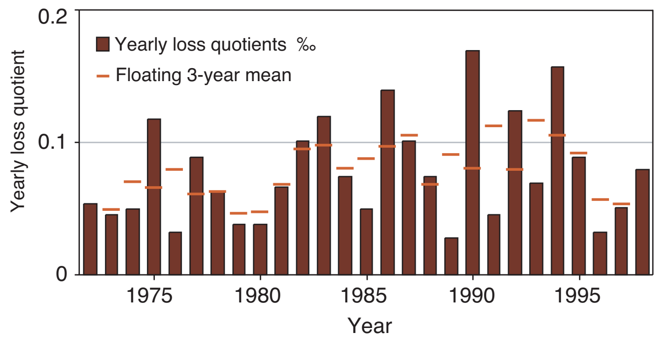

Fig. 18 Yearly loss quotients for building losses of the 19 PBIs[7] (in ‰ of the sum insured 1972 – 1998)

possibility of a year with such extreme losses. The return period of the losses in 1999 lies between 50 and well over 100 years. This clearly shows the range of the variability of losses and that even more extreme events could occur at any time.

Never before have so many individual losses been registered in the space of a single calendar year than in 1999. Almost 300 000 of a total of nearly 2 million insured buildings suffered damage. In 1999, total building losses of the 19 PBIs amounted to over 1 billion CHF, the total value of all insured buildings being about 1'500 billion CHF.

By spreading these losses over the 19 cantons with PBIs and over the various categories of elemental losses a certain compensating effect can be achieved. Despite this, several exceptional events coincided in 1999, leading to extreme losses over the year:
- avalanches and snow pressure in the spring (approx. 80 million CHF)
- flooding at Ascension and Whitsun (approx. 200 million CHF)
- hailstorm on 5th July 1999 (approx. 80 million CHF)
- storm 'Lothar' on 26th December 1999 (approx. 600 million CHF)

The choice of insurance accounting period – usually corresponding to the calendar year – can also have a substantial influence on annual losses. The damages caused by storm 'Lothar' are a good

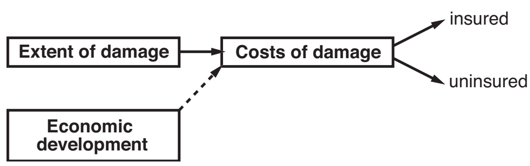

Fig. 19 Diagram showing the influence factors which determine costs of damage.

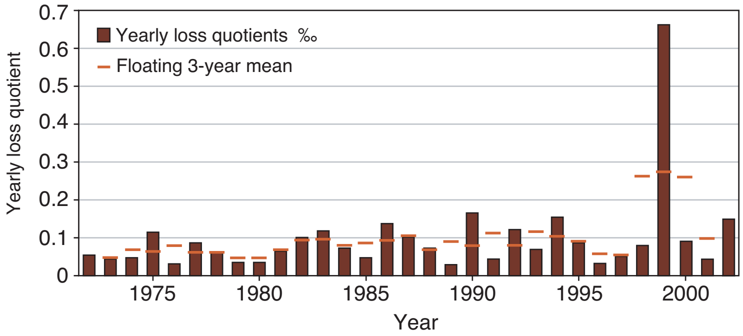

Fig. 20 Yearly loss quotients for building losses of the 19 PBIs[7] (1972 – 2002). The distances between the grid lines correspond to those in Figure 18 (different scale).

example of this. Had Lothar occurred one week later, the damage would have fallen in the year 2000, lessening the effect on 1999. For this reason, and to reveal the evolution in the losses over 30 years, a 'floating' 3-year average was calculated.

Fig. 18 shows a rise at the beginning of the 1980's. The average loss quotients are somewhat higher after 1981 than in the period from 1972 to 1981. Variability rose during the 1980's. In the final decade, an even steeper increase in variability is evident.

The role of prevention

Further natural catastrophes must be expected in the future. The responsibility to be carried by individuals and communities in handling the losses must be formulated. In the future, prevention (protection and mitigation) will play an increasingly important role.

The PBIs are extending their prevention activity, which has proven its effectiveness in the domain of fire hazard over several decades, to also include natural hazards[8]. In the case of PBIs , protection means that buildings are constructed taking a certain extent of natural hazards into account. Should a more serious event occur, a well-trained and equipped fire service can help to mitigate the resulting damage. Finally, the compulsory public building insurance, only available through the PBIs, guarantees that all buildings are adequately insured and that losses are fully compensated. The synergies of building protection, organised emergency services and insurance leads to a comprehensive, inexpensive and mutual insurance cover. Therefore, the regulation of elemental loss insurance and prevention is carried out in an exemplary manner by the PBIs in Switzerland compared to European standards.[9]

1 Public building insurance companies exist in the following cantons: Zurich, Bern, Luzern, Nidwalden, Glarus, Zug, Freiburg, Solothurn, Basel-Stadt, Basel-Land, Schaffhausen, Appenzell-Ausserrhoden, St. Gallen, Grisons, Aargau, Thurgau, Waadt, Neuenburg, Jura. Cantons without public building insurance companies: Genf, Uri, Schwyz, Ticino, Appenzell-Innerrhoden, Valais, Obwalden.

2 Elemental losses: sudden and unexpected damage caused by storm, hail, floods, avalanches, snow pressure, debris flow, landslides, rockfalls, collapsing cliff faces and rock avalanches.

3 Wanner C., Vorbeugen – schützen – entschädigen. Die Entstehung der Elementarschadenversicherung in der Schweiz. Lizentiatsarbeit, Historisches Institut der Universität Bern, 2002.

4 Building losses: Damage to immovable parts after deducting the excess of the policyholder, excluding losses to furniture and the costs of business interruption.

5 The determination of the insured assets and the damage assessment is carried out by trained internal and external building professionals (architects, building engineers, etc.). For this reason, and owing to the almost complete registration of the damage, high data quality is assured.

6 In cantons with public building insurance companies, all buildings are insured against elemental losses.

7 Losses in cantons without public building insurance companies are not included in the Figure (cf. footnote 1). Thus the floods in Brigue in 1993 and the flooding in Ticino and Valais in October 2002 are not included.

8 Kantonale Gebäudeversicherungen, Manifest der Kantonalen Gebäudeversicherungen zur Elementarschadenverhütung, 2001.

9 von Ungern-Sternberg T., Gebäudeversicherung in Europa – Die Grenzen des Wettbewerbs. Haupt Verlag, Bern,178 S., 2002.

1.6.4. Extreme events from the standpoint of the insurance business

Gerry Lemcke

The losses due to natural events fluctuate from year to year. The annual growth in insured losses amounts to approximately 5.2%. Two-thirds of all losses due to natural hazards are of atmospheric origin. Any change in the climate has the potential to alter the frequency and intensity of these events. By application of the precautionary principle and the development of new products, the insurance business is exerting its best efforts to provide adequate cover now and in the future

With its total insured losses[1] of 28.6 billion USD, and incurred losses of 7 billion USD, 1999 was the second most expensive year in the history of the insurance business worldwide, and ranks among the record years subsequent to 1989. In the period 1970-2000, Swiss Re's Sigma statistics show 47 cases of damage with losses extending into the billions. Of these, 33 are attributable to the years 1989–2000. The losses due to natural events are characterised by extraordinary fluctuation (Fig. 21). At an annual average loss quota of 20.2 billion USD since 1989, the standard deviation was 8.2 billion USD. On average, storms contribute 11.0 billion USD, earthquakes 2.0 billion USD and flooding 1.1 billion USD. The remainder is distributed among 'other risks' such as tornados, hailstorms and earthquakes. The growth rate in insured losses due to natural hazards is at present approximately 5.2% per year. If these figures are simply extrapolated over the next 20 years, society and the insurance companies will be confronted with annual average insured losses of 60 billion USD in 2020.

The Lothar storm, together with Martin, which is mostly taken in conjunction with it, were reported in the press as records of the century. They claimed 80 human lives, of which 13 occurred in Switzerland, involved losses to the national economy of the order of 12 billion USD and insured losses of some 5.8 billion USD. With the exception of the storm damage in 1990 caused by Daria, Herta, Vivian and Wiebke, losses due to storms of this magnitude have never before occurred. Although regarded from a European perspective, Lothar and Martin were of only average intensity, the fact that these two storms followed one another in short succession brought the European prime insurers to their financial limits. Typically reinsurance programmes are designed to protect against isolated and very seldom events, but not against several successive events of this kind.

In recent years, vulnerability to natural hazards, and thus the potential risks, have drastically increased through demographic movements, technological progress and sozio-economic factors. Today, almost 40% of the world's population lives in coastal regions that are disproportionably vulnerable to natural hazards. Even assuming the risk from natural hazards were to remain constant, the likelihood of incurring very substantial losses would still increase simply through the growth in insured assets. Over the past decade, the losses to the national economy were some 8 times higher, and the insured losses some 12 times higher, than in the 1960s.[2] Even though it is widely accepted that the increase in insured assets is mainly responsible for this trend, variations in the frequency and intensity of natural hazards due to climate change cannot be neglected.

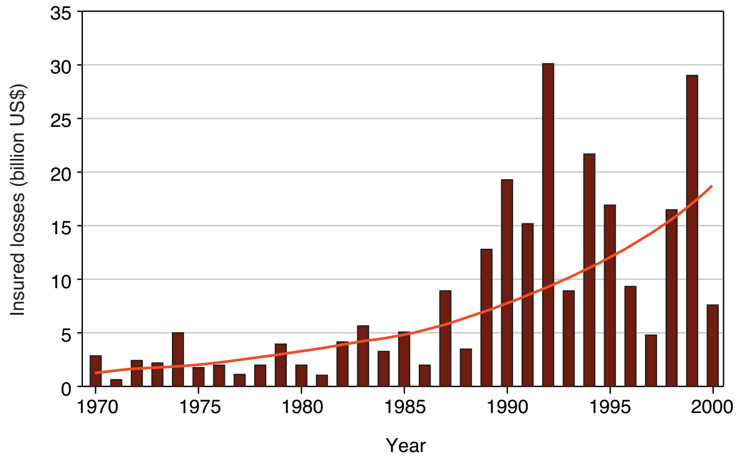

Fig. 21 Insured losses for natural catastrophes between 1970 and 2000 in billion USD at 2000 prices (Swiss Re Sigma statistics, adjusted for inflation).

Increased risk potential

The phenomenon of extreme events cannot be reduced to physical or statistical quantities. Rather, it results from the intensity and frequency of an event, and the material and immaterial assets involved. From the point of view of the insurance business, it is absolutely essential in assessing extreme events to couple these with the monetary losses incurred. From a humanitarian standpoint, however, this approach must be questioned. It should always been borne in mind that non-insured losses have to be carried by the owner or the community at large. In the developing countries, this may have serious consequences, as in the case of hurricane Mitch, which devastated Honduras in 1998, claiming 9000 human lives.

Some two-thirds of all losses from natural hazards are of atmospheric origin, e.g. caused by storms, flooding or hail. Basically, any change in the climate – i.e. of the global energy content of the atmosphere – has the potential to alter the frequency and intensity of regional – or at least local – climatic events.

Climate change is mostly discussed purely in terms of changes in the long-range average values. In this, it is often overlooked that average values in fact arise from a trend. The following points should therefore be borne in mind:

- Fluctuations in the average value result from fluctuations in the frequency and/or intensity of events. The increase may apply both to 'normal' and infrequent events. Should the probability of occurrence of an extreme event alter, this has a major effect on the magnitude of a hypothetical high-loss scenario (EML scenario), which is defined in terms of very rare extreme events.
- Where events of average magnitude increase in frequency, this has a direct effect on the so-called basic loss burden: such events absorb a large fraction of the premiums set aside for more seldom natural catastrophes.

Whether, and to what extent, global warming may lead to an intensification of natural hazards and to changes in their frequency is not at present clear. Although the acceleration of the hydrological cycle already appears to be responsible for an increase in heavy precipitation events, there are no clear indications that this may true for changes in winter storm activity. Nonetheless, it is clear that even a slight increase in the frequency of storms of the magnitude of Lothar would have a major effect on present and future insurance premiums.[3]

Role and scope of reinsurance

The insurance business is closely following developments in losses, which have risen sharply over the last 10 years. The principal procedures to ensure adequate coverage now and in the future are the application of the precautionary principle, including proactive risk management and risk assessment based on the latest scientific studies, and – in addition to the classical insurance systems – the development of innovative products such as capital market transfer (so-called Cat bonds) and weather derivatives.

Risk management is cast significantly wider than the provision of technical structures for combating natural hazards. It includes the development of public awareness as a principal element. It is important that the public should became aware of the extent to which present-day technologies and modern lifestyles, in conjunction with the changing climatic conditions, are creating a risk potential that cannot always be carried and absorbed by third parties as at present. Those who wish to build in highly exposed areas subject, for example, to flooding, must either be prepared to carry the higher risk themselves, or to pay a higher insurance premium to cover it, ensuring that the burden is not placed on the community. Where changes affecting the community are concerned, such as an increase in the frequency of floods due to climatic changes, the available capacity must be used to cover large-scale losses, and not the petty losses. At the present cost contribution of the policyholder of 0.2% of the insured sum, the major part of the coverage is absorbed by small and petty losses, which do not represent a threat to individuals' existence.

Risk assessment is an important part of risk management and deals with the application of scientific know-how to the assessment of natural hazards. Probabilistic techniques are used to model natural hazards, the distribution of assets, the geographical distribution and the insurance provisions, and to estimate the occurrence of infrequent events via the loss frequency characteristics with sufficient precision. This also requires a precise record of the location of exposed assets and their quality, and a complete record of historical events.

Concentrated efforts to further develop the classical insurance models (e.g. non-proportional insurance models and alternative risk transfer) have enabled existing insurance and reinsurance capacities to be constantly expanded. However, there are limits to the extension of classical models, particularly since additional capacity is mainly demanded in areas already displaying a high rate of coverage. This fact militates against the demand for diversification, i.e. risk compensation over space and time, and results in sharply rising premiums, so that the cost of coverage may become exorbitant in certain areas.

Both to protect its own interests and those of policyholders, it is an important task of the insurance business to assess the current and the future direct and indirect consequences of the changing climate. Despite major uncertainties concerning the precise consequences, this must be done at the earliest time. It must be remembered that the development of insurance products to cope with changes in demand, e.g. in the case of floods, requires substantial time expenditure.

1 We are concerned here solely with losses resulting from natural hazards. Man-made extreme events, such as those in the USA on 11 September 2001, are not included.

2 Müncher Rück, Nat Cat Service, 2001.

3 Swiss Re, Despite continued price erosion and overcapacity: Cat markets on the rebound? 1999.

Part 2

Present knowledge

2.1. Temperature extremes

Patricia Jungo

During the 20th century, the temperature level of both the hot and cold temperature extremes increased at all times of year. At high altitudes, a marked increase in the level of the hot temperature extremes in winter was observed. At low altitudes, cold extremes occurred somewhat less frequently. It is expected that the temperature level of both the hot and cold temperature extremes will increase in accordance with anticipated global warming in the 21st century.

Introduction

Long-range changes in the air temperature at the ground can have multiple effects on ecosystems (particularly on plants[1]), the water content of the ground, glaciers and permafrost (cf. Chapter 2.8). Changes in the average temperatures and the appearance of temperature extremes are of central importance in this connection. In addition to their effects on the areas mentioned, extreme hot and cold periods may cause enduring damage to ecosystems, damage commercial plants, and in some cases endanger the health of humans and animals. Whilst the pattern of extreme temperatures may vary, their duration and regional distribution are decisive. The most extreme forms are heatwaves and extremely cold periods affecting wide areas of the country. Typical examples are the very cold winter of 1962/63 and the very hot summer of 1947.[2] In analyzing trends and possible future changes, temperature extremes of this kind with very long return periods are of little value (cf. Chapter 1.4). In this chapter we shall therefore discuss the behaviour of a larger range of temperature extremes, namely the 10% hottest maxima and the 10% coldest minima during a season. For purposes of simplification, it may be assumed that the maximum temperatures occur during the day and the minimum temperatures at night.

The air temperatures at the ground are subject to large fluctuations over the year and are very sensitive to regional and local influences owing to the very varied terrain in Switzerland. A rough division will be made between Alpine regions lying above 1500 m and low-lying regions below 800 m to the north of the Alps. The Alpine region is of particular significance, since ecosystems at high altitude closely adapt to the local climate and are particularly sensitive to change. Further, temperature measurements in these remote areas are less influenced by non-natural causes (e.g. urbanisation).[3]

Observed trends in the 20th century

In the 20th century, not only in the Alps, but also in low-lying regions, the temperature level of both hot and cold temperature extremes increased at all times of the year. Since 1900, the hottest days, the hottest nights, the coldest days and the coldest nights all increased in temperature by between 0 and 3.3°C depending on time of year.[4]

In addition, the number of hot and cold temperature extremes varied (the method of determining these is explained in the legend in Fig. 22). Cold temperature extremes have become less frequent over the years, particularly in the winter months.[5] In the 1990s, the number of hot temperature extremes in winter, spring and summer was significantly higher, and the number of cold temperature extremes significantly lower, than the average for the previous 90 years. The sharpest change occurred in the hot temperature extremes in Alpine regions in winter (Fig. 22). In the 1990s, an average of 16 hot days and 17 hot nights occurred, whilst in previous periods of comparable length, only between 1 and 9 hot days and nights were recorded.

In lower-lying regions, warming tends to manifest in the form of somewhat less frequent cold temperature extremes. In the Central Lowlands, 50 frost days less were recorded in the 1990s than in the first decade of the century (cf. Chapter 2.2).[6]

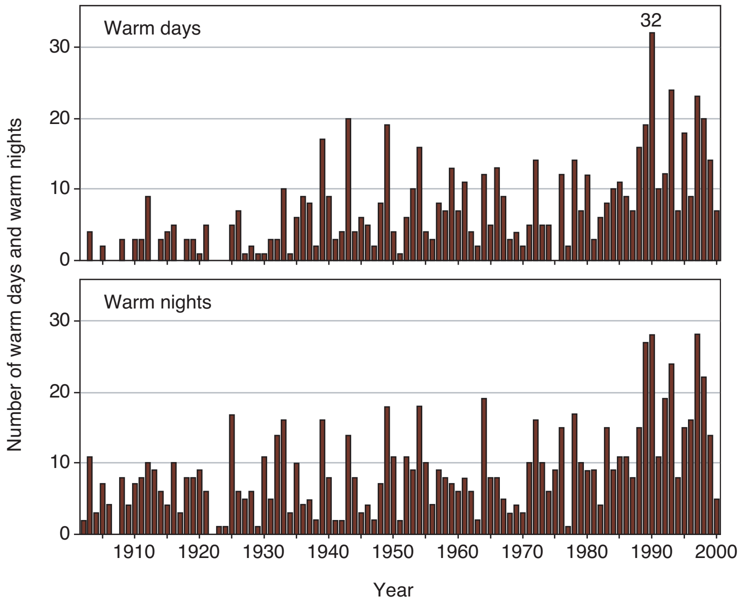

Fig. 22 Annual number of hot temperature extremes for 1902-2000 in the winter months in Alpine regions above 1500 m. The threshold value was defined as the 90 percentile of the maximum temperatures (day) and the minimum temperatures (night) for the climatological reference period 1961-1990.[4] That is to say, the threshold value was not defined according to the highest maximum (or minimum) value during the reference period, but as that value which was exceeded by 10% of the measured maximum (or minimum) temperatures.

Factors involved in climate change

Climate change can exert an influence on the temperature through a variety of coupled processes. Foremost among these is the greenhouse effect resulting from the increased greenhouse gas concentration leading to warming of the atmosphere. However, the air temperatures near the ground are also determined by dynamic processes. The origin of an air mass present at a particular location is determined by the distribution of the large-scale pressure systems over the globe. In Switzerland, a close relationship exists between the occurrence of climatological weather types[7] and the frequency of hot and cold temperature extremes (cf. Chapter 1.3). For example, the comparatively low frequency of cold winter days during the 1990s resulted from the increasing occurrence of high-pressure and west-wind weather types at the expense of those weather types involving cold north-easterly winds. This shift appears to be closely related to changes in air movements above the North Atlantic and the increase in the North Atlantic oscillation index (NAO index).[8] Whether these flow changes result from global climate change or simply from an exceptional phase lying within the normal range of climatic variation is not yet clear.

In addition to the greenhouse effect and the dynamic influences mentioned, local ground conditions and cloud cover also play a part. For example, the presence of snow cover modifies the radiation conditions, so that the anticipated reduction in snow cover in winter as a result of global warming could lead to a regional intensification of warming. This process is likely to be particularly relevant to winter temperature extremes.

Influence of climate change

The expected increase in average temperatures in the course of the 21st century will very probably be accompanied by an increase in the temperature level of the temperature extremes in Europe. The temperature extremes simulated over a 20 year period using a global climate model show a general increase in the temperature level of the minima and maxima towards the end of the 21st century.[9] Depending on the region, the minima were found to rise by over 5°C, and the maxima by between 1 and 4°C, compared to today's climate. At the regional level, the cold extremes are found to increase particularly at locations with reduced snow cover, and the hot extremes in areas with reduced ground humidity in summer. For the Alps, whilst a scenario assuming declining ground humidity would be accompanied by large uncertainties, a shortened period of snow cover in winter would be plausible. It is interesting to note that the simulated increases in the extremes are greater than the increases in the averages.[10] Care should be taken in interpreting the simulated results for cold extremes in the Alpine region, and the values cited must be regarded with caution. Changes in the large-scale air flows are an important factor in determining regional changes in the temperature extremes. In this respect, the available simulations are subject to considerable uncertainty.

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2 Pfister C., Wetternachhersage. 500 Jahre Klimavariationen und Naturkatastrophen 1496–1995, Haupt Verlag, Bern, 304 S., 1999.

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6 Heino R., R. Brazdil, E. Forland, H. Tuomenvirta, H. Alexandersson, M. Beniston, C. Pfister, M. Rebetez, G. Rosenhag, S. Rösner, and J. Wibig, Progress in the study of climatic extremes in northern and Central Europe, Climatic Change, 42, 151–181, 1999.

7 Schüepp M., Klimatologie der Schweiz, Band III, in: Beiheft zu den Annalen der Schweizerischen Meteorologischen Anstalt, Zürich, 89 S., 1978.

8 Wanner H., R. Rickli, E. Salvisberg, C. Schmutz, and M. Schüepp, Global climate change and variability and its influence on Alpine climate – concepts and observations, Theor. Appl. Climatol., 58, 221–243, 1997.

9 Kharin V. V. and F. W. Zwiers, Changes in the extremes in an ensemble of transient climate simulations with a coupled Atmosphere-Ocean GCM, J. Climate, 13, 3760–3788, 2000.

10 Gregory J. M. and J. F. B. Mitchell, Simulation of daily variability of surface temperature and precipitation in the current and 2xCO_2 climates of the UKMO climate model, Q. J. Roy. Meteorol. Soc., 121, 1451–1476, 1995.

2.2. Risk of frost

Claudio Defila

Frost often causes damage to commercial plants. Plant damage occurs when low temperatures coincide with an early stage of plant growth. Thus late frosts in spring are particularly feared in Switzerland. Since 1951, the development time of certain plants starts earlier in spring on average by 11.6 days, whilst in autumn it lasts longer by 1.7 days. Parallel to this, the last day of frost in spring has occurred ever earlier at some measurement stations over the last 30 years. Though the risk of frost will continue to vary in future in relation to the change in climate, it is not possible to predict with certainty whether it will increase or decrease.

Introduction

In climatology, a frost day signifies a day with a minimum temperature below 0°C. In contrast, in biometeorology, which deals with the influence of the weather and the climate on living organisms, the term frost must be regarded in more detail. Thus in agro-meteorology, the term frost only applies when damage to commercial plants occurs. Since the resistance of plants to frost alters depending on their stage of growth, a minimum temperature below 0°C does not always signify a frost day. Frost therefore takes on a different meaning depending on the time of year. Frost is therefore defined in relationship to the time of year in which it occurs.

In Switzerland, *winter frosts* are of little significance, since indigenous plants are well adapted to the low temperatures. They can withstand temperatures down to –30°C without harm. By contrast, exotic commercial plants and decorative plants may suffer damage at less extreme temperatures in winter. In 1985 and 1987, some regions in Switzerland experienced damage to grapevines when the temperature sank below –20°C.

In Switzerland, *early frosts* in autumn present no great problem. Nonetheless, damage may occur to field crops if these are stored outdoors, and in horticulture.

Late frosts in spring are a cause of serious concern in Switzerland. For this reason, *MeteoSwiss* issues frost alarms in April and May. Late frosts can cause sizable damage in orchards, vineyards and in horticulture, since in spring, the plants are very sensitive at certain stages of growth (Fig. 23). Thus although closed flower buds can withstand temperatures down to –8°C, flowers in full bloom can only withstand temperatures slightly below the freezing point.

In assessing a frost event, the minimum temperature, the time of year and the length of the frost period all play a part. No simple definition of an extreme frost event is available. In the following, the agro-meteorological definition, which takes account of harm to commercial plants, will be used.

Meteorological conditions

Late frosts are divided into so-called advective frosts, transpiration frosts and radiation frosts. In Switzerland, the radiation and advective frosts are of main importance.

Advective frosts mainly occur with cold air masses coming from northerly to easterly directions. Thus they are primarily associated with the large-scale atmospheric circulation, and do

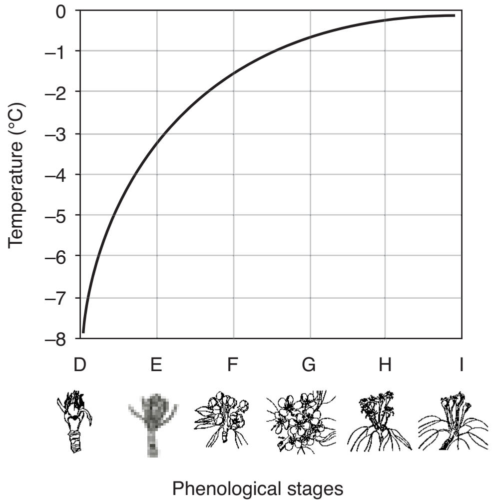

Fig. 23 Sensitivity of pears to frost at various phenological stages.

not depend on the time of day, and only to a small extent on cloud cover.

Radiation frosts occur when the radiation balance is negative, i.e. when the radiation from the ground or plants is greater than the incident radiation. This situation often occurs in spring in the early morning hours, and with a clear sky.[1]

Phenological trends

In Switzerland, surveys on seasonal plant growth and development have been carried out at yearly intervals since 1951. Additionally, a very long record starting in 1894 is available on the blossoming of cherry trees in Liestal (Fig. 24), and another beginning in 1808 on leaf sprouting of horse chestnut trees in Geneva.

A trend analysis of data in the interval 1951–1998 shows a time displacement and prolongation of the vegetation period. The changes are particularly conspicuous in spring, with leaf sprouting and full bloom occurring 11.6 days earlier. In autumn, the vegetation phases (leaf discoloration and leaf fall) show a small retardation of 1.7 days. There are, however, large regional differences.[2]

With an earlier start to the vegetation period, the risk of frost damage increases, since the number of frosts in March is higher on average than in May. Early awakening of the vegetation can lead farmers to commence earlier with sowing, increasing the likelihood of frost damage.

However, the higher risk of damage due to frost is compensated by the fact that over the last 30 years, the last day of frost has tended to occur earlier in the year at certain measurement stations. Thus in Zurich, the last day of frost now occurs on average about 10 days earlier than in 1975 (Fig. 25).

Influence of climate change

Climate change can affect frost events in several ways:

(a) *Increase in the minimum temperature*
The climate simulations available for the late 21st century display a tendency towards less frequent cold temperature extremes (see Chapter 2.1). Also, an increase in night temperatures was identified in the 20th century.[3] This could lead to a reduction of the frost risk.

(b) *Change in atmospheric circulation*
Climate change can influence the large-scale atmospheric circulation. Changed flow patterns in the atmosphere could lead to more – or to less – frequent advective frosts. The changes in circulation simulated by present-day climate models are still very contradictory, and at present allow neither quantitative nor qualitative conclusions to be drawn.

(c) *Changes in cloud cover*
Cloud constellations play a large part in the occurrence of late frosts. Nightime cooling of the atmosphere is less pronounced with a cloudy than with a clear sky. Should cloud

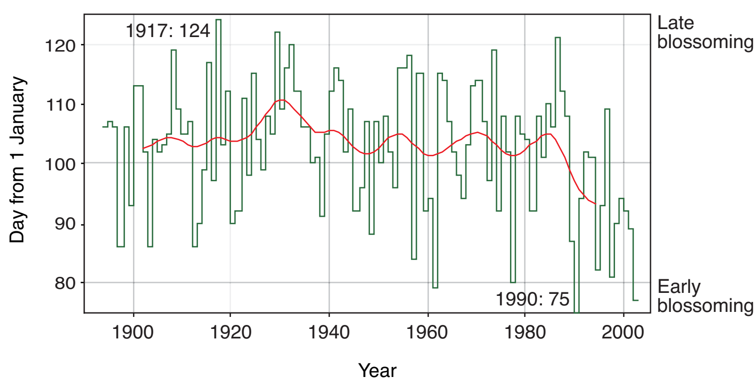

Fig. 24 Date of commencement of full bloom of cherry trees in Liestal 1894-2001. Since the beginning of the 1980s, cherry trees have tended to blossom ever earlier in the year. The vegetation period has shifted towards the spring.

cover increase as a result of higher temperatures and a higher rate of evaporation, the number of frost days could decline. It is conceivable that the frost risk in Switzerland could alter as a result of climate change. Our knowledge on changes in large-scale circulation, cloud constellations and earlier vegetation growth permit nothing more than speculations. Current scientific knowledge allows neither an increase nor a decrease in the frost risk to be forecasted owing to the fact that two important parameters can change, i.e. the status of vegetation and the temperature. Furthermore, a single night with frost can heavily damage commercial plants. Even if the risk of frost days were to decline, individual frost episodes leading to plant damage could not be excluded.

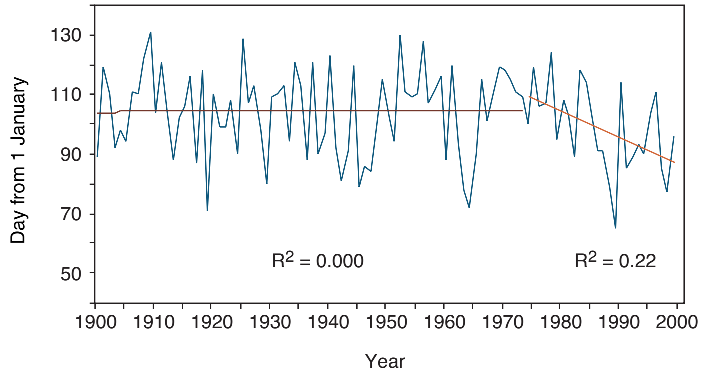

Fig. 25 At the measurement station in Zurich, the last day of frost has tended to occur ever earlier in the year since 1975. Not all Swiss stations display this tendency.

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2.3. Drought

Bruno Schädler

Drought has a detrimental effect on humans, animals and plants. Periods of drought in Switzerland occur in different measure and at different times in the various climatic regions. In the Central Lowlands, no trend could be established for droughts in the 20th century. Only limited scientific knowledge is available on possible changes in drought as a result of climate change. To the south of the Alps, lower runoff rates and drier soils are expected. In the same way, the rivers north of the Alps that are fed by melting snow will probably carry less water owing to reduced snowfall in summer and autumn.

Introduction

Drought is a complex phenomenon, and definitions vary considerably. These are often based not only on meteorological, climatological and hydrological criteria but also on the economic consequences of drought. From the meteorological standpoint, drought signifies "a period of abnormally dry weather sufficiently prolonged for the lack of water to cause serious hydrologic imbalance in the affected area".[1] More generally, "drought is a condition of moisture deficit sufficient to have an adverse effect on vegetation, animals, and man over a sizeable area".[2]

During dry periods, precipitation is absent for a longer period, the ground dries out, the groundwater table sinks, and rivers, streams and smaller standing waters carry less water or dry out entirely. The effects on agriculture and other commercial sectors depend significantly on the time of year at which they occur (e.g. growth season in agriculture, start of the ski season in winter tourism, etc.). Drought must also be seen in relation to the average climatic conditions in a region.

At least where the Swiss Central Lowlands are concerned, the water levels of the small and medium-sized streams and rivers, and/or their runoff, are a good measure of drought. These indicate the hydrological balance in an entire catchment area, and are hardly affected by occasional rainy days during a longer period of drought. In order for it to serve as a useful indicator, a stream or river should neither be fed directly by a lake, nor have artificial inflows or outflows. In the mountains, runoff is an unsuitable measure of drought owing to the influence of melting snow and ice. Here, low runoff occurs in the winter months.

From the standpoint of natural science, the MAM7 (7 day duration mean annual minimum) index has proved a useful measure of drought. This is based on the lowest average runoff during seven successive days within a calendar year. MAM7 is a sensitive measure of pronounced dry phases, since for low MAM7 values to occur, the time period of 7 days identified must be embedded within a longer period of drought.

Importance of drought

Drought has detrimental effects both ecologically and economically[3,4], and certain of these may have political consequences.

Ecological effects

During dry weather periods, less water is in motion. Also, since periods of drought and heat often coincide, the water temperature is often higher. Dissolved substances are not diluted to the same

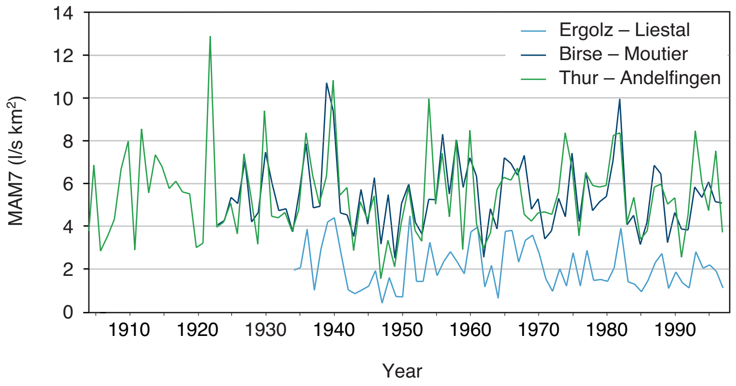

Fig. 26 Lowest average runoff for 7 consecutive days (MAM7 in l s^{-1} km^{-2}) for each year of the time series for the rivers Thur (in Andelfingen), Ergolz (in Liestal) and Birs (in Moutier).[5]

extent and are therefore present in higher concentrations. The dissolved oxygen content of the water decreases. The situation is made more serious if during dry phases water is taken from the rivers for irrigation purposes. Many water organisms thereby experience stress, particularly fish. Their mortality rate increases. Waterside vegetation also suffers from drought, and this can adversely effect animals in the wild.

Economic effects

The water supply is affected by enduring periods of dry weather. Drinking water (from springs and groundwater) can become scarce, and those branches of industry having a high demand for water can suffer restrictions in production (e.g. paper industry and those with high cooling water demands). Energy production in run-of-river and reservoir power stations can be reduced. Also, thermal and atomic power stations may be affected where insufficient cooling water is available, or where additional heating of the river is not permissible. In agriculture, arable and livestock farming may suffer losses in yield. Winter tourism may be affected by inadequate snowfall, and shipping by low water levels.

Political consequences

When water is scarce, the authorities must order restrictions on the use of water (water saving measures, rationing, etc.), and issue and enforce regulations on the use of water from public sources. In severely affected areas, logistic provisions such as water tankers, water pumps, supply pipelines and temporary reservoirs must be provided to avoid scarcity, and measures to maintain hygiene introduced.

Overall, drought is not an existential problem in Switzerland thanks to linked international markets and the plentiful supply of water in mountain regions. Furthermore, periods of dry weather are of varying intensity and often do not occur simultaneously in the different regions.

Observations and trends

By analysing the variations in precipitation and temperature, dry summers may be identified. Over the past 500 years, four extremely dry summers occurred in the Swiss Central Lowlands, namely in 1540, 1669, 1603 and 1947 (in descending order of intensity).[6] Prior to 1730, dry summers occurred about every 12 to 15 years. Since then, dry summers have occurred only about every 50 years. In the 20th century, only one dry summer was recorded, namely in 1947. The 20th century can therefore be regarded as a particularly favoured century where drought is concerned.

The low-water runoff in various rivers in the Central Lowlands (Fig. 26), which are hardly influenced by human activity except in periods of drought, present a consistent picture.[5] Here, the year 1947 mostly appears as the driest year. No trend is identifiable in the Swiss Central Lowlands during the 20th century.

Owing to a lack of suitable data to evaluate, the situation to the south of the Alps, and in the Alps themselves, cannot be assessed.

Future changes

According to IPCC[7], an increase in the intensity of continental summer droughts, and thus the risk of drought over most inner continental areas in central latitudes, is probable in conjunction with climate change.

When dry periods or drought arise in an area, the entire water regime is affected. However, information on changes in precipitation and temperature are not sufficient to assess possible changes in the occurrence of drought. Rather, a knowledge of changes in the intensity of precipitation and the sequence of rainy days at different times of year are needed.

Forecasting precipitation trends is difficult, and is accompanied by considerable uncertainty.

Possible changes include a shift in precipitation distribution in the Alpine region and in other parts of Europe, an increase in the average intensity of precipitation, and a decline in the water content of the ground in summer.

As a result of climate change, more rain and less snow will fall at low and central altitudes, and the snow reserves in the mountains will decline. In areas lacking large water reserves in the form of snow – particularly to the south of the Alps – reduced runoff, more extreme low water and drier soils must generally be expected in summer owing to reduced precipitation and higher temperatures. Also, rivers to the north of the Alps fed by melted snow will probably show reduced runoff owing to reduced snow reserves in summer and autumn. Particularly in the lower reaches of the Rhine, this will lead to more extreme low water, with associated adverse affects on shipping.[8]

Our knowledge of future changes in the occurrence of drought in Switzerland is limited. Any such changes could have relatively extensive consequences. In the past, drought often affected large areas. Despite international trade links, future short-term economic consequences could be significant. The ecological consequences are also very difficult to assess. Notwithstanding this, water is not generally expected to become scarce in Switzerland or in Alpine regions in other European countries favoured by ample precipitation.

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2.4. Forest fires

Marco Conedera

Forest fires occur more frequently to the south of the Alps than to the north. They are mostly caused by human activity. Humans will continue in future to influence trends in extreme forest fires both by starting them and through measures to prevent them. Natural factors such as drought and heavy winds, which could increase to the south of the Alps as a result of climate change, would also lead to an increase in the risk of fire.

Introduction

Fire occurs when combustible material, oxygen and ignition energy are all present at the same time and place. With forest fires, vegetable material – particularly dead material – supplies the fuel. Depending on its density, chemical composition and humidity, vegetable material varies in flammability.

The effects of forest fires depend, among other things, on the vulnerability of the ecosystem to fire, on the tree species involved, on the previous fire history and from other natural hazards arising subsequently in the area. Till now, the influence of fire on the environment has been little studied.[1] It is, however, clear that fire adversely affects the protection capability of the forest. As a result of the high temperatures and the ash arising in fires, the pores in the ground are sealed and the ground displays higher repellency to water.[2] During heavy rainfall, surface runoff and erosion are thereby increased.[3] In areas that have not suffered fire for more than 10 years, this effect is particularly marked, since none of the vegetation there is adapted to fire.[4] For example, in a fire which occurred in the area of Ronco near Ascona (Canton of Ticino) in 1997, 80% of the catchment area of the River Buffaga was affected. In the following period (in August), heavy rainfall of an intensity occurring only once a decade caused a flash flood – a century-wide record. A mud slide carrying some 4000 m^3 of material descended on inhabited areas causing losses to property of several million Swiss francs.

By chance, there were no casualties. The costs of fire fighting, which may in extreme cases top half-a-million CHF, appear quite low in comparison to the material losses.

In this chapter, an extreme event is defined as one or more forest fires that occur during dry weather, and are therefore very intensive, that affect an area of over 100 ha and/or entire catchment areas, and occur in areas that have not been affected by forest fires for over 10 years.

Causes

Of the forest fires occurring to the south of the Alps between 1981 and 2000, 8.6% were caused naturally by lightening (Tab. 3). With lightening, ground fires occur that spread only slowly. However, the frequency of the fires and of the circumstances causing them fluctuate heavily from year to year. For about 40% of all fires, the cause is unknown. Among fires of known cause, on average over 90% may be traced to premeditated or negligent human actions. Between 1981 and 2000, almost 97% of the areas burnt down resulted from these causes.

In addition to lightening – a direct cause of forest fires – natural factors exist in certain areas that increase the fire risk (Tab. 3). Frequently, lack of precipitation, high windspeeds, and low relative humidity are decisive. Solar radiation, humidity deficit and wind frequency also exert an influence. Failing precipitation and low humidity may exert an influence enduring for many years.

Humans cause forest fires mostly through negligence or arson. In rare cases, fires are caused by sparks from the railway or from an electrical short circuit, and through the impact of projectiles from military exercises. Human activity can alter the fire risk in an area. Today, legislative measures are the dominating influence. Also important are socio-economic influences (e.g. retreat of traditional agriculture and depopulation of remote valleys), landscape maintenance and measures to enhance environmental awareness. The effects of these are mostly long-term.

Table 3 Summary of the main factors influencing forest fires in Switzerland.[5]

			Frequency/ weighting	Time frame
Predisposing factors	natural	Precipitation	++	one day to several years
		Wind frequency	+	one to several days
		Wind speed	++	one day
		Relative humidity	++	one day
		Solar radiation	+	one day
		Humidity deficit	+	one day to several years
	human	Socio-economic developments	+	several months to several years
		Landscape maintenance	+	several months to several years
		Legislative framework	++	several months to several years
		Measures to enhance environmental awareness	+	several months to several years
Direct causation	natural	Lightening	8.6%	
	human	Negligence	26.1%	
		Arson	15.2%	
		Railway	3.6%	
		Military	1.7% 52.5%	
		El. connections (short circuit)	1.7%	
		Cross-frontier	1.7%	
		Others	2.4%	
	Cause unclear or unknown		38.9%	

++ = frequent / decisive; + = repeated / substantial influence
The figures in percent apply to the period 1981-2000

What trends are already visible?

Deposits of carbon particles in Lake Origlio (Canton of Ticino) suggest that the area south of the Alps has always been naturally vulnerable to fire (Fig. 27). Also, humans have continued to exert an influence on the frequency of forest fires, firstly by fire clearing (in the iron and bronze ages), and secondly by exerting a control function (from Roman times onwards). Data from Lake Lobsigen (Canton of Bern) show that in all probability the general level of forest fires to the north of the Alps is a factor of 2-5 lower than to the south of the Alps. Here too, the influence of human activity through fire clearing in the iron age may be seen.[6]

In the 20^{th} century, the annual number of fires to the south of the Alps increased in the 1960s from the previous average of 30 to 80 (Fig. 28a). Since the early 1980s, the number of forest fires has declined. The areas burnt down have decreased since the early 1960s, and most sharply since the early 1980s. One exception to this is the extreme year of 1973. Extreme events in which forest fires affected areas of over 100 ha were most frequent between 1941 and 1980 (Fig. 28b). Between 1981 and 2000, the number of fires declined to the level pertaining between 1921 and 1940.

No figures are available covering the whole area north of the Alps. In the (Alpine) area to the north of the Canton of Valais, the number of fires and the extent of the areas affected by fire have in general increased since the 1990s by a factor of 3-4 in comparison to previous decades (namely from 5.2 to almost 20 per year[7]). From 1978 onwards, a natural cause, namely lightening, was recorded in 12% of cases. In 34% of cases, the cause remains unknown.[7] In the Canton of Grisons, systematic recording of forest fires did not begin until the early 1980s. In most cases, smaller areas are involved (1-10 ha), but some larger areas were affected (Calanda near Choir in 1943, approx. 477 ha; Münstertal in 1983, approx. 60 ha; St. Luzisteig in 1985, approx. 110 ha; Misox in 1997, approx. 405 ha). Contrary to areas south of the Alps, the evaluation of these fires pointed to significant differences in time and extent between fires caused by human activity and those of natural origin. Fires arising predominantly from human activity (74% since 1980, incl. those of unknown origin) were identified mainly in the Grisons Oberland, Rhine Valley and Central Grisons. Fires of natural origin (26% since 1980, which were caused by lightening was) are concentrated in the regions of lower Engadine, Münstertal and the southern Grisons valleys.[10]

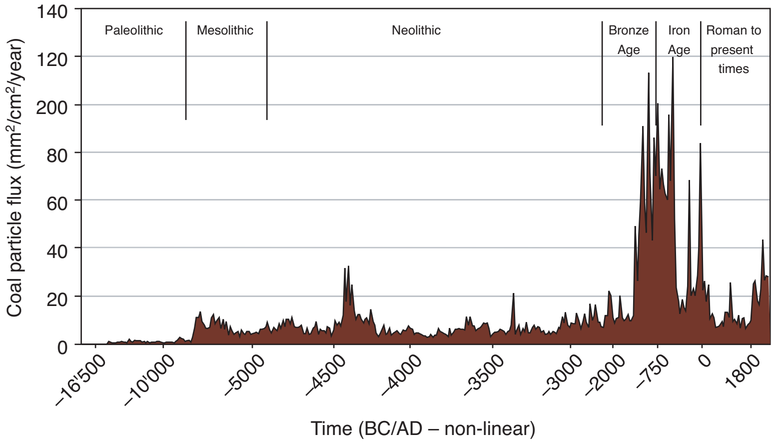

Fig. 27 Human activity also influenced the frequency of forest fires in earlier times. Deposits of carbon particles in the post-ice age, as identified in the sediment of Lake Origlio, are directly related to the frequency of forest fires.[8] The period 5000-7200 BC shows the level of natural forest fires under climatic conditions similar to today's. The very high frequency of forest fires in the bronze and iron ages is attributable to fire clearing by humans. However, fire clearing ceased when the Romans introduced the sweet chestnut around the year 1 AD.[9]

Trends in the frequency of forest fires mirror the influence of human activity. To the south of the Alps, the expansion of forest areas and the increasing quantities of combustible material left lying on the ground since the early 1960s have led to a larger number of fires. However, thanks to the proficient organisation of the fire services, the average area affected and the number of extreme events has declined. The reorganisation of the fire brigades in Ticino has been in progress since 1980. The Ordinance on Complete Prohibition of Outdoor Fires was introduced in 1987 (and partially relaxed in 1996). Furthermore, reports in the media have proved to be very effective, and the public is now more aware of environmental issues in general. In the Canton of Valais, this effect is less pronounced, environmental awareness there lagging behind by about 20 years. In the Canton of Grisons, the general prohibition applying to outdoor fires was repealed when the new cantonal forest law was introduced in 1996. However, the Grisons Forest Agency is authorised to issue temporary regional fire prohibitions when necessary via the Incendi forest fire forecasting system (www.wald.gr.ch).[11] Further forecasting methods are now being developed to cover the whole of the southern side of the Alps.[12]

Through landscape maintenance, legislation and measures to prevent fire, humans are modifying the conditions under which fires occur. By applying measures to combat fire, they are also exerting a controlling influence. Humans, however, are still responsible for most of the fires, both through negligence and arson.

Influence of climate change

Extreme events will continue to occur in the future, particularly where exceptionally unfavourable weather conditions arise. Following an extended dry period in early 1997 – and despite the generally declining tendency (Fig. 28b) – several larger forest fires occurred to the south of the Alps on days with heavy föhn gusts.[13]

In an analysis of dry periods in Ticino, although somewhat longer periods of low precipitation were found towards the end of the 20th century[14], no connection was found between these and the forest fires shown in Fig. 28. It was mentioned in Chapter 2.3 that in future, particularly to the south of the Alps in summer, reduced discharge, more acute low water and drier soils must be expected as a result of reduced precipitation and higher temperatures. This could increase the probability of several critical fire conditions arising at the same time.

The occurrence of extreme forest fires will continue to be influenced on the one hand by human action such as landscape maintenance, fire protection and fire fighting, and on the other by the frequency of extreme weather conditions such as longer periods of drought in conjunction with heavy winds. In predicting trends in forest fires, research must take both these factors into account.

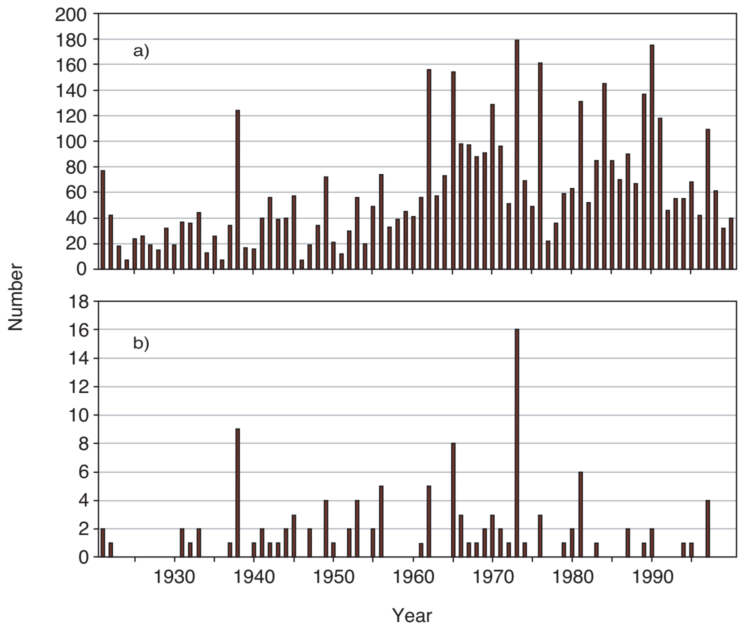

Fig. 28 Trends (a) of the number of fires per year and (b) the number of extreme events involving an area >100 ha. Reference time period 1900-2000. Database on forest fires to the south of the Alps.[5]

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2.5. Heavy precipitation

Christoph Frei

In Switzerland, heavy precipitation may either be intensive and of short duration in connection with summer thunderstorms, or less intensive and of several days duration in connection with stationary weather systems. Extremely heavy precipitation can lead to floods, rivers overflowing their banks, debris flows and landslides. In the course of the 20th century, the frequency of intensive daily precipitation events has increased over wide areas of the Central Lowlands and at the northern fringe of the Alps. Trend predictions on extremely heavy precipitation cannot be made. Most simulations based on climate models indicate a future increase in the average intensity of precipitation and the frequency of intensive daily precipitation. Assuming an acceleration of the hydrological cycle, intensive precipitation of long duration could become more frequent in the Alps.

Types of heavy precipitation in Switzerland

Roughly speaking, there are two types of heavy precipitation in Switzerland: short and intensive, and longer and less intensive.

Heavy rain of short duration (one to several hours) and high intensity (40-80 mm per hour) occurs mainly in summer in connection with thunderstorms, and is confined to the actual path of the storm (several kilometres to several dozen kilometres long). Extreme events can lead to overflowing of streams and smaller rivers, and also to debris flows in the mountains (cf. Chapter 2.7 and 2.8). In inhabited areas, should the capacity of the drainage systems be exceeded, this can lead to flooding. Occasionally, short and intensive rainfall is accompanied by hail (cf. Chapter 2.6). An example of an extreme short-range heavy precipitation event is that of the Sachseln thunderstorm of 15 August 1997.

Heavy precipitation of longer duration (one to several days), but lower intensity (100-400 mm per day), can occur at any time of year in connection with intensive and/or more-or-less stationary large-scale weather systems. Extreme and persistent rainfall can lead to floods and possibly also to overflowing of larger rivers and lakes, and to debris flows and landslides (cf. Chapter 2.7 and 2.8). Examples in this category are the enduring precipitation events in May 1999 in eastern Switzerland, those of October 2000 in Valais and Ticino, and the devastating extreme precipitation in Central Europe in August 2002. Extreme and enduring precipitation in the form of snow can cause widespread and large-scale avalanche falls (cf. Chapter 2.9).

The damage from heavy precipitation does not usually arise directly but via intermediate effects such as floods, landslides and avalanches (cf. Chapter 2.7, 2.8 and 2.9), or hail (cf. Chapter 2.6). Therefore the resulting damage depends not only on the duration and intensity of the precipitation, but also to a large extent on existing conditions in the area (e.g. ground humidity and effects such as melting snow).

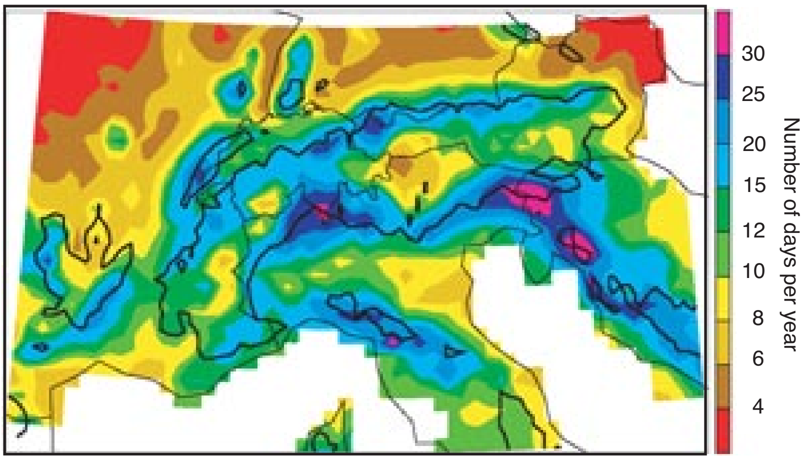

Fig. 29 Climatological frequency of daily precipitation values greater than 20 mm per day in the Alpine region between 1971 and 1990 (number of days per year).

Climatology

Topographical effects such as the uplift of air-masses by the Alps, and triggering of thermals over hills and mountain chains, play a significant role in the generation of heavy precipitation in Switzerland. Thus the topography is mainly responsible for determining where, and how frequently, heavy precipitation occurs. Precipitation rates of 20 mm per day and above occur more frequently along the northern and southern fringe of the Alps and in the Jura than in the Central Lowlands and the inner Alpine valleys (Fig. 29). Ticino is affected about twice as frequently as the Central Lowlands. In fact, the large number of heavy precipitation events in Ticino is exceptional for the Alpine region.

In Ticino, heavy precipitation occurs particularly frequently in the autumn. Here, weather fronts and low-pressure areas enter the Mediterranean region on more southerly paths than in summer, resulting in massive humidity transport towards the southern Alps. During the heavy precipitation event of October 2000, the quantity of water impinging on the Alps from the south over a period of 5 days was estimated to equal the total volume of Lake Geneva (Fig. 30). Also, Valais and Puschlav are often affected by southerly flow phenomena of this kind.

Trends observed in the 20th century

Precipitation in the Alpine region fluctuates heavily from one year to another. Depending on the time of year and the region considered, humid and dry years may differ by factors of 2 to 4. Observations show that in northerly and westerly regions of the Alps, average winter precipitation increased by 20-30% in the course of the 20th century.[1] In contrast, average precipitation in the Mediterranean part of the Alps in autumn has decreased by a similar amount.

Reliable predictions of trends in extremely heavy precipitation are not possible, since rare events of this nature are poorly ascertainable from the statistics (cf. Chapter 1.4). Trend analyses are confined to more frequent events having intensities well below those leading to damage. At most of the stations of long-standing in the Swiss Central Lowlands, and at the northern fringe of the Alps, intensive daily precipitation values (return period 30 days) have increased in winter and autumn (Fig. 31).[2] The trend is significant at about 30% of the stations, the increase being of the order of 20-80% per 100 years. Similar trends have been demonstrated for intensive precipitation of 2-5 days' duration. No systematic trends are evident for intensive daily summer precipitation values (Fig. 31).

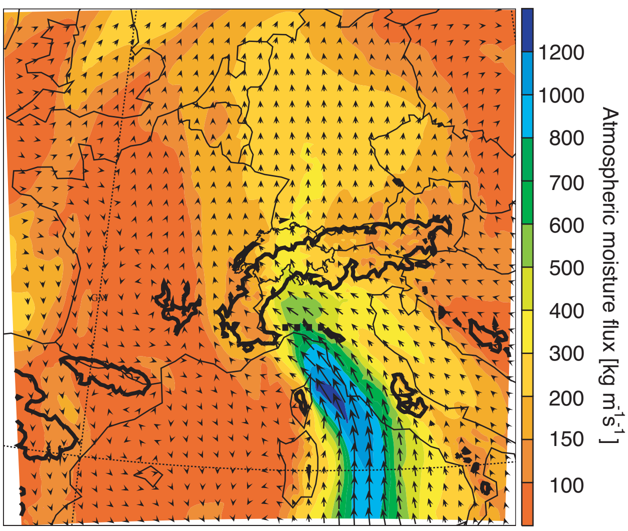

Fig. 30 Vertically integrated atmospheric moisture flux on 15 October 2000. Between 12 and 16 October, the quantity of atmosphere-borne water impinging on the Alps from the south was estimated to equal the total volume of Lake Geneva.

Despite this, the possibility of trends in the intensity of summer thunderstorms cannot be excluded. Owing to the short duration of thunderstorms, trend analyses based on hourly precipitation intensity would be more conclusive. For this, the time resolution of the long-range measurements is insufficient.

As in Switzerland, an increase in average and intensive winter precipitation values has been observed in neighbouring parts of Europe.[3] Changes in autumn precipitation to the south of the Alps – where the average is decreasing and intensive events are increasing – have been confirmed by trend analyses for Italy.[4]

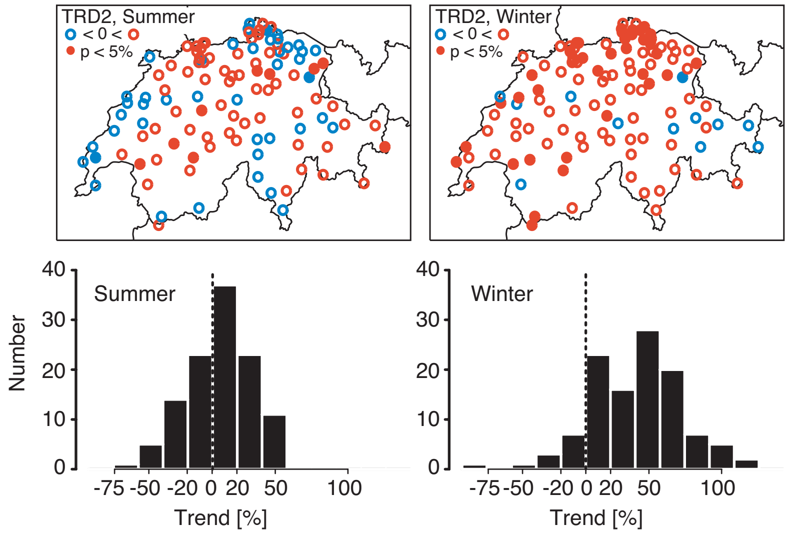

Fig. 31 Trend in the frequency of intensive daily precipitation values (one event per month on average) at 110 Swiss precipitation stations in the period 1901-1994. Top: stations with an increase (in red), and with a decrease (in blue). Full circles for stations with statistically significant changes. Bottom: histograms of the percentage change (change in probability) since 1901 for all stations.[2]

Effects of global climate change

Three chains of causation may be discerned connecting the frequency of extreme precipitation with global climate change:

(a) It is expected that climate change will lead to more pronounced warming in polar than in tropical regions, and that the vapour content of the atmosphere will increase. Both of these factors could influence the intensity, frequency and path of low-pressure areas in central latitudes. Changes of this kind may be directly coupled to changes in the geographical distribution and intensity of precipitation in Europe, with the inclusion of the Alpine region.

(b) In central latitudes, warming of the atmosphere is associated with an increase in the vapour content of approx. 6% per degree (Clausius-Clapeyron equation). At present, it seems fairly well established that the resulting intensification of the hydrological cycle will contribute to an increase in the average intensity of precipitation. The intensification will also have a disproportionately large effect on the frequency of heavy precipitation.[5]

(c) The intensification of the hydrological cycle is also associated with increased evaporation. In regions with a long dry season such as the Mediterranean, this could lead to a decrease in the water content of the ground in summer and autumn. This in turn could affect the thermodynamics of the lower troposphere and the precipitation dynamics. The possible significance and extent of this effect on the Alpine region are not yet fully understood.

Several global climate simulations for the second half of the 21st century were analysed for characteristic indicators of heavy precipitation. The majority suggest a global increase in the average intensity of precipitation and the frequency of intensive daily precipitation values.[6] This tendency is confirmed by the available regional model analyses for Europe, which show an increase in the maximum annual daily precipitation values of 10-25%. Increases by a factor of 2 and more have been identified in the frequency with which the current yearly and the current 50-yearly extreme precipitation values will be exceeded.[7] An analysis of the results of 19 global climate models shows that the frequency of winters with extreme precipitation (current return period 40 years) could in fact be exceeded by factors of 3-5 (Fig. 32)[8]. In the winter months, the increases are expected to affect the whole of the European continent, and in summer particularly central and northern Europe.

The increases in heavy precipitation found in many of the models is interpreted primarily as a result of the intensification of the hydrological cycle arising from global warming (chain of causation b). It is now regarded as probable that the hydrological cycle will intensify over the entire continent during the winter months.[9] In the Alpine region, this could result above all in increased heavy precipitation of long duration. This effect depends not only on the particular weather constellation but also on the quantity of water vapour borne in by the atmosphere. The particularly extreme autumn events to the south of the Alps could also be in this category.

Note, however, that the models display wide differences in the regional patterns of change. The differences are attributable to the fact that the typical paths and intensities of the low-pressure areas (chain of causation a) change to a different extent in the models. Thus it is still not clear how, and where, any changes in large-scale weather dynamics would accelerate – or compensate for the intensification of – the hydrological cycle. Therefore, the quantitative results for the Alpine region should be regarded as no more than rough approximations. At present, neither qualitative nor quantitative estimates may be made of heavy precipitation in the Alpine region in summer. No model analyses are available based on hourly time intervals, and existing models display large systematic errors in summer. Furthermore, the interactions between soil hydrology, vegetation and precipitation dynamics in summer (chain of causation c) are still not sufficiently understood, and are therefore not yet included with sufficient precision in the models.

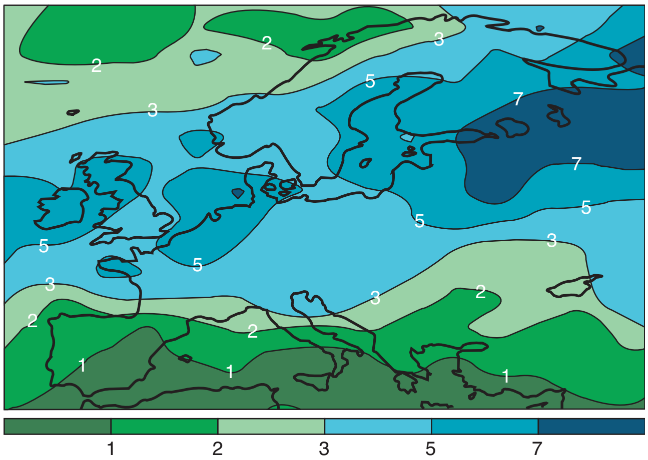

Fig. 32 Relative change in the frequency of extremely wet winters for a doubling of the CO_2 content of the atmosphere. For current winter precipitation intensities occurring on average every 40 years, simulations show an increase over Central and Northern Europe of a factor of 3-5. Results of 19 coupled climate models.[8]

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2.6. Hail

Hans-Heinrich Schiesser

With extreme hail events, the individual storm cells are distributed along a line extending across the entire Central Lowlands and the Alpine foothills for several 100 km. Over five-hundred communes were affected by the five extreme hail events that occurred since 1920. These events are distributed evenly over the period of observation. However, the frequency of the four characteristic large-scale weather constellations responsible for extreme hail events has increased significantly since 1940. If the increase in frequency of these weather constellations continues, a rising number of extreme hail events must be expected in the future.

Definition of an extreme hail event

Hail events often occur over a very confined area. An individual hail cell generates a hail swathe that deposits several stripsof hail along the ground. In a large storm system, several hail cells can form producing numerous bands of hail in the whole of Switzerland. The hail, water and wind resulting from these can cause widespread damage to agriculture, forests, buildings and cars. In rare cases, several storm systems may arise covering the whole of Europe.

Extreme hail events can arise both from individual cells and from storm systems. In hail cells, extreme hailstone sizes of 5-10 cm, gusts of 144-180 km/h, rain intensities of 100 mm/h, precipitation of 30-50 mm/m^2 and several lightening strikes per km^2 may arise.[1] In an extreme storm system, the individual storm cells are situated along a line extending from west to east right across the Central Lowlands and the Alpine foothills, and cover a distance of several 100 km. Meteorologists term these systems mesoscale convective storm systems (MCS). In the wake of the linear formation, an extensive precipitation regime ensues in which rainfall may be intensive. In hail cells belonging to a formation, higher hail and rain intensities, rain quantities, windspeeds and lightening activity are observed than in isolated cells.[2]

In the following, we shall define these storm systems (MCS) in Switzerland to be extreme events. They impact over a large part of the country and cause widespread damage.

Meteorological conditions

Extreme MCS are known to occur in Switzerland under very specific meteorological conditions[3]:

(a) The large-scale weather constellation is characterised by a so-called trough system, with winds impinging on Switzerland from the south-west.
(b) A cold front with large temperature differences lies over France and extends well into Spain.
(c) Warm and humid tropical or subtropical air preceding the front is carried into Switzerland.
(d) The pressure differences over Switzerland are low and the stratification is unstable.
(e) Shortly before the arrival of the cold front from the west, solar radiation over the Central Lowlands is at a maximum. The lowest air strata heat up to over 30°C.

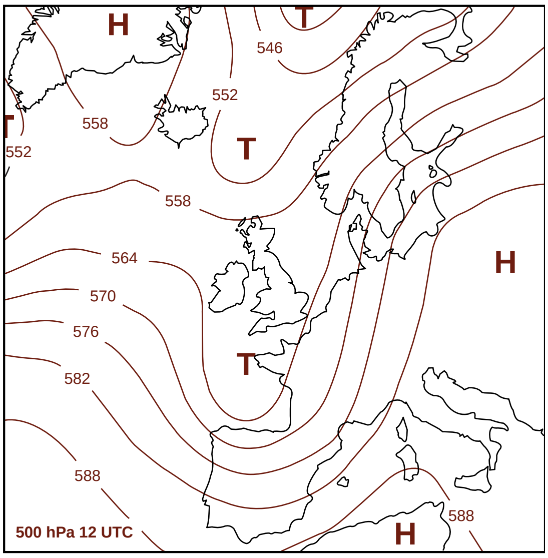

Fig. 33 Typical trough system over the Bay of Biscay with a south-westerly flow towards Central Europe (500 hPa niveau). The example refers to 5 July 1999.

(f) The cold front arrives in the late afternoon. In advance of, and within, the front, storm cells begin to form.

(g) The storm cells are positioned along one or more linear MCS.

Four characteristic large-scale weather constellations were responsible for the five extreme hail events occurring in the last 80 years. A common factor of all these is the south-west wind in advance of the front. A characteristic trough constellation over the Bay of Biscay that advanced on Central Europe from the south-west led to the extreme hail event on 5 July 1999 (Fig. 33).

Extreme event: frequency and trends

Areas of precipitation may be tracked, and large and intensive hail cells identified by means of weather radar. Individual hail cells may also be assigned to larger storm systems. However, systematic radar measurements did not begin in Switzerland until around 1980.

Thus no long-term measurements are available that could enable the frequency and trend of extreme events (MCS) to be analysed. However, the area affected by hail may be determined from hail insurance data. Also, the loss statistics permit scientific assessment of the effects of climate change on extreme hail events.

Statistics are available in the form of reliable and relatively homogenous measurement series beginning in 1920[4,5], showing the number of communes north of the Alps that reported hail damage in agriculture on each day of the year. These figures provide an indication of the extent of a storm system, assuming at least one farmer reported damage.

Fig. 34 shows how many communes reported hail damage in agriculture on how many days between 1920 and 1999. In total, 5690 days of hail were recorded. In five cases (0.1%), 500 or more communes (from among 2400) were affected. The fact that these five extreme hail days represent an MCS event is illustrated by the distribution of communes reporting damage during the hail event on 21 July 1992 (Fig. 35). This led to (insured) losses of approximately 100 million CHF. To these must be added the uninsured losses, including extensive losses to forest areas.

All days of hail between 1920 and 1999, for which over 100 communes reported damage, are shown in Fig. 36. The five extreme events are evenly distributed over the observation period.

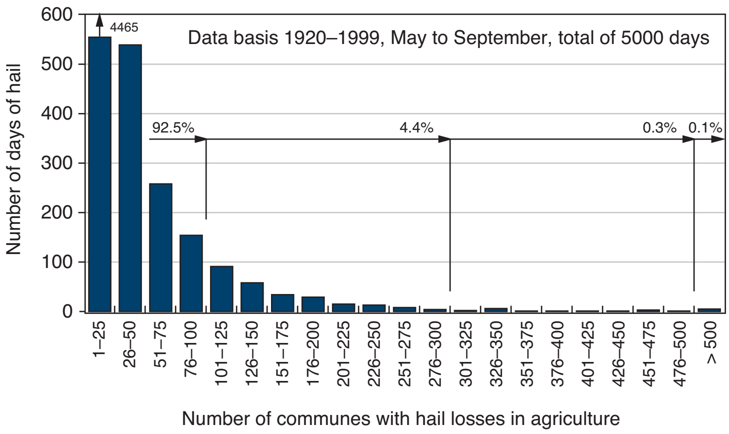

Fig. 34 Number of days of hail for a specified number of affected communes (from among 2400 Swiss communes to the north of the Alps) with hail losses in agriculture. On five (0.1%) of the 5690 days of hail between 1920 and 1999, over 500 communes were affected (last column). These cases are defined as extreme. Days with 100-200 affected communes are designated as heavy (3.9%, columns 5-8). The 4465 days of hail with only 1-25 affected communes occurred during the same period (79%, first column).

From 1980, the number of 'heavy' hail events causing losses in 100 to 200 communes increases. This trend is clearly shown in Fig. 37. Whilst prior to 1980 the frequency of hail events is approximately constant, it increases significantly between 1980 and 1994. Following the intensive year of hail in 1994, it decreases again, but remains above the average for the period before 1980.

Since 1940, the frequency of the four large-scale weather constellations responsible for extreme hail events has increased significantly in Central Europe in summer (Fig. 38).

Influence of climate change

Should the frequency of the four large-scale weather constellations continue to increase in the European region as a result of climate change, the conditions under which storm systems arise will become more frequent. In this case, more extreme hail events would be expected. Furthermore, the trend among the 'heavy' hail days could continue to increase.

Whether or not the events will become more intensive or not also depends on whether the stratification of the troposphere during the summer months becomes less stable as a result of climate change. Unstable stratification encourages the formation of storm cells during the progression of the front. Balloon measurements performed between 1954 and 1993 have shown that the temperature of the lower troposphere has risen more sharply than that of the upper troposphere, and that stratification stability has diminished.[1,5]

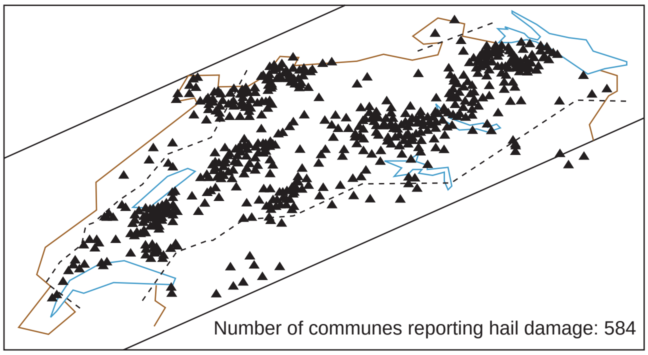

Fig. 35 Distribution of communes reporting hail damage on an extreme day (21.7.1992). The hail swathe accompanying the storm system (SW-NE direction) is clearly discernable from the distribution of the communes.

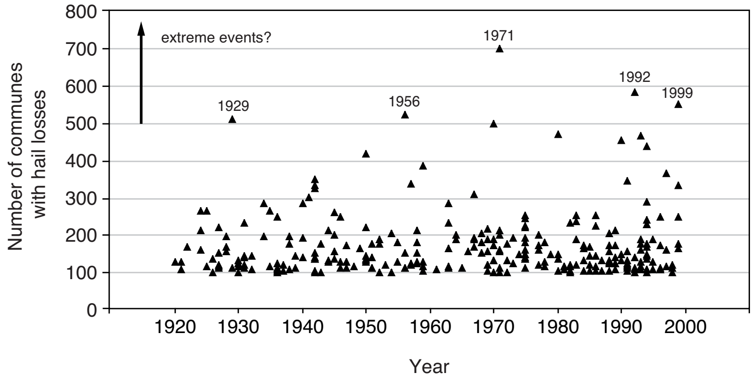

Fig. 36 Time series of days between 1920 and 1999 on which 100 and more communes north of the Alps reported hail damage in agriculture. The five extreme days are fairly evenly distributed over the observation period. For between 100 and 200 of the affected communes, somewhat more heavy bunching of hail days following 1980 may be seen.

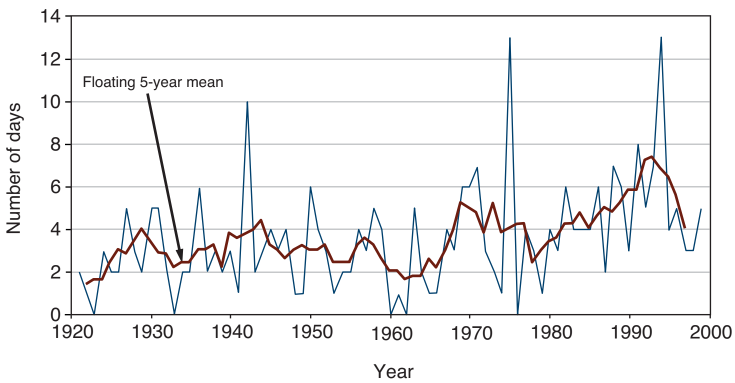

Fig. 37 Time series of the number of days with 100 and more affected communes between 1920 and 1999. The increasing trend of heavy hail days between 1980 and 1994 may be clearly seen.

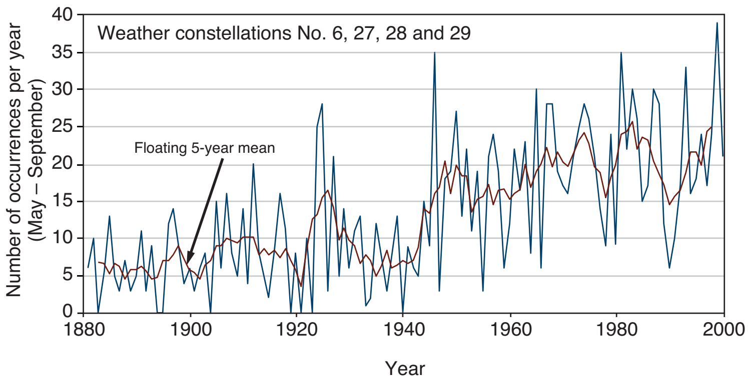

Fig. 38 Time series for 1881-2000 of the four weather constellations[6] responsible for extreme hail days. The south-westerly flow in advance of the front is common to all four constellations (Fig. 33). Since 1940, a marked increase in the frequency of the four weather constellations is observed.

The data series for hail days was processed up to 1999. New data for 2000 show a further 'extreme day' (3 July) on which 620 communes were affected. This means in affect that in the 10 years from 1992, 3 cases were recorded in comparison to only 3 cases in the 70 previous years. However, insufficient data are available to discern whether this represents a real trend or an incidental concentration (cf. Chapter 1.4).

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2.7. Floods

Armin Petrascheck

Floods arise through the interaction of precipitation, temperature and the physical condition of the catchment area. During extreme floods, the long-range flood peaks are substantially exceeded. The flood peaks in Switzerland show no uniform increase or decrease in the course of the 20th century. Climate change can, however, influence the occurrence of floods through increases in temperature, changes in precipitation and changes in the catchment area. In those areas of the Central Lowlands in which floods already occur in winter, an increase in the risk of floods is probable. For catchment areas in the high Alps, factors that increase or decrease runoff must be considered, so that changes in the risk of floods are very difficult to predict.

Introduction and definition

The term flood denotes a runoff rate significantly above the average. In hydrological science, peak runoff values are assigned various probabilities (return periods), reference being made to a 10 or 100-year flood (HQ10 or HQ100). Although a HQ100 is a rare event, it only results in damage where the runoff rate is significantly larger than the majority of peak values observed up to that point. Thus a comparison of the high-water peaks in the River Albula in Tiefencastel and of the Rhine in Domat-Ems (Fig. 39) shows that the natural variation must be taken into account. For the Rhine, the runoff is 40% higher for a 100-year event than for a 10-year event, and the water level is 1.5 m higher. Contrary to this, for the River Albula, the runoff is only 20% larger for a 100-year event than for a 10-year event, and the water level rises by only 25 cm more.

Although probability values are essential for many purposes, they contain no information on the extent of runoff and its significance to humans and the environment. From the standpoint of the natural environment, the runoff quantities of interest are those that initiate bed load transport, flood alluvial forests or alter the course of a river. Events of this sort are usually relatively frequent, with return periods of less than 2 to 10 years. Also, they generally do not lead to damage, and little notice is taken of them since humans and the ecosystem have adapted to them. From the human standpoint, runoff rates are of interest for which the river leaves its bed and penetrates into exploited areas.

As a rule, extreme events considerably exceed all floods recorded in the recent past. Thus, for example, the runoff of the River Reuss in the Canton of Uri was 50% larger in 1987 than over the previous 90 years. Flooding of the River Langeten in Lotzwil (Canton of Bern) in November 1975 (Fig. 40) was even more extreme, exceeding all previously recorded flood peaks since 1924 by a factor of several times. Events of this kind reshape the hydrological system, and areas well beyond the normal river bed are flooded. Where nature is concerned, such events are part and parcel of normal landscape dynamics. For humans, they signify high losses and/or natural catastrophes.

Floods are recognised as events that cause damage: whether or not they lead to losses is

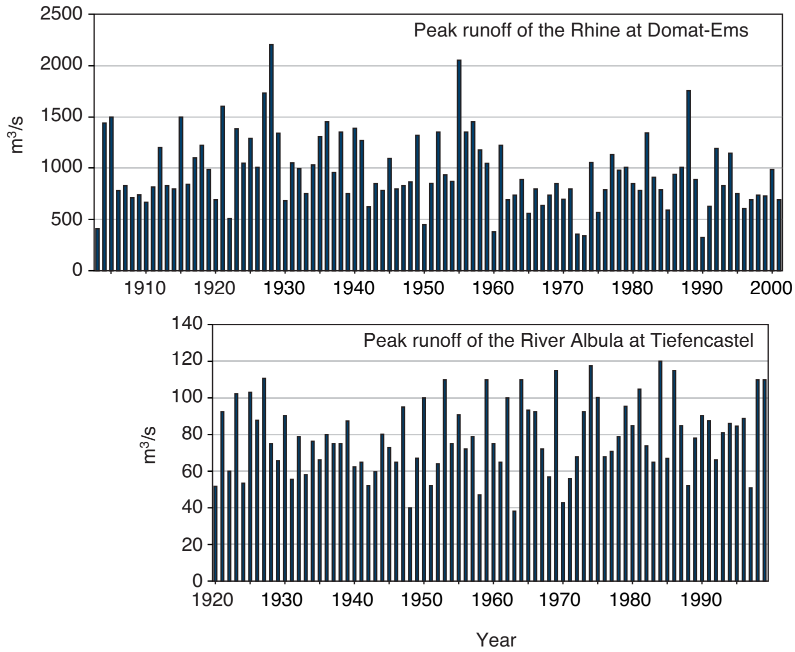

Fig. 39 Flood peaks of the Rhine at Domat-Ems display considerable variability. In the period 1899-1962, a 10-year flood corresponded to runoff of 1550 m³/s and a high-water mark of 10.1 m. For a 100-year flood, the runoff was 43% higher (2200 m³/s) and the high-water mark 1.5 m higher (12.6 m). In distinction, the flood peaks of the River Albula at Tiefencastel are more evenly distributed, a 100-year flood hardly being experienced as extreme. A 10-yearly flood corresponds to runoff of 105 m³/s and a high-water mark of 8.2 m. For a 100-yearly flood, runoff is 130 m³/s and the high-water mark 8.45 m.

influenced by the presence of protective structures. Thus in September 1993, a runoff of 90 m³/s in the River Saltina in Brigue resulted in losses of approximately 500 million CHF. In October 2000, although the runoff was higher at 125 m³/s, the safety structures erected in the meantime prevented more extensive damage. For Brigue, of course, 1993 remains the critical year for floods.

Conditions leading to floods

Floods arise through the interaction of precipitation, temperature and the physical condition of the catchment area.

In rivers with large catchment areas (>300 km²), extreme flood events are associated with frontal weather systems leading to long-enduring precipitation over the entire catchment area (cf. Chapter 2.5). The extensive flood events of 1910 and 1999 are attributable to large-scale weather systems centred over the northern Alps, and those of 1987, 1993 and 2000 to humid air flows from the south. Where small catchment areas (<100 km²) are concerned, thunderstorms in summer represent the greatest danger (examples: Sachseln 1997 and Gantrisch 1990).

There is no direct connection between precipitation quantity (or intensity), and peak runoff, since the quantity of water stored in the catchment area varies according to the weather history. Thus the extreme runoff in the River Langeten (Fig. 40) resulted not from exceptionally high precipitation alone, but also because its capacity for water storage had already been exhausted. Previously – but under different conditions – comparable precipitation had been heavily damped by the river overflowing its banks.

In Alpine regions, temperature plays an important role. With a low zero degree line, part of the precipitation falls as snow and does not run off immediately. Thus in October 2000, Valais was spared more serious consequences by a fall in the zero degree line from 3000 m to 2600 m in the final precipitation phase. Temporary storage of precipitation in the form of snow reduces peak runoff. In contrast, melting snow increases runoff, whereby the latter is more likely to take the form of a moderate increase over one to two weeks than of an extreme peak. Thus in spring 1999, thawing of snow in combination with heavy, but not exceptional, precipitation led to record water levels in the Central Lowland lakes and to high water in the Rhine, the Thur and the Aare.

Trends in the 20th century

No consistent trends are identifiable in peak runoff in Swiss rivers during floods. This is also related to the heavy influence humans have on them. Thus between 1955 and 1970, the exploitation of the Rhine at Domat-Ems for hydropower (Fig. 39) resulted in a reduction of annual peak runoff. Other factors such as the increasing areas of forest and extended flood protection affect runoff. In a systematic study of the Bavarian Landesamt für Wasserwirtschaft[2], no trend at all was identified at 73 stations, whilst 2 others displayed a positive and a negative trend, respectively.

The identification of trends in these very rare extreme events is almost impossible on a statistical basis (cf. Chapter 1.4). Recent times have seen a conspicuous concentration in floodscausing heavy losses (1987, 1993, 1999, 2000 and 2002). Note, however, that a comparable concentration also occurred in the 19th century (1834, 1838, 1852 and 1868). Moreover, a glance at the long-range data and the chronicles shows periods without any significant floods, for example between 1940 and 1950. Thus till now, it has only been possible to speculate on – but not to explain – this episodic behaviour.

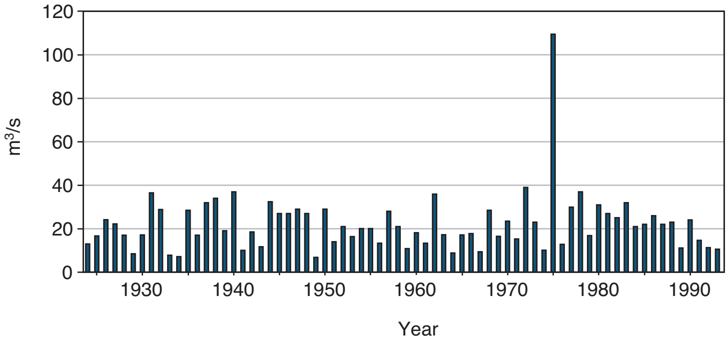

Fig. 40 Maximum summer and winter flood peaks of the River Langeten during the observation period 1924-1993.[1]

Influence of climate change on flood processes

Climate change can influence the occurrence of floods via various processes:

Influence of temperature increase

In Switzerland, the risk of floods cannot be discussed independently of where the zero degree line lies. In the Alpine catchment areas with their extremely varied altitude, snow has an important function, firstly in retarding runoff and secondly as a supplier of water in the thawing season. As a result of climate change, the zero degree line will rise, and rain will fall over wider parts of catchment areas. The likelihood that heavy precipitation will coincide with a high zero degree line, leading to extremely high runoff, is increasing. In addition, should the precipitation quantity per event increase with the change in climate, the peak runoff and the probability of floods will rise. If the effects of safety measures are for the moment ignored, the danger of floods, and thus of more frequent and more extensive losses, would be expected to increase.

Changes in precipitation

The latest simulations show that in winter, precipitation in the Alps will probably increase as a result of climate change. At low and central altitudes of the Central Lowlands, there will be more rain and less snow, so that the frequency of floods in winter will increase. This will particularly affect the Rhine downstream of Basel. Also, certain areas in the Cantons of Aargau, Thurgau, Basel Land, Jura and Zurich will be put at risk. Whether or not the increase will affect both frequent and extreme events will depend on changes in the frequency and intensity of the frontal weather systems.

In spring, floods occurs when thawing coincides with heavy precipitation. The 'heat input' in spring will probably change little as a result of climate change. Therefore the change in precipitation will have a larger influence on floods than the melting of snow. Although the increase in average winter precipitation will lead to larger quantities of snow in the high Alps, snow cover at lower altitudes will decrease owing to the higher winter temperatures. Which of these effects will have a greater influence on the occurrence of floods depends on the altitude profile in the catchment area, the increase in the quantity of winter precipitation and the frequency with which snowfall and melting snow alternate. Altogether, the 'flood-free' periods resulting from low winter temperatures will become shorter.

Floods in the smaller catchment areas are mostly associated with summer thunderstorms. Local thermal updrifts are responsible for the intensity and quantity of precipitation. Any predictions of an increase or decrease are purely speculative. Frequency changes resulting from thundrous weather conditions tend to have a greater effect on losses due to hail (cf. Chapter 2.6) than on those due to floods.

Changes in the catchment area

Glaciers and permafrost at high altitudes in the Alps are on the retreat as a result of climate change. For this reason, more debris can be mobilised. Furthermore, soil generation is influenced by changes in vegetation, indicated, for example, by the rising tree line. These processes can alter the course of rivers, thereby altering the risk of floods. Such processes take place very slowly – changes in permafrost requiring decades or centuries, and those in soil generation centuries to millennia.

More immediate effects will result from higher transpiration of plants at higher temperatures, causing more rapid depletion of the water reserves in the ground, and having a damping effect on flood generation. This effect will be mainly noticeable in areas with frequent floods, but also in Alpine and sub-Alpine regions subject to summer floods, and where no significant changes in summer precipitation are to be expected.

In conclusion, it may be said that the risk of floods will increase in those parts of the Central Lowlands in which the influence of floods in winter is dominant. This follows from the predicted increase in winter precipitation and the reduced snow fraction at altitudes between 1000 and 1500 m. At high-Alpine altitudes subject to typical summer floods, the rising zero degree line could lead to an extension of the period in which snow-free precipitation occurs and there is a risk of floods. To what extent this effect may be compensated at lower altitudes by plant transpiration is difficult to predict.

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2.8. Mass movements: landslides, blockfalls and rock avalanches

Hugo Raetzo and Olivier Lateltin

Where a large input of water persists over longer periods, it can lead to mass movement. Unstable slopes represent approximately 7% of the land area in Switzerland. In western Switzerland, the increase in precipitation has led to more frequent movements in many landslide areas since the early 1970s. In recent times, heavier winter precipitation in combination with large volumes of snow water have also provoked more frequent landslides. Receding glaciers, thawing of permafrost in the ground, increasing winter precipitation and the rising snow line could cause a general increase in slope instability.

Definition

Mass movement is defined as a downward displacement of compact and/or loose rock. It mainly comprises gravitational processes (stonefalls, blockfalls and rock avalanches), landslides und earth flows. These can occur either quickly and suddenly, or slowly and continuously.

It is estimated that about 7% of the land area of Switzerland is affected by slope instability. Extensive landslide areas occur particularly in flysch formations[1] containing a high fraction of clay and silt, making them susceptible to instability. Owing to the fine-grained soils in these areas, rainwater seepage is hindered, so that the water content is high the whole year round. The presence of water in the soil and the rock renders the ground more vulnerable to instabilities.

Smaller mass movements often occur unnoticed in uninhabited areas; larger mass movements are perceived as extreme when they cause losses to assets. Smaller earth flows too, can have devastating effects at the local level (e.g. Gondo on 14.10.2000, Lutzenberg on 1.9.2002 and Schlans on 16.11.2002). In this chapter, large and infrequent movements of very large landslide-prone slopes (with a volume exceeding 1 million m^3) and concentrated occurrences of several smaller landslides (up to several 100000 m^3) are designated as extreme events. Following abundant precipitation in the summer of 2002, approximately one-thousand spontaneous landslides occurred in Switzerland, several hundred of which occurred in central and eastern Switzerland.

Critical weather conditions and tendency towards instability

Mass movements occur when a large input of water occurs over longer periods. In the mountains, this is only the case for temperatures above the freezing point, since otherwise the precipitation is stored in the form of snow and ice. Large quantities of water are available in the spring in cases where heavy thawing and heavy precipitation coincide, and before and during summer and autumn in the case of heavy and

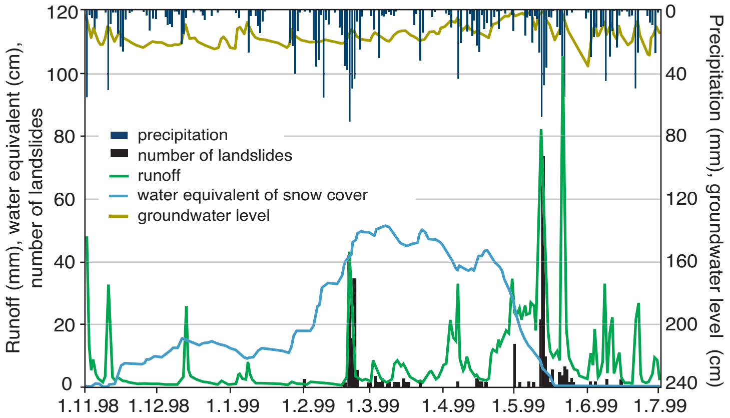


Fig. 41 Precipitation and groundwater variations in the storm year 1999.[2] The figure shows the precipitation (top: blue), the groundwater level (top: brown), runoff (bottom: red) and the water equivalent of snow cover (bottom: light blue) in Alptal in the Canton of Schwyz (WSL data). For comparison purposes, slope instabilities are shown at daily intervals (bottom: black). The first period of high landslide activity occurred between 20 and 23 February 1999 following the last snowfalls in the mountains. A second landslide period occurred between 12 and 17 May 1999 in the course of heavy precipitation, coinciding with the end of the thawing season.

enduring precipitation (cf. Chapters 2.5 and 2.7). For example:

- In the avalanche winters of 1888/89, 1950/51 and 1998/99 (cf. Chapter 2.9), large quantities of snow lay on the ground in late winter. Owing to higher temperatures the following spring, the snow thawed rapidly. At the same time, it rained prolifically over a long period. This resulted in increased movement of numerous landslide-prone slopes, and many debris flows occurred (cf. Fig. 41). A similar but locally more confined event occurred in Falli Hölli in the Canton of Fribourg in spring 1994, when large quantities of snow water caused a rapid acceleration of the landslide. Forty houses were carried 200 metres down the slope and completely demolished.
- In 1987, 1993 and 2000, numerous Alpine valleys were visited in summer and autumn by intensive precipitation over a period of several days (cf. Chapters 2.5 and 2.7). These carried with them large quantities of water, causing slope instabilities and flooding. On 13/14 October 2000, an extreme event occurred in the area of the Simplon Pass. A southerly flow situation carried hot and humid air from the South towards the Alps for 8 days. Almost 500 mm of rain fell within two days, corresponding statistically to a 300 to 1000-year event. On 14 October 2000, the safety barrier above Gondo broke. The resulting landslide with earth flow claimed 13 human lives.

Slope instabilities in the past

Prehistoric age

Towards the end of the last ice age when the glaciers receded, and at the beginning of the Holocene about 11 600 years ago, the large landslide areas in the Alps were very active (Fig. 42). In the absence of the retaining forces of the ice masses, the flanks of the valleys that were formed by glacial action loosened. At the same time, extensive areas of permafrost, in which compact and loose rock masses had been held together, thawed out. This resulted towards the end of the last ice age, and to a lesser extent at the end of the little ice age, in landslides and numerous rockfalls[3,4]. The Alpine valleys were filled with landslide debris and in some places mass movements dammed the rivers, forming lakes and swamps (e.g. in Davos, Flims, Pfynwald and Schwarzsee).

Over the last 9000 years (Holocene), temperatures remained fairly constant. Over that period, slope instability was probably caused mainly by fluctuations in precipitation. However, the temperature and precipitation data for the Holocene still remain incomplete and imprecise, so that the relationship between slope instability and climate is poorly defined. Significantly more landslides occurred, for example, in the Löbben ice age about 3000 years ago. During this high precipitation epoch, numerous mass movements occurred all over Europe (Fig. 42).

Historical era and 20th century

In the period after the 15th century, climatic data can be reconstructed with considerable precision. The duration and trend of the so-called little ice age (late 13th to mid 19th century) are known within close limits. In this phase, years of high precipitation can be correlated with years of high landslide activity.

Since the early 1970s, heavier precipitation has led to an increase in mass movements in various landslide areas in western Switzerland. In the recent past, an increasing number of landslides have occurred due to increasing winter precipitation in conjunction with snow water.

Statistically, the events that occurred in the years 1951 (Alpine winter), 1987 (summer precipitation in the Alpine region), 1993 (heavy storm in Brigue), 1999 (thawing season and spring precipitation) and 2000 (heavy autumn storm in Valais and Ticino) were extreme events.

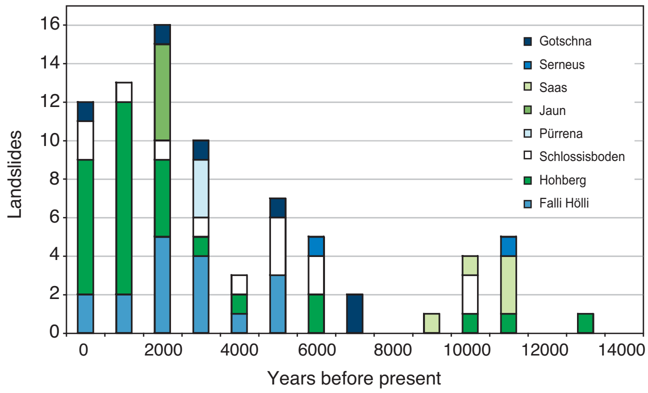


Fig. 42 Frequency of landslides in Switzerland in the Holocene.[5,6] The selection covers large landslide-prone slopes with a volume of several million m^3. These large volume landslides have experienced several acceleration phases since the last ice age. By means of C14 dating of fossilised tree trunks embedded in the debris in the course of earlier events, qualitative conclusions may be drawn for the Holocene both on the physical activity and, to a more limited extent, the climatic conditions. Samples are obtained using borings or excavations, whereby the probability of finding younger wood fossils is greater, since these lie closer to the surface than older wood. Thus for the last 2 to 3 millennia, more C14 datings are available than for the period prior to that. In the Hohberg landslide, the oldest dating goes back to the Young Dryas (12 700 years ago). After the glaciers had receded, several large debris flows occurred in the course of the 12th and 11th millennia in the Freiburg and Grisons Alps (Hohberg, Schlossisboden, Saas and Serneus). This epoch is characterised by climate warming. Numerous slope instabilities occurred between 7000 and 5000 years ago during a variable climatic phase. Following a relatively quiescent phase about 3400 years ago, landslide activity increased steeply in several areas, i.e. Falli Hölli, Hohberg, Schlossisboden, Pürrena and Gotschna. From a climatological standpoint, the end of the Sub-boreal is significant for the whole of Europe. The cold phases of the Löbben (3500 to 3100 years ago) and the Göschenen I (2830 to 2270 years ago) periods are also characterised by glacial expansion. The phase of high landslide activity continued into the second century BC, after which the frequency declined slightly, while continuing to vary in concert with the wet phases.

Consequences of climate change

The frequency of mass movements is influenced by changes in the temperature, the hydrological cycle, the glaciers and permafrost. The rise in winter and spring temperatures changes the form that precipitation takes, the amount of snow cover and the ground temperatures. Climate change gradually alters the stability of large landslide masses. Extreme events such as heavy precipitation and thunderstorms can, however, trigger smaller landslides and earth flows.

Glaciers and permafrost

By virtue of receding glaciers and thawing permafrost, large volumes of debris are free to move. In the presence of water, this can lead to mass movements. Global warming will have drastic effects on the glacial and periglacial mountainous areas.[3] However, quantitative predictions of the effects of climate change on permafrost are difficult.

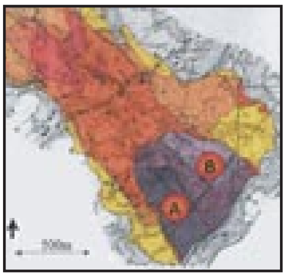
In general, it is probable that the long-term temperature increase will cause slow, retarded, thawing of the permafrost. This trend is coupled with seasonal fluctuations depending mainly on the thickness of snow cover. In autumn and winter, early snow cover retards cooling of the ground. Ground heat is thus stored, reinforcing the trend to thawing the following summer. In distinction, the cold ground in spring is insulated by enduring snow cover. Large quantities of snow extend the period required for complete thawing. Owing to later thawing in spring, less heat can be absorbed by the ground during the summer months. However, the seasonal fluctuations mentioned will probably have little effect on long-term thawing of permafrost.

The permafrost system reacts sluggishly, since the heat capacity of ice and the ground are larger that of air. Thus only the long-term changes will have an influence, and this will persist over a long period. The permafrost will first warm up in the topmost strata, in snow-free zones and in smaller and shallower permafrost areas. In these areas, blockfalls, erosion, landslides und debris flows will increase. As an example, debris flows have repeatedly broken loose in the Ritigraben (Canton of Valais) over the past ten years, having their origin in the block glacier at 2500 m. Also, smaller – and some larger – rock masses have descended from permafrost zones into the valleys (e.g. in Tschierva, Piz Scerscen, Mättenberg, Monte Rosa (Italian side), and Gruben[7,8]).

Precipitation

The acceleration of the hydrological cycle (cf. Chapter 2.5) has a negative influence on slope stability. Owing to the increase in winter precipitation, landslide activity could increase in future. Higher temperatures will result in more rain and less snow. Through the increased quantities of water in supply in the winter months, slope stability will decrease.

Climate scenarios show that southerly flow situations, leading to greater quantities of water vapour being transported from the Mediterranean region towards the Alps, will increase. One such southerly flow situation led to the extreme event of 13/14 October 2000 in the Simplon region. If during southerly flow situations of several days' duration the frost line also lies very high, an increase in landslides and debris flows would be expected.



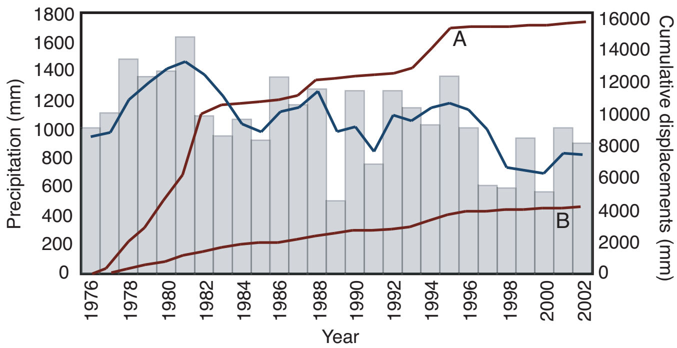


Fig. 43 Landslide in La Frasse near Aigle.[9] The net precipitation (grey bars) and the cumulative displacements (red lines) in zones A and B for the period 1976-2002 are shown for comparison purposes. The blue line shows the 3-yearly average of net precipitation. When this lies above 1150 mm, the landslide front accelerates towards the river bed of the Grande Eau. While zone A reacts with marked acceleration (particularly from 1977-1982), zone B displays only small speed changes. Thus the landslide front reacts more-or-less sensitively to the precipitation and the pressure of groundwater, that is to say, it reacts only indirectly to climatic changes.

1 Sediments from threshold zones above the ocean surface that concentrated in narrow troughs in the course of mountain formation (marine sandstones often rich in aconite, marl, shale and limestones in alternating strata).

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9 Bonnard, persönliche Mitteilung.

2.9. Avalanches

Walter J. Ammann

Catastrophes involving large numbers of heavy avalanches lead to severe loss and damage. In Switzerland, they normally result from rapidly alternating north-westerly and southerly weather situations, with heavy precipitation and new-snow cover of well over 1 m. During the 20th century, winter snow cover neither increased nor decreased at the Alpine stations examined and no changes were observed in the activity of avalanches causing damage. It is not possible to make reliable predictions of changes in the activity of avalanches causing damage as a result of climate change.

Definition, significance and extent

In mountainous countries such as Switzerland, avalanches are a serious natural hazard. Many avalanches occur every winter. An avalanche denotes the entire displacement process of snow masses from the starting zone via the avalanche track to the deposition area. Avalanches can be classified based on purely visible, morphological, features in the starting zone, in the avalanche track and the deposition area. Also, avalanches differ significantly in magnitude.

Avalanches consisting of relatively small masses of snow, with short tracks and predominantly flowing movement occur every winter, and are known as slab avalanches. They occur throughout the winter and are evenly distributed in space and time. In Switzerland, the number of casualties averaged over several years is 23 per year (cf. Chapter 1.6.2).

Avalanches involving large volumes of snow and having long tracks (often up to several kilometres) are referred to as catastrophic avalanches, large-scale avalanches or valley avalanches. In addition to the more frequent flowing snow avalanches, powder avalanches, or a combination of flowing snow and powder avalanches, often occur. The term flowing snow avalanche is applied to compact falling snow masses, whereas powder avalanches involve swirling motion and entrainment of the snow masses in the air.

Extreme avalanches occur relatively seldom in any particular area. Their return period is 10 to 30 years, but for extremely large avalanches as many as 100 years and more. They are referred to as 'avalanches causing damage' when they lead to injuries, and damage built-up areas and transport routes. They have repeatedly led to large numbers of casualties and damage to material assets in the past, the last case of which was in February 1999. At that time, over 1200 avalanches causing damage claimed 17 human lives and caused losses of over 600 million CHF.[1] Extreme events of this nature are catastrophes in the true sense of the word.

Origin and conditions

Extreme events involving a large number of destructive avalanches occurring during the same period and distributed over a large area always originate under specific weather conditions. In the Swiss Alps, these are usually characterised by rapidly alternating north-westerly or southerly flow situations leading to heavy snowfall over several days and to new-snow

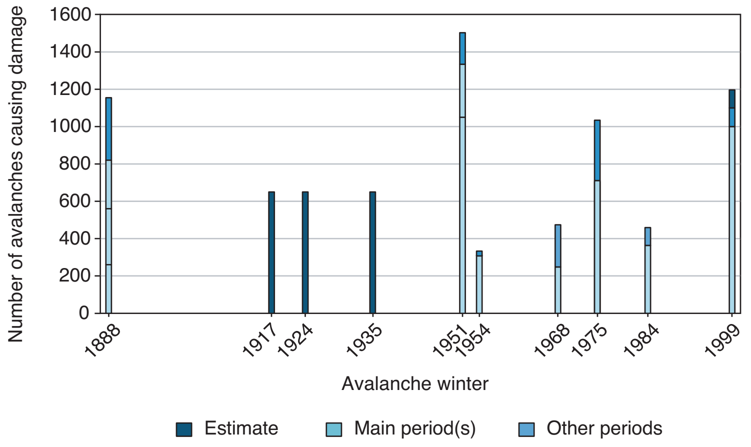

Fig. 44 The catastrophic avalanche winters in the Swiss Alps since 1887/88. The comparison is based on the number of avalanches causing damage. An avalanche causing damage includes avalanches that – for example – damage an Alpine hut, demolish a house, or block a main road. The bars shown are divided according to the main avalanche periods. In 1888, there were three distinct avalanche periods (between mid-February and the end of March), and in 1951 there were two (in January and April). The data for 1916/17, 1923/24 and 1934/35 were estimated.[2,3]

cover of well over 1 m. Weather conditions of this kind can occur throughout the winter from December to April, whereby, however, the resulting heavy snowfall does not necessarily lead to a catastrophic avalanche situation. In the avalanche winter of 1999, the prolific snowfall in February led to an accumulation of new snow with a total depth of over 5 m.[1] Extreme precipitation periods of this kind are often accompanied by storm winds, resulting in extensive drifting of the new snow, and, particularly on steep slopes in the vicinity of ridges, to further accumulations of snow. Under these conditions, large-scale avalanches can occur with a starting magnitude (i.e. thickness of the departing snow layer) of several meters, a starting width of over 1 km, and a volume of up to one million m^3.

As a rule, the starting zone of large-scale avalanches lies considerably above the tree line. In the avalanche winter of 1999, the starting zones lay at an average of 2300 m altitude. Large-scale avalanches descend at very high speeds into the valley. Flowing snow avalanches attain a speed of over 100 km/h and powder avalanches up to 300 km/h. The destructive power of large-scale avalanches is very large, and pressures of up to 1000 kN/m^2 can occur. It would be inconceivable to protect building structures from such high pressures. During their descent, the snow masses lose energy through friction. Since, however, the friction between the gliding snow masses and the ground is only small, flowing snow avalanches do not come to rest until the terrain becomes flatter, i.e. at slope angles below 12°. Therefore both the area affected and the destructive force of a large-scale avalanche are very large.

Under springtime conditions, or when rain saturates the snow layer, the intensity of the avalanche may be higher. Wet-slab avalanches, however, have higher frictional resistance. They are therefore significantly shorter than dry avalanches in midwinter, even with comparable volumes of descending snow.

Historical avalanche catastrophes and identifiable trends

Avalanche winters in the past

Extreme events comparable to the avalanche winter of 1999 occurred in the winter of 1950/51, claiming 95 lives[4], and in the winter of 1887/88 (Fig. 44). Furthermore, similar extreme events are known to have occurred over the entire Alpine region in previous centuries.[5]

In the period after 1500, large-scale avalanche events are increasingly documented. Since 1888, all larger events causing damage have been recorded. Prior to that, the data are sporadic. Since 1945, all reported avalanches causing damage have been recorded individually in a special archive at the Swiss Federal Instititute for Snow and Avalanche Research (SLF). This database enables a detailed impression to be gained of the temporal and spatial distribution of avalanches causing damage in the region of the Swiss Alps. In combination with meteorological data, the probability of avalanches causing damage occurring under particular weather conditions can be estimated. For this purpose, historical data extending as far as possible into the past were prepared for Andermatt, Bever and Davos in the context of the National Research Programme, NFP31.[5] All sites lie at approximately the same altitude (around 1500 m a.s.l.) but in climatically different regions of the Swiss Alps. Data on the thickness of snow cover are available at daily intervals since 1896 for Davos, 1910 for Bever and 1947 for Andermatt.

Based on this data, trends in snow cover during the 20th century were studied. For the Davos site, a parameter describing the activity of potential avalanches causing damage was determined based solely on meteorological data. The following conclusions may be drawn from the evaluation (cf. Fig. 45):

(a) Snow cover varies considerably from year to year. However, no trend could be identified over time, since today, the average winter temperature still lies well below 0°C. In recent years, the thickness of snow cover at the stations investigated was not unusual. A slow downward trend in average snow cover was identified during the 1990s. However, years with a snow deficit had also occurred at frequent intervals in the 1920s.

(b) In the case of Davos, the activity of avalanches causing damage has neither increased nor decreased (cf. Fig. 45).

(c) Events causing damage are restricted to individual regions. In the course of the last 600 years, the case of all Alpine regions in Switzerland being affected simultaneously by avalanche catastrophes has never occurred. There is no identifiable trend indicating increased or reduced avalanche activity.

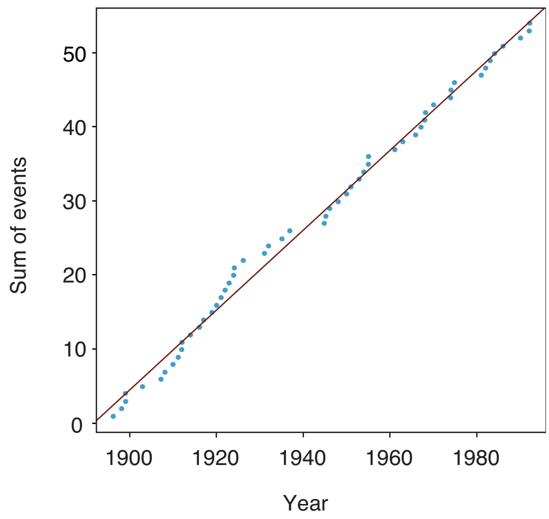

Fig. 45 Date and sum of events with snow cover and 3-day new-snow cover, each greater than 75 cm. The straight line shows the average trend between 1896 and 1993 for Davos. Time periods with potentially higher avalanche activity are steeper than those with low avalanche activity.[5]

Safety measures and losses

Following the avalanche winter of 1887/88, the first structural measures for the protection of residential areas from avalanches were taken. Initially, stone-blocks were used to terrace the slopes, and later, retaining structures – mostly in steel – were built to stabilise the snow masses in the starting zone. These efforts were strongly intensified following the avalanche winter of 1950/51. To date, the Swiss Confederation has invested some 1.5 billion francs in avalanche defence structures.

The extensive losses occurring in the avalanche winter of 1999 should not be taken as grounds to question the effectiveness of the safety measures taken in earlier decades. On the contrary, the preventive activities extending over many years with the collaboration of the communes, cantons and the Confederation have stood the test! Since 1950/51, the susceptibility of humans and material assets to damage has increased enormously, leading to an increase in the risks.[1] Despite this, about six times less lives were lost in 1999 than in 1950/51. The material losses increased only slightly above the insured value of buildings and infrastructure. With the aid of organisational, technical and land-use planning measures, in combination with the large-scale protective function of the mountain forests, it was possible to maintain the damage in Switzerland within tolerable limits.

Influence of climate change

Extreme situations resulting in avalanches occur as a result of exceptional weather constellations leading to massive snowfall above about 1200 m altitude over several days.

It is expected that climate change will lead in future to an increased average air temperature and to an increase in precipitation and in the frequency of extreme weather situations in winter. Very few studies on this exist, and those that do only calculate the influence of increased temperature on snow cover and avalanche activity.[6] The influence of other changes – alone and in combination – on snow cover and avalanche activity has not yet been studied. It is therefore only possible to provide qualitative estimates[7] as follows:

(a) The snowline will rise several hundred metres as a result of warming. Taken in isolation, warming will generally result in thinner snow cover of shorter duration.[6]

(b) In contrast, the increase in precipitation above the tree line in winter, i.e. in potential avalanche starting zones, will lead to thicker snow cover. If the increase in precipitation occurs mainly during exceptional weather situations, and is not therefore spread over the whole winter, the risk of extreme avalanche situations will increase.

(c) At present, approximately every third exceptional weather constellation in winter leads to an extreme avalanche situation.[1] Thus with the increasing frequency of exceptional weather conditions during the winter months, the probability of an extreme avalanche situation arising in winter will also rise.

(d) At lower altitudes, more frequent rainfall on the snowpack may lead to an increase in wet-slab avalanches. However, as this situation is already common in spring, the risk would hardly be expected to rise.

(e) In general, gliding of the snow layer over the vegetation will attain greater significance as a result of climate change, and the resulting shear forces could cause increasing damage to vegetation and to the landscape.

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2.10. Winter storms

Heini Wernli, Stephan Bader and Patrick Hächler

Winter storms arise in connection with intensive low-pressure systems. In Central Europe, the frequency of storm events rises in periods of high Atlantic cyclone activity. The frequency of intensive low-pressure systems over the North Atlantic has increased since the 1930s. Many simulation models predict an increase in cyclone activity in the eastern North Atlantic and over Western Europe as a result of climate change. In Western Europe, more intensive storms are cautiously regarded as a possible development. No predictions are available on future changes in föhn frequency.

Introduction

Extreme winter storms such as Lothar (December 1999) and Vivian (January 1990) are rare individual cases. Therefore it is not possible to make statistically reliable statements on changes in the frequency and intensity of these events. Trend predictions on whether the events will become more or less frequent are therefore very unreliable.

The intensity of a storm is defined in terms of the wind speed above the ground (at a height of 10 m). It is important to distinguish between the peak values in gusts (at one-second intervals) and average wind speeds (mostly at 10 minute intervals). In media reports, peak values are normally used. Furthermore, the insurance business uses the peak value to define the liability threshold, which lies at 75 km/h. The term 'storm' is in fact a misnomer and lies in contradiction to the arguments advanced below. The best known and oldest standard for classifying winds is probably the Beaufort scale. In this, however, average values are used. On the Beaufort scale, force 9 signifies a storm, and refers to average values from 75 km/h upwards. The term 'hurricane' (extreme event) corresponds to force 12 on the Beaufort scale, i.e. to average values upwards of 118 km/h, and these hardly ever occur in low-lying inland areas. To determine peak gust values from the average wind speeds, these must be increased by 30 to 80%.

Meteorological conditions

Winter storms arise in connection with intensive low-pressure systems (cf. Chapter 1.3). They arise in regions with large horizontal temperature differences, that is in areas intermediate between the warm subtropical and cold polar air. The western North Atlantic is an example of a region having a strong climatological temperature difference between north and south. Here, numerous low-pressure systems arise that often drift towards north-western Europe. The path of the low-pressure areas rarely passes directly via Central Europe, so that it is mostly the cold fronts of these that reach Switzerland in the form of troughs. Under weather conditions characterised by a large pressure difference between the Azores and Iceland, the Atlantic west winds increase in intensity, and the frequency of low-pressure systems that finally reach Europe increases.

Extreme winter storms arise through the interaction of numerous processes (heavy north-

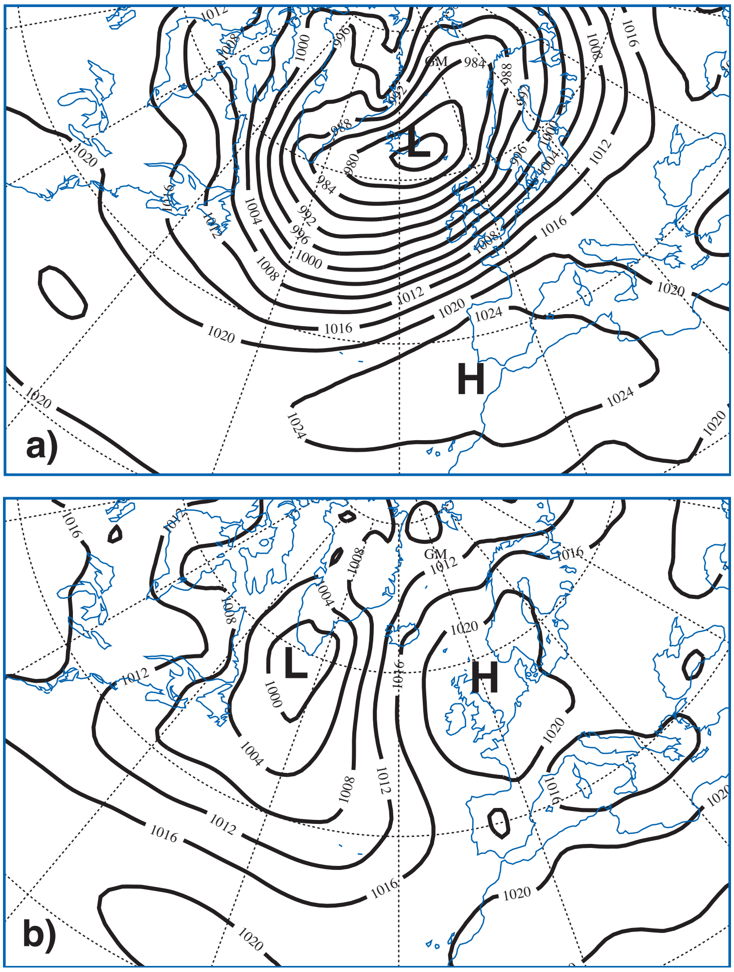

Fig. 46 Ground pressure distribution for (a) a month with a high positive NAO index (February 1990) and (b) a month with a heavily negative NAO index (January 1987). The distance between the isobars is 4 hPa. A positive NAO phase (in terms of the monthly average) is characterised by an intensive low-pressure area over Iceland and an extensive high-pressure area extending from the Azores over Spain. A negative NAO phase is characterised (in terms of the monthly average) by a high-pressure area over North-West Europe and a moderately intensive low-pressure area over the southern extremity of Greenland.

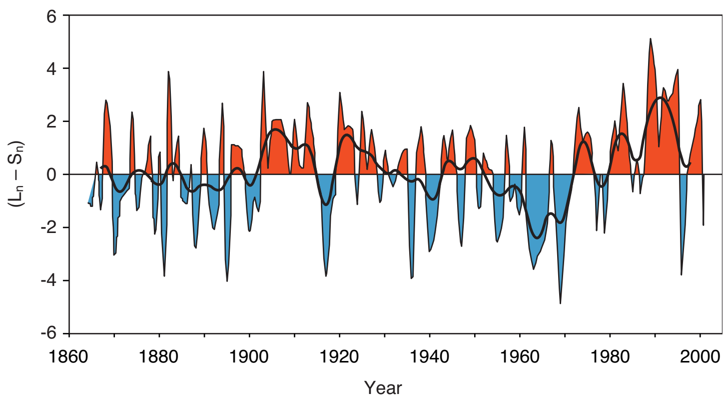

Fig. 47 Reconstruction of the NAO index since 1864. The NAO index designates the pressure difference between the Azores and Iceland.[4] With a high NAO index, the pressure difference is large. Since the early 1970s, the NAO index has mostly been positive.

south temperature gradients; strong jet stream; perturbations at an altitude of approx. 9 km (position of the tropopause), and condensation of water vapour), each of which play a different part in individual cases. In the case of Lothar (December 1999), computer simulations show that the condensation of water vapour played a very important part in the generation and intensification of the weather system above the Atlantic[1] (cf. Fig. 10 and box *Lothar – a process analysis*).

Observed trend in the 20th century

In periods of high Atlantic cyclone activity, the frequency of storm events in Central Europe increases. The index of North Atlantic Oscillation NAO[2,3] is an indicator of the degree of cyclone activity over the North Atlantic and Europe on a monthly basis. The NAO index specifies the difference in pressure at the ground between the Azores (or Portugal) and Iceland (Fig. 46).[4] In periods with a high NAO index, the pressure difference is large.

Over the past 30 years, weather conditions over the North Atlantic and Europe in winter have been characterised by a high NAO index (Fig. 47). This also applies to the winters of 1989/90 and 1999/2000 when the Vivian and Lothar storms occurred. However, it has not proved possible to establish a connection between the NAO index and the frequency of heavy storms in Central Europe.

Statistical analyses of all (i.e. extreme and moderate) low-pressure systems in winter from 1958 to 1999 show that these have become somewhat more seldom over the North Atlantic. Their paths have shifted towards the North.[3] Over Central Europe, the shift is not significant. In distinction, the frequency of intensive low-pressure areas over the North Atlantic has increased since the early 1930s[5] (Fig. 48). The paths of these have also shifted towards the North. Thus today, Switzerland increasingly lies at the southern fringe of the storm fields, and sometimes completely outside of these.[6] Between 1880 and 1930, the number of days with high wind speeds in north-eastern Switzerland lay significantly higher than in more recent times (Fig. 49). It is also noteworthy that in the course of time, heavy storms in Switzerland have increasingly begun in December rather than in October/November. Seen from a global perspective, there are no significant trends in the intensity and frequency of non-tropical storms in connection with climate change.[7]

Furthermore, several of the significant processes in connection with relatively small and very intensive low-pressure areas (Lothar, Vivian) are probably not yet sufficiently well modelled. Thus, for example, the maximum wind speeds near the ground are heavily influenced by the local topography, and have to be estimated using very complex numerical methods.[11]

Both from measurements and simulation results, more intensive storms are cautiously forecast as a possible development in central latitudes (e.g. Western Europe). On the other hand, most climate models predict greater warming in high than in lower latitudes. Should this be the case, the temperature differences, and thus the potential for the generation of intensive low-pressure areas, would decrease.

Future events in connection with climate change

Global climate change could affect the occurrence of conditions favouring extreme winter storms. Climate simulations are practically unanimous in predicting an increase in water vapour in the atmosphere, and this could increase the intensity and frequency of storm cyclones.

Many simulations of the global climate predict that cyclone activity in the eastern North Atlantic and over Western Europe will increase.[8,9] The physical processes underlying this are, however, not yet clear.[7] Thus the question must remain unanswered as to whether cyclone activity will increase as a result of increased frequency or intensity of low-pressure areas.

Forecasts on the frequency of heavy (and extreme) winter storms must be treated with caution. The global climate models often display relatively large deviations in predicting the paths of individual low-pressure areas.[10]

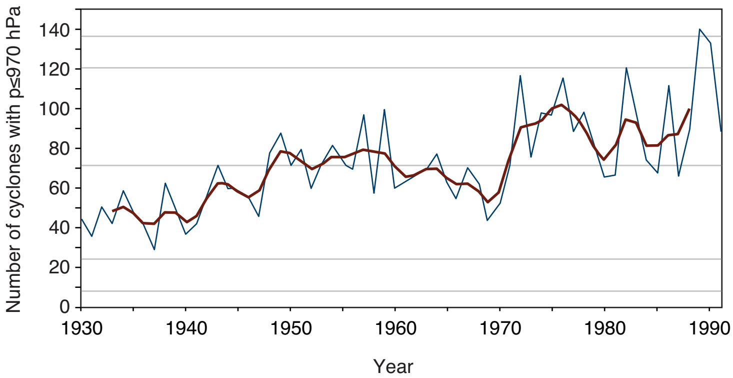

Fig. 48 Time series of the annual number of intensive low-pressure areas over the North Atlantic and Europe from 1930-1990. An intensive low-pressure area is one in which the minimum air pressure lies below 970 hPa.[5] The figure shows a significant increase in the frequency of intensive low-pressure areas over the observation period.

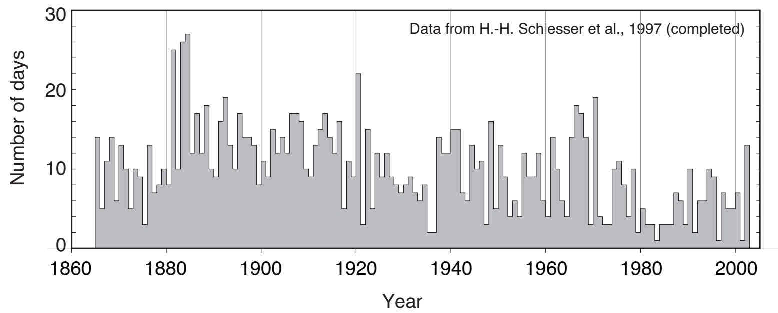

Fig. 49 Number of days with heavy winds (peak gusts of 90 km/h (50 knots) and more) during the winter months in the period 1864/65-2001/02 at the Zurich measurement station[6] (missing values calculated). This station is regarded as representative of North-East Switzerland. Neighbouring stations were used for comparison purposes and for calculating missing data.

Föhn as a form of extreme wind

To the north of the Swiss Alps, in addition to the classical westwind storms, föhn storms add to the storm risk. This includes extreme events. The föhn storm of 7/8 November 1982 left behind it a path of destruction in Alpine forests.

Föhn is a very frequent phenomenon in the Alpine valleys. The peak wind speeds during föhn mostly lie below 100 km/h. However, an analysis of the yearly maxima shows that heavy storms repeatedly occur in north-south oriented valleys, which channel the föhn winds and give them additional momentum. At the measurement station in Altdorf, föhn gusts with maxima of 110 km/h and above occur almost every year. Every 10 years, 140 km/h are attained, and the estimated 50-year maximum lies just under 160 km/h. Similar values were determined for Vaduz, although these lie on average some 5 km/h lower than in Altdorf.

It is generally assumed that föhn storms with peak values of over 100 km/h occur in most föhn valleys. In rare cases, this may also affect areas that are not especially prone to föhn (e.g. Appenzellerland, Zugerberg, Obwalden, Bernese Oberland). At altitudes over approx. 2000 m, storm force is attained over the entire northern Alpine region under the influence of föhn. In exposed locations near the Alpine crest (e.g. at Gütsch near Andermatt), gusts as high as 200 km/h and more are attained.

Both due to the high wind loads generated and the danger of fire, the risk of föhn should not be taken lightly. Föhn winds may persist over long periods: not only can they start fires, but may also increase the intensity of fires already raging. Fire-fighting under föhn conditions is an extremely demanding duty.

At present, no predictions on future trends in föhn frequency as a result of global climate change are available. Although föhn is known to be closely associated with particular weather conditions and their regional characteristics, reliable predictions will not be possible until data on future trends in regional weather conditions are available.

Patrick Hächler

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