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3.1.11 Change of regional extremes

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SUMMARY: *During the last decade floods and droughts with significant impacts have been observed in Europe and other parts of the world. Thus, the question arises whether these events are caused by a man-made global warming. A lot of datasets show increasing frequencies of extreme precipitation events, but the lack of reliable long-term data makes it difficult to identify clear trends. Trends in the frequency of droughts are even less distinguishable. Due to physical reasons more extreme events should be expected in a warmer climate. However, the spatial pattern is influenced by the complex dynamics of atmosphere and ocean. Sophisticated climate models lead to conclusions which are in agreement with the theoretical considerations.*

Catastrophic floods and droughts around the world

In Europe a new awareness concerning the risk of floods arose from the so-called »centennial« and »millennial floods« of the last few years. This applies particularly to the centennial floods in the Odra basin in 1997 and, especially the millennium flood in the Danube, Moldau and Elbe basin in the year 2002, see *Fig. 3.1.11-1*, with 37 fatalities and an economic damage of 15 billion Euro. In Germany this flood even influenced the result of an election of the Federal Parliament. Even more devastating floods occurred in other parts of the world, as for example the enormous flood in the Chinese Yangtze basin in the year 1998, with 3000 fatalities, 14 million homeless people and damages of about 36 billion US $ or the catastrophic monsoon floods in the same year in Bangladesh and India, also with around 3000 fatalities. The south-eastern part of the African continent was affected by devastating rains and floods in the year 2000 with several thousands fatalities. In the Mississippi, a centennial flood occurred in 1993 with 18 billion US$ of material damages and more than 60,000 destroyed houses.

Nature and mankind not only suffer from too much water, but also from too little water. In some regions droughts belong to the most severe natural catastrophes because of their long duration and large spatial extent. Well-known examples in the 20th century are the droughts in the mid-west of the US in the 1930s, the 1950s and the 1980s, as well as the drought in the Sahelian zone at the southern border of the Sahara during the 1970s and 1980s. Europe suffered from an extreme heat wave in the year 2003 with large-scale dryness, forest fires and more than 30,000 premature deaths among old people, especially in France.

The debate concerning catastrophic floods and droughts focuses more and more at the question whether a man-made climate change may be responsible for these phenomena. The US drought in the year 1988 brought the thesis of a man-made greenhouse effect for the first time to the attention of the United States policy makers. Also in Europe, storms, floods, dryness, and heat waves lead to an intensifying public discussion of this question of human responsibility. This was especially the case after the extreme weather events of the years 2002 (Elbe river flooing) and 2003 (extreme hot and dry summer). There is no simple and definite answer to this question as the mechanisms are complex and difficult to clarify; see Chapter 3.1.3. In the following the socio-economic and hydrological aspects of catastrophic floods and droughts are discussed as well as their meteorological causes. Finally, an assessment of future developments is presented.

Socio-economic and hydrological aspects

An increase over the last decades is evident in the economic costs of weather-related natural disasters. The world-wide

Fig. 3.1.11-1: The millennium flood 2002 in the Elbe river basin (Photo: Thomas Wöhling).

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costs rose from 13 billion US$ in the 1950s to 72 billion US$ in the 1990s (see Chapter 3.2.12). Estimates of the losses in different regions of the world indicate a similar tendency. The annual economic damages due to floods in the US increased from 1 billion US$ in the 1940s to approx. 5 billion US$ in the 1990s (inflation-adjusted). The flood damage per inhabitant also shows a significant increase (*Fig. 3.1.11-2*).

One reason for the increasing flood damages are social causes such as increasing populations or increasing settlements in areas affected by flood-risk combined with an increase in economic values in these areas. Land use changes are an essential cause for droughts, too. However, floods are also directly related to runoff, water levels, and the spatial extent and duration of precipitation. Trends are difficult to detect, as data on runoff and water levels do not reach far enough back into the past in many regions and are not homogeneous due to changes in the measuring methods and other external conditions.

Extreme events are rare by definition and therefore data series over half a century are too short for a reliable detection of trends. Rough calculations led to the conclusion that in 29 large river basins around the globe so-called centennial floods (i.e. extreme hydrologic events occurring only once in a century on a statistical average) increased substantially in the 20th century. Sixteen out of 21 of these events, i.e. almost 4/5 occurred after 1953 (SCHNUR 2002). Changes in land use contributed strongly to this development. For instance, the catastrophic Chinese flood of the year 1998 was only to a minor part caused by meteorological conditions; rather, it was mainly a consequence of the disappearance of former floodplains due to land reclamation. From a meteorological point of view it was only an average event. However, the information shown in *Fig. 3.1.11-2* suggests that the increase in the flood damage for the US could also be influenced by changes in meteorological conditions.

Meteorological trends

The availability of meteorological data is only satisfactory for a few parts of the world, because only relatively seldom homogeneous time series of sufficient quality reach back further in time than to the mid of the 20th century. According to the assessments in the IPCC report from 2001 (IPCC

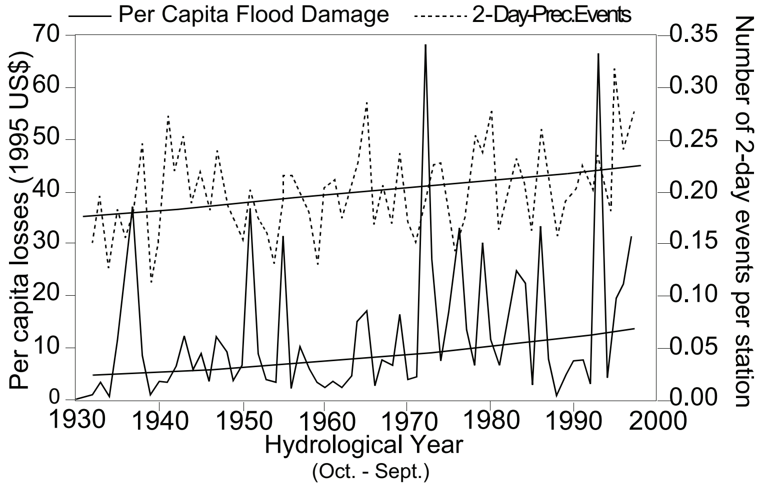

Fig. 3.1.11-2: Flood damages per inhabitant in the US during the period 1932–1997 (equivalent values of 1995) and the number of heavy rainfall events with a duration of at least 2 days per measurement station (after PIELKE & DOWNTON 2000).

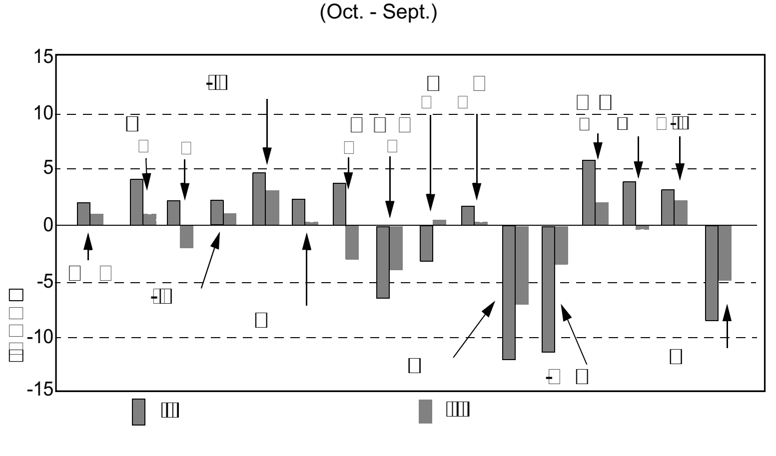

Fig. 3.1.11-3: Change in the total amount of seasonal precipitation (in the season with highest precipitation) and the number of heavy precipitation events (daily precipitation exceeding a certain limit that regionally differs) in different regions of the Earth during the last 50 years (after IPCC 2001a).

2001a; Kundzewicz & Schellnhuber 2004), precipitation extremes have increased more than total precipitation during the past 50 years in the mid and high latitudes of the northern hemisphere, in south-east Australia and in southern Africa. In some regions where total precipitation has decreased, extreme precipitation has decreased even more. However, there are also regions where a decrease of average precipitation occurred together with an increase in extreme precipitation (see *Fig. 3.1.11-3*).

For some regions the availability of data allows the detection of differentiated trends. In the United States, extreme precipitation events of a duration of about 1–7 days increased by 3% per decade since the 1930s and the number of days with precipitation above 101.6 mm increased by 50% during the 20th century (Kunkel 2003). In Kunkel's study digitised data of the period 1895 to 2000 from 1076 stations were evaluated for the first time. However, this analysis also shows that the frequency of extreme events around 1900 was already as high as at the end of the 20th century.

A similar increase in the frequency, duration, and intensity of heavy precipitation events is visible in European studies (see also Chapters 3.1.5 and 3.1.6). In Germany, the number of days with heavy precipitation (defined as the days with an amount of precipitation that is exceeded only at 100 days in the period 1941 to 2000) increased about 46% during the winter seasons of the period 1901 to 2000. The intensity of precipitation on days with heavy rainfall in winter increased by 42% during 1921 to 2000 (Grieser & Beck 2003). In Great Britain the number of days with heavy rainfall (defined as days with more than 15 mm of precipitation) increased countrywide significantly between 1961 to 1995, at several stations even by more than 100% (Osborne & Hulme 2002).

Trends in precipitation deficits are more difficult to detect than those of heavy rainfall. In addition to the US and the African Sahelian zone, droughts also occur regularly in other regions of the world, such as in the Mediterranean area (see Chapter 3.1.8), South Africa, Australia or South- and East Asia. In the US the high variability of dry periods in the 20th century is striking. Distinct events are the droughts in the 1930s, the 1950s, and at the end of the 1980s. However, similar events also occurred in earlier centuries.

One contribution to the development of droughts is the decreasing accumulation of snow, which decreased by up to 60% in the second half of the 20th century due to the higher temperatures (Service 2004). Thus, rivers contain less water in spring and summer, soil moisture is reduced and drought risk is increasing.

The extreme decrease in precipitation in the Sahelian zone since the end of the 1960s is unique for the 20th century world-wide. Between the periods 1931–1960 and 1970–1990 mean precipitation has decreased by 20–49% (IPCC 2001b). Since the end of the 1990s precipitation has increased again, without showing a new trend (*Fig. 3.1.11-4*). A significant reduction in precipitation also occurred in the Mediterranean area and in Central Europe, e.g. about 5% in North Italy and of about 15% in South Italy. In the coastal regions of Southern Spain the number of rain days decreased by 50% between 1964 and 1993 (IPCC 2001b). Consequences are dry periods in summer which, in combination with significantly increased temperatures, led to devastating forest fires. Globally the very dry areas have more than doubled since the 1970s (Dai et al. 2004).

Basic physical background

Basic physical considerations suggest that global warming will lead to increasing precipitation and heavy rainfall events in some regions, but also to dry periods and droughts in other regions. Higher surface air and sea surface temperatures have two important consequences: first increasing evaporation, and second increasing water vapour capacity of the atmospheric air.

The increase in atmospheric water vapour capacity of about 7% per degree Celsius and the increased evaporation lead to an increased absolute water vapour content of the

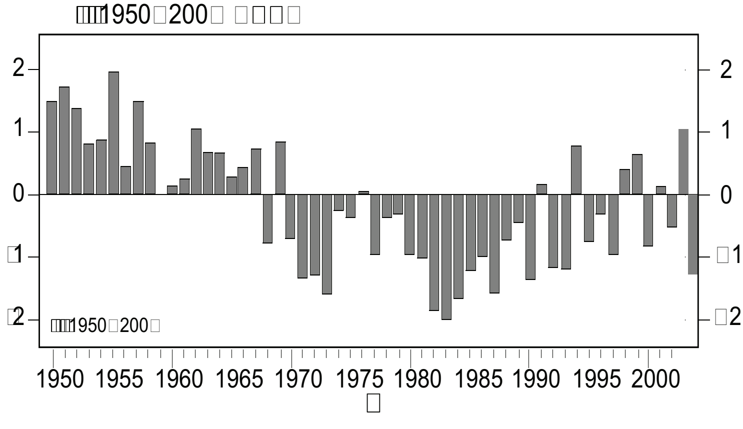

Fig. 3.1.11-4: Precipitation anomalies in June-October in the Sahelian zone 1950–2002. The mean of the whole period is set to 0, the standard deviation to 1. Well identifiable are the wet period from 1950 to 1969 and a very dry period from 1970 to 1997. The last 5 years do not show a distinct trend. (Source: Joint Institute for the Study of the Atmosphere and Ocean (JISAO):http://tao.atmos.washington.edu/data_sets/sahel/)

air. In contrast to that, the relative humidity only changes insignificantly. Consequently, the frequency of rainfall may only change slightly in a warmer climate. However, more water vapour is available per area and therefore heavy rainfall events may become stronger and may occur more frequently. In addition, in the context of the man-made greenhouse effect, it is likely that the atmosphere will warm primarily near the surface and will cool in stratosphere so that this warming is less pronounced in the upper troposphere. This leads to an increased thermodynamic instability of the atmosphere and enhances the tendency towards the development of convective clouds and, in turn, heavy rainfall. So, in general, global warming should lead to a reduction of light and moderate rainfall and, simultaneously, to more intense and more frequent heavy rainfalls. On the other hand, reductions in surface solar radiation due to clouds and aerosols may lead to weaker latent and sensible heat fluxes and hence to reductions in evaporation and precipitation despite global warming (Liepert et al. 2004). Where higher evaporation is not compensated by additional precipitation, droughts will occur more frequently.

For some regions the precipitation type is of importance. In mountainous areas of the mid-latitudes winter snow masses are a water reserve for spring and summer, when snow melts. Warming leads to a shorter snow season, more precipitation falling as rain instead of snow and an earlier snow melt. Hence, less soil moisture is available in spring and summer, consequently favouring droughts. This trend is counteracted by increasing cloud coverage in the mid-latitudes, leading to reduced evaporation.

Atmospheric and oceanic dynamics

As we have seen, physically-based considerations suggest an amplification of droughts and extreme precipitation on a global average under global warming. However, heavy rains and strong droughts are regional phenomena and are driven by weather situations. Whether it rains a lot, a little or not at all in a certain region depends only to a minor part on temperature and evaporation in this area. On the global average, 90% of the rainfall of a specific precipitation event comes from other regions by advection, especially from the large ocean basins (Trenberth et al. 2003).

So, atmospheric circulation systems are of central importance for the transport of water vapour, as, for example, for tropical monsoons and the storm tracks in the mid-latitudes, which are controlled by the jet stream. These systems are influenced by oceanic surface temperatures on longer time scales. For instance, a band of high pressure cells in the upper troposphere was responsible for the observed droughts during the period 1998–2002 in many regions of the lower mid-latitudes throughout the northern hemisphere. The long duration of this pressure distribution was maintained by the tropical ocean, which showed unusually high surface temperatures in the Western Pacific and the Indian Ocean and La-Niña-related unusually cold temperatures in the Eastern Pacific (Hoerling & Kumar 2003).

Similarly, the well-known great droughts of the 20th century, i.e. the American »dust bowl« of the 1930s and the Sahelian drought of the 1970s and 1980s, were mainly caused by temperature conditions in the surface waters of the neighbouring oceans. It is well known that the Pacific ENSO-variability has a strong influence on heavy rainfall and droughts in many regions of the world. It is characterised by an alternation between warm (El-Niño)- and cold (La-Niña-)-phases in the surface temperatures of the eastern tropical Pacific.

Although the connection between global warming, extreme precipitation events and oceanic and atmospheric temperature and circulation patterns is not completely understood, specific statements on probabilities are possible, based on climate simulations. It is probable that the global temperature increase favours El-Niño-phases, and, related to that, extreme precipitation combined with

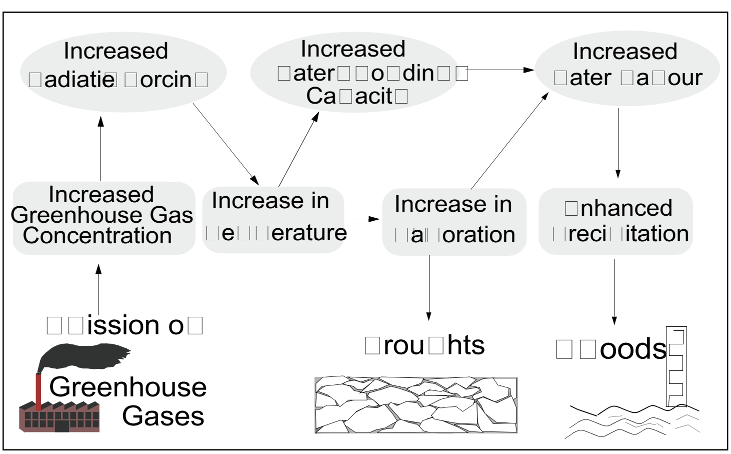

Fig. 3.1.11-5: Increasing greenhouse gas concentrations lead to a warming of the atmosphere. Thus, evaporation and atmospheric moisture capacity are also increasing. The consequences are droughts, on the one hand, and increasing atmospheric water vapour and stronger precipitation, on the other hand.

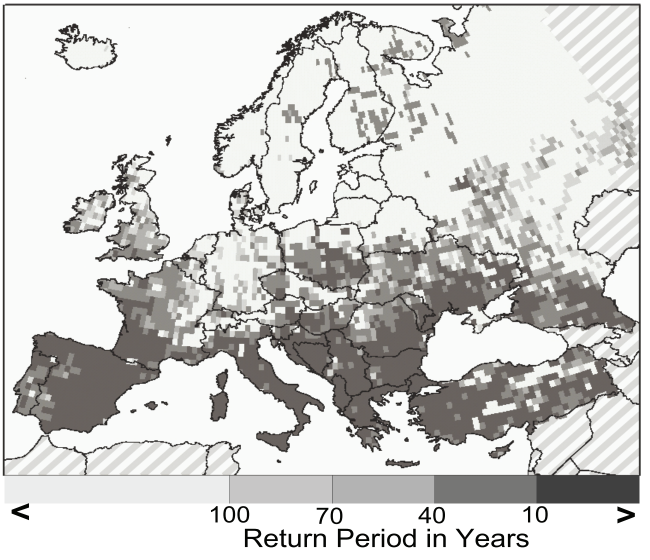

Fig. 3.1.11-6: Change in the return period of droughts in Europe according to model computations. Shown is the return period of a drought in the 2070s, which is expected to occur once in a hundred years under current climate conditions. A significant increase in the frequency is predicted for Southern Europe (after Lehner et al. 2006).

the risk of floods at the South American west coast, in East Africa, in the South-west of the USA and extreme dry periods with the risk of droughts in Indonesia, Australia, South Africa and North-east Brazil. Furthermore, an enhancement of the North Atlantic Oscillation (NAO) due to the man-made greenhouse effect is possible. The NAO has a strong influence especially on winter precipitation in Europe (IPCC 2001a).

In summary, the observed increase in extreme events is largely consistent with the predicted changes caused by anthropogenic forcing. However, the situation is complicated, so many details remain unsolved, especially as far as particular regional events are concerned. Note, following the data of Kunkel (2003) on the frequency of extreme events in the US since the end of the 19th century, that natural variability is relatively large, even on the decadal scale, and should not be neglected as a cause or at least a contribution to the increase at the end of the 20th century.

Predictions

As climate is a complex, non-linear system, the probability for the occurrence of individual events cannot be derived satisfactorily only from some basic physical considerations. However, model-based computations, which are tuned to the development of the real climate system, support the theoretical assumptions.

Early model simulations already led to the conclusion that an increase in greenhouse gas concentrations would enhance the intensity of precipitation events and that the proportional increase in extreme precipitation events would be higher than the increase in average precipitation. Hence, the return period of extreme precipitation events would become shorter almost everywhere. Model experiments also indicate that the return period of droughts would also become shorter (*Fig. 3.1.11-6*). Nevertheless, regional differences are large and it is difficult to derive reliable predictions for individual regions because of the still coarse resolution of the climate models.

The impact of increasing greenhouse gas concentrations on the natural dynamics of the climate system is of significant importance for many regions. For instance, the number of El-Niño-events, and therefore the number of related extreme events, will increase according to most model projections. Likewise it is possible that the North Atlantic Oscillation (NAO) will be strengthened and will therefore be responsible for wetter winters in Europe. Climate models also project an intensification of the Indian monsoon leading to an increased risk of flooding on the Indian sub-continent (IPCC 2001a). The projected warming of the oceans will also strongly influence extreme precipitation events on the continents.

Final conclusions

The knowledge on extreme events is in many respects not satisfactory. We do not understand the causes of extreme precipitation events and the relationship to global warming in detail, nor do we know enough about the observed trends in the 20th century and even less about the future developments in the 21st century. However, several reasons suggest that the floods of the recent past are not only a natural fluctuation, but influenced by global warming due to increased greenhouse gas concentrations. This could also be the case for heat waves, droughts and forest fires. Physically-based considerations as well as model simulations suggest that an increased risk of such catastrophes has to be expected. The related costs for society would be significantly higher than the costs that are necessary for effective climate protection strategies today and in the near future, in order to at least reduce the associated risks ♦