1.2 Climate Change and the Water Cycle - Some Information Concerning Precipitation Trends

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1.2.1 Introduction

Water in sufficient quantity and acceptable quality is of vital importance for all life on Earth. Unfortunately, these conditions are not fulfilled in many parts of the world, especially in the suptropical and partly also in tropical regions, so that approximately 1.2 billion of people (c. 20 % of the world population) have no secure access to clean drinking water (Lozán et. al., 2007). Moreover, agriculture suffers from water supply problems. Even in some industrialized regions of the mid-latitudes climate zone where humid conditions prevail, for instance Central Europe, dry spells can lead to serious problems. An example is the hot-dry summer 2003 (Schönwiese et al., 2004) leading to at least 35,000 additional deaths and economic loss of c. 13 billions of dollars in Europe (Jendritzky, 2006; MunichRe, 2004; Schär and Jendritzky, 2004). Another problem, in addition to too few water, is too much water as a consequence of heavy precipitation episodes leading to flooding. The question arises whether such problems may become more frequent in the future.

In the following the problem of global climate change is briefly addressed (chapter 1.2.2), mainly in terms of temperature rise. Then, the consequences for atmospheric circulation and, in turn, the global water cycle are outlined. The most important component of the water cycle is precipitation playing a crucial role not only with respect to both dryness and flooding but also concerning water supply of mankind. Therefore, two chapters address the observed precipitation trends on a global scale (chapter 1.2.3) and in Europe (chapter 1.2.4). As a case study, in the context of precipitation trends observed in Germany, the problem of extreme events is discussed (chapter 1.2.5). Finally, some conclusions are added (chapter 1.2.6).

1.2.2 Global climate change

Climate varies on all scales of time and space since Earth exists. However, within industrial time, roughly since 100-200 years, mankind has become an additional climate forcing factor of growing intensity although the anthropogenic influence on climate can be traced back several thousands of years due to land-use effects (development of agriculture and pasture), including deforestation. The most important recent effect, however, is the emission of infrared(IR)-active trace gases

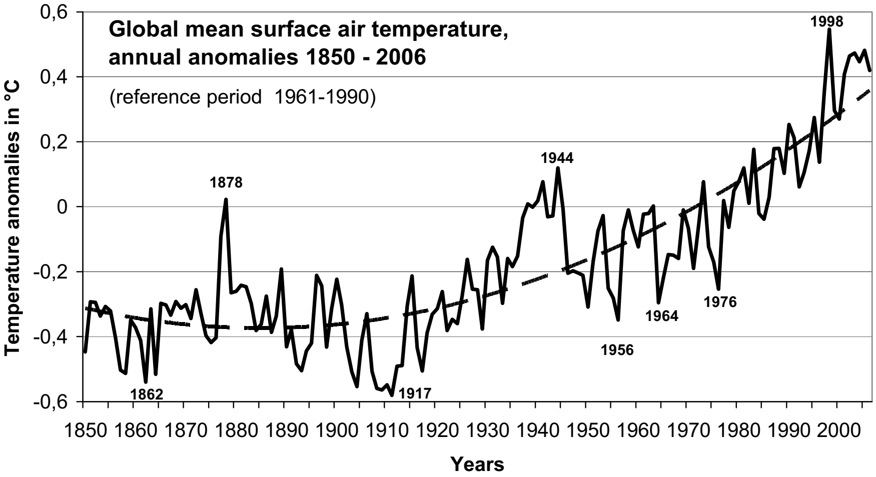

Fig. 1.2.1. Annual anomalies 1850-2006 of the global mean surface air temperature (from Jones, 2007). The dashed line indicates the polynomial trend. The linear trend 1901-2000 amounts to 0.7° C.

(greenhouse gases GHG) such as carbon dioxide (CO_2) and others due to fossil energy use (IPCC, 2007; Schönwiese, 2003). In consequence, the atmospheric CO_2 concentration has increased from pre-industrial values of approximately 270-280 ppm (nearly constant since the termination of the last ice age c. 10,500 years ago) to more than 380 ppm in 2006. In combination with the concentration increase of some other GHG (CH_4, N_2O, CFCs, tropospheric O_3 etc.) climate model simulations as well as statistical assessments attribute to this GHG forcing an increase of the global mean surface air temperature of approximately 0.7 K within the recent 100 years (IPCC, 2007); see Fig. 1.2.1. Other external forcing of the climate system like solar activity and volcanism or internal mechanisms of the climate system like El Niño and other have predominantly produced fluctuations around this long-term trend.

However, such as this trend is not uniform in time, it is also not uniform in space. This is shown for the recent 50 years in Fig. 1.2.2. We find the most pronounced temperature increase in some land areas of the northern hemisphere whereas some other relatively small regions have experienced a weak cooling. There is a marked interacting between the different temperature regimes of the Earth and atmospheric circulation and this interaction may be modified due to global climate change. Moreover, global atmospheric circulation is linked with the global water cycle; see Fig. 1.2.3. Briefly characterized, evaporation and transpiration (from vegetation; combined evapotranspiration) leads to water vapour transport into the atmosphere where in the context of uplift processes, like in case of low atmospheric pressure, clouds are formed and some of these clouds produce precip-

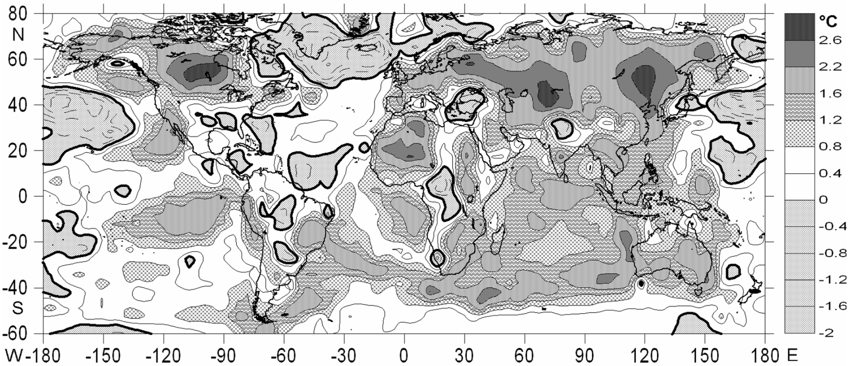

Fig. 1.2.2. Linear surface air temperature trends 1951-2000 in °C within the 80°N-60°S zone in a 5° grid resolution, contour lines at 0.4° C intervals. Data source: Jones, 2007; analysis: Schönwiese (2003, updated). The heavy lines encircle areas were a temperature decrease is observed (within these areas dashed contour lines).

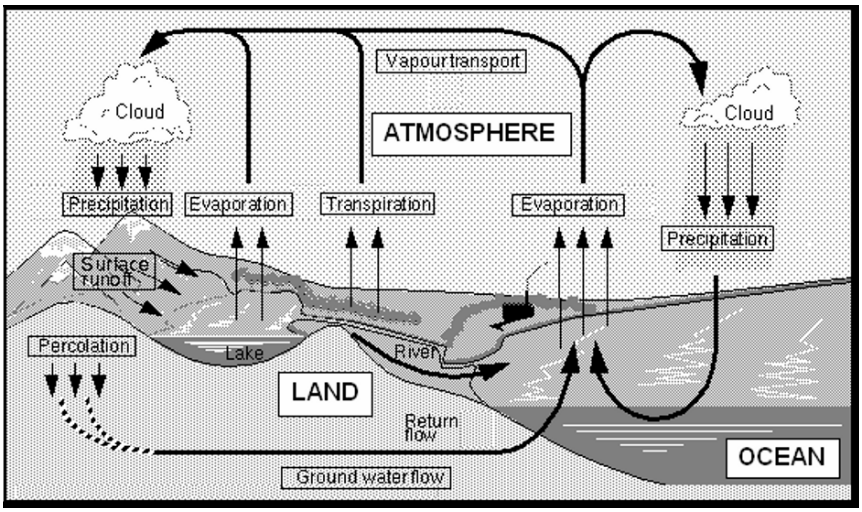

Fig. 1.2.3. Scheme of the global water cycle (from CHIAS, 2007, modified). Quantitative description see Table 1.2.1.

itation. On average, see Table 1.2.1, in case of ocean areas evaporation exceeds precipitation (arid climate) and the surplus of water vapour is transported to land areas where, again on average, precipitation exceeds evapotranspiration (humid climate). In the latter case, the surplus is transported to the ocean by river runoff and groundwater flow. Table 1.2.1 presents also the results of related climate model simulations.

Table 1.2.1. Evaporation E, precipitation P and run-off R as assessed from observational data and modelled (Max Planck Institute for Meteorology MPIM, Hamburg, coupled atmosphere-ocean circulation model ECHAM4-OPYC, reference period 1990-1999); all data from Marcinek, 2007.

Author	E (ocean)	P (ocean)	P (land)	E (land)	R (land)
Baumgartner and Reichel, 1975	425 (1176)	385 (1066)	111 (746)	71 (480)	40 (110)
Trenberth et al., 2006	413 (1143)	373 (1033)	113 (759)	73 (494)	40 (110)
Model, MPIM, cit. Marcinek, 2007	453 (1253)	411 (1138)	118 (793)	78 (527)	46 (127)

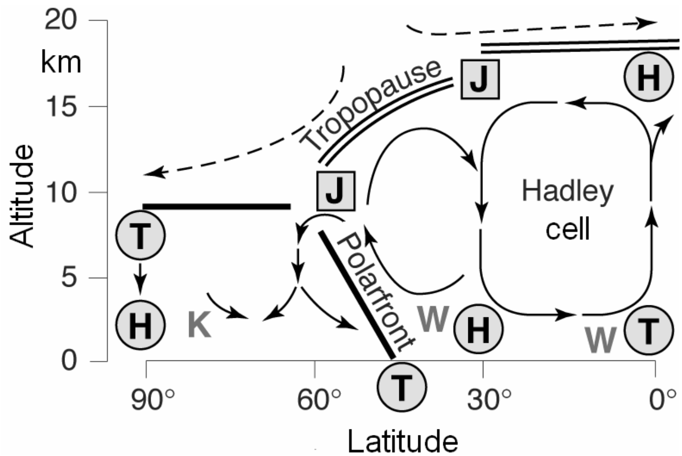

Fig. 1.2.4. Cross section of the atmospheric circulation, schematic, troposphere, one hemisphere (from Schönwiese, 2003, modified). Note that, in general, uplift (low pressure near surface, T) leads to cloud formation and precipitation whereas subsidence (high pressure near surface, H) to dryness. W means warm, K cold air masses; J = jet stream.

On a regional scale, the situation is much more complicated because as a consequence of the atmospheric circulation patterns, see Fig. 1.2.4, land areas may be humid (under the influence of relatively frequent low pressure situations, like within the tropics and mid-latitudes) or arid (high pressure situations prevailing, like in the subtropics). Now, if temperature increases, one may expect – on a global average – more evapotranspiration and more precipitation. In other words, the global water cycle may be speed up. On the other hand, there are a number of side effects. For instance, the Hadley Cell (see Fig. 1.2.4) may intensify so that the sub-

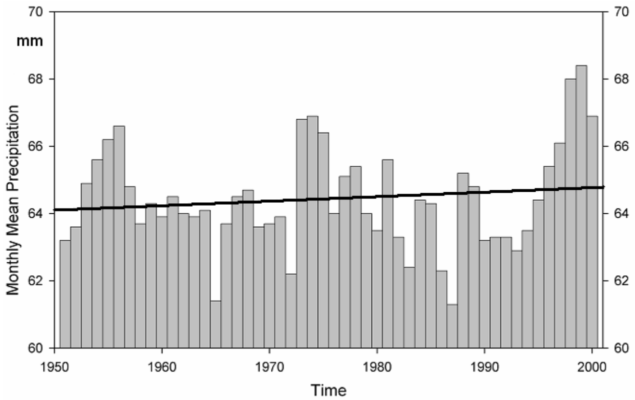

Fig. 1.2.5. Global mean (land areas) annual precipitation 1951-2000 (columns) and linear trend (heavy line). This trend shows a small statistically insignificant increase (from Beck et al., 2007).

tropical high pressure influence extends poleward. In the Mediterranean area, including the Middle East and North Africa, this may lead to less precipitation and therefore increasing aridity. Note that due to the annual cycle of the atmospheric circulation these regions are characterized by summer dryness and more or less precipitation in winter. The Hadley Cell intensification effect as mentioned above may lead to less precipitation also in winter and, in turn, growing problems with respect to water supply.

In the context of monitoring changes in the water cycle, the analysis of observed long-term precipitation trends may be helpful, both global and regional, including the regional (or sub-regional, respectively) and the seasonal patterns. So, the following chapters have their focus on global, European, and German observational precipitation trend patterns. Before this is done, it has at least to be mentioned, that precipitation implies measurement errors and poor representativeness (Schönwiese and Rapp, 1997). The measurement errors depend on the different rain gauge realizations used in different countries and are maximum in case of precipitation falling as snow under the influence of relatively strong wind. In this case, the precipitation total may be underestimated as large as roughly by >50 %. The poor representativeness means a small station-to-station correlation of precipitation measurements so that a very dense measurement network is needed not available in all countries. The shortcomings of this problem are somewhat mitigated if monthly or annual averages are considered instead of hourly or daily data.

1.2.3 Global precipitation trends

First, we may look on the global average of precipitation. However, due to huge measurement gaps over the ocean areas, such an information is available in a

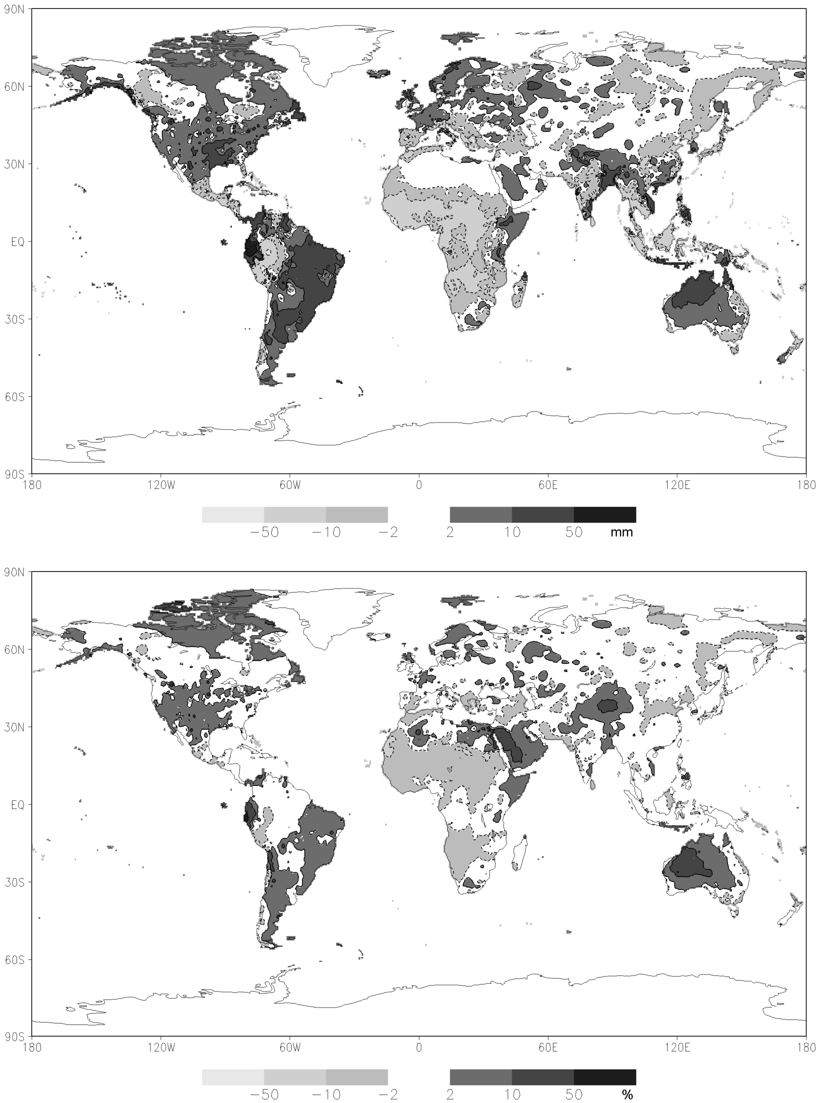

Fig. 1.2.6. Linear annual precipitation trends 1951-2000 in mm (upper plot) and percent (lower plot) per month, global patterns, 5° grid resolution (from Beck et al., 2007, modified). White areas neglected due to a small data base (Greenland, Antarctica, and a small region in northeast Africa). Dashed contour lines indicate a decrease.

sound form only for land areas. Sponsored by the German Climate Research Programme (DEKLIM) and in cooperation with the Global Precipitation Climate Center (GPCC) operating under the leadership of the German Weather Service (DWD), a Frankfurt research group (Beck, Grieser, Rudolf, Schönwiese, Staeger, and Trömel, 2007) has produced a comprehensive and intensively corrected global precipitation data set 1951-2000 based on 9,343 stations. This data base is used to assess the year-to-year change of global (land areas) and annual means of precipitation; see Fig. 1.2.5. We detect a small increase which, however, is not statistically significant because of the superimposed fluctuations which in part are correlated with El Niño years. In a similar analysis which covers the 1901-2005 period (using a considerably smaller data base) presented by the IPCC (2007) again fluctuations dominate although the increase 1901-1950 is somewhat more pronounced than afterwards. Keeping in mind, that a related analysis of oceanic data is missing, there is, based on such precipitation trend analyses, no clear indication of an global water cycle intensification, at least not within the recent decades.

However, we observe a very remarkable rearrangement of precipitation where both increasing and decreasing trends appear (more or less balanced on a global average), see Fig. 1.2.6. The most outstanding increasing trends appear *inter alia* in major parts of northern, eastern, and southern North America, extended regions in South America (especially in the east, but also Ecuador, Columbia, and Surinam), most of northwest and northern Europe, within some sub-regions scattered over Asia, some small regions in eastern and southern Africa and major parts of Australia. In the remaining regions, *inter alia* eastern Canada, northwest Brasilia and Peru, the Mediterranean and southeast Europe, nearly all of Africa, major parts of Siberia, China, India, and Indonesia, mostly a precipitation decrease is detected. Greenland, Antarctica, and a small sub-region in northeast Africa are not considered due to a too small data base (white areas in Fig. 1.2.6, such as those areas where the trends are smaller than 2 mm or 2 %, respectively.

These results of a global precipitation trend analysis are based on gridded data at a 5 degree resolution and therefore regionally very restricted. Moreover, such trend patterns are not stable in time, due to the superimposed fluctuations (see analogous situation in case of temperature, Fig. 1.2.1) and not uniform in different seasons.

1.2.4 European precipitation trends

In an earlier publication (Schönwiese and Rapp, 1997) we have presented a collection of European precipitation trend charts for the year, different seasons and months, based on data covering 1891-1990. In recent time, a majority of these charts was updated (1901-2000), where the trend analyses 1951-2000 are based on 521 stations. For comparison (see chapter 1.2.3), again this half-century period is selected and only a few examples are discussed.

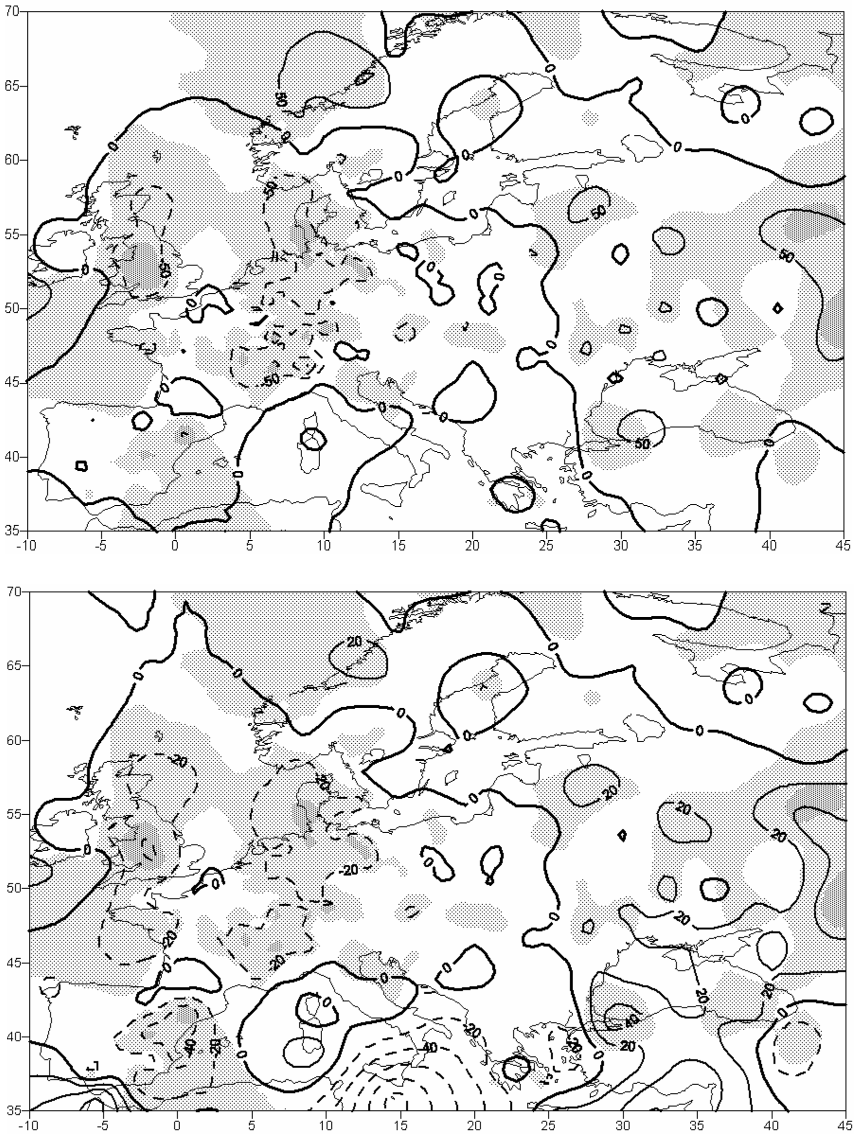

Fig. 1.2.7. Linear precipitation trends 1951-2000, European pattern, in absolute (mm, upper plot) and percent (lower plot) values, summer (June, July, and August) data (from Beck et al., 2007, based on Schönwiese and Janoschitz, 2007).

These examples refer to the summer (average of June, July, and August) and winter (average of December, pervious year, January, and February) within the coordinates 35° - 70° N, 10° W - 45° E, see Figs. 1.2.7 and 1.2.8. The trends are

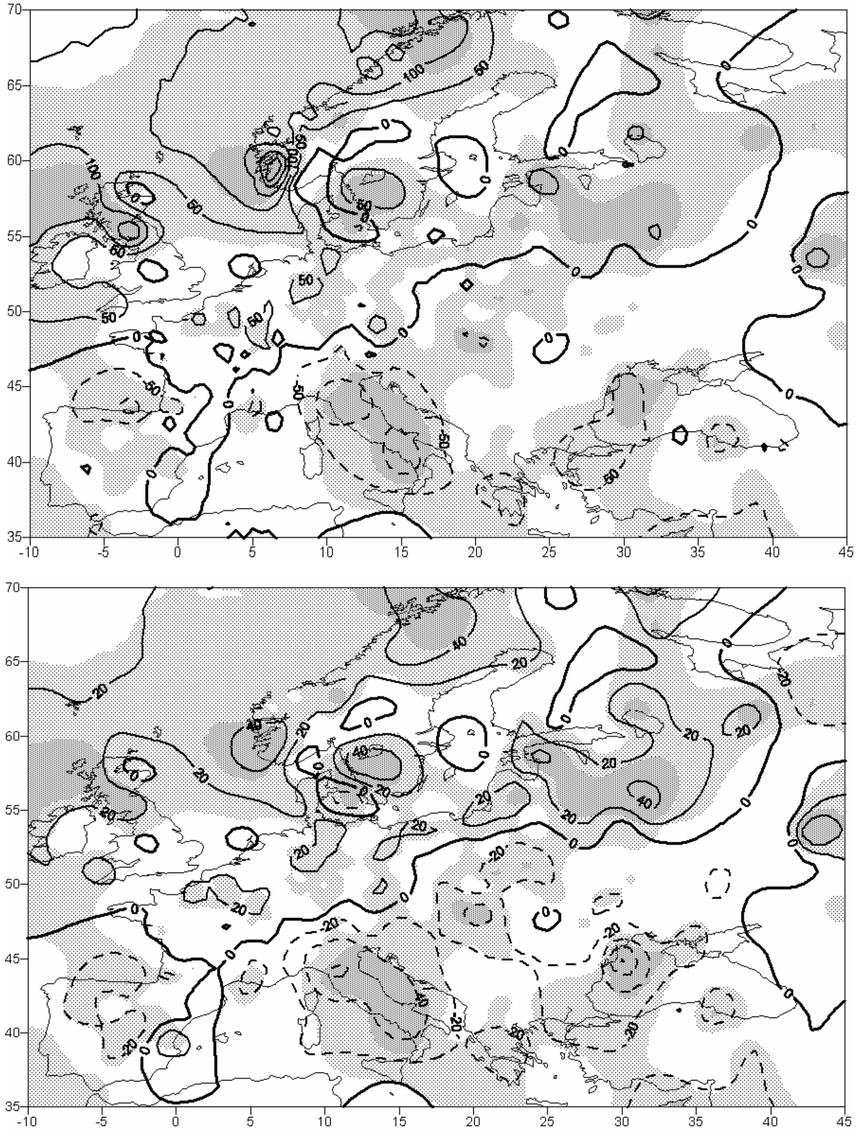

Fig. 1.2.8. Linear precipitation trends 1951-2000, European pattern, in absolute (mm, upper plot) and percent (lower plot) values, winter (December of previous year, January, and February (from Beck et al., 2007, based on Schönwiese and Janoschitz, 2007).

shown in absolute (mm) and relative (percent) values and shading indicates confidence (see Figure caption). In summer time which is of minor interest for the Mediterranean area (dry conditions) most of Europe except Eastern parts and NW Scandinavia show a decrease with maximum values >50 mm (corresponding to >20 %) in England, Germany and Switzerland. Some isolated increase areas in Northern and especially in Eastern Europe should be interpreted with care because some of this „island-like“ structures may be due to measurement shortcomings or imply representative problems, respectively. Note that the very high percent values south of Italy are based on very low absolute trends and therefore are not confident.

In winter time we see a bipartition which seems to be realistic: Roughly north of a line Brest (NW France), Munich (S Germany), Kiev, Moscow (all Russia) increasing trends prevail where maximum values of >100 mm (>49 %) appear (especially Scotland and parts of Scandinavia). South of this line precipitation has decreased where the maximum values (>50 mm corresponding to >40 %) are found in Italy and some western parts of the Black Sea area. Keeping in mind that winter precipitation is very important for the Mediterranean and North Africa region concerning ground water formation and water supply, this climate trend may lead to serious socio-economic problems. In spring and autumn (trend charts not shown) the line defined above moves somewhat southward but within the Mediterranean area again a precipitation decrease prevails (for more details see Beck et al., 2007).

1.2.5 Extreme events: a case study for Germany

As can be derived from the previous chapter (in particular Figs. 1.2.7 and 1.2.8) in Germany a pronounced summer precipitation decrease is observed whereas in the other seasons, especially in winter, increasing trends dominate, concentrated on western and southern parts (for more details see Schönwiese and Janoschitz, 2005). However, long-term trends are just one aspect of climate variability among others. Neglecting the problem of fluctuations in this paper, we may briefly address the question whether climate trends are linked with a change in the frequency and magnitude of extreme events. This is an important question because in case of precipitation extreme events may lead to flooding or dryness, respectively. In order to enable an innovative approach to empirical-statistical climate extreme analysis, Trömel (2005; see also Trömel and Schönwiese, 2005), based on earlier work of Grieser et al. (2002), has evaluated a generalized method of time series decomposition into significant components and the assessment of the change of these components in time. In case of extremes the key point is an adoption of an appropriate probability density function (PDF, in empirical form frequency distribution) to the observed data and the assessment of the PDF parameters change in time.

An example may illustrate this procedure. To come to marked results, the period 1901-2000 is considered and the data refer to the German station Eppenrod (in the west, near rivers Lahn/Rhine), January totals of precipitation. Fig. 1.2.9 specifies the PDF change where the 1901 and 2000 „snapshots“ are plotted. Simultaneously to an increase of the average from approximately 55 mm to 70 mm, the PDF has „broadened“ which means an increase of variance. The effect on extremes is as fol-

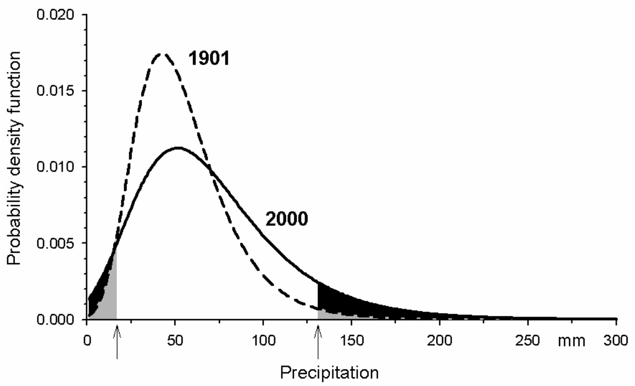

Fig. 1.2.9. Probability density function (PDF) change 1901-2000 of the January precipitation at station Eppenrod, Germany (50.4° N, 8.0° E), where the arrows indicate the (lower) 5th and the 95th (upper 5th) percentiles which amount to 17 mm or 131 mm, respectively, at this station. The related extreme value occurrence probabilities (indicated by grey or black shading, respectively) have increased for both extreme low and extreme high precipitation (for more explanation see text; from Schönwiese, Trömel, and Janoschitz, 2007).

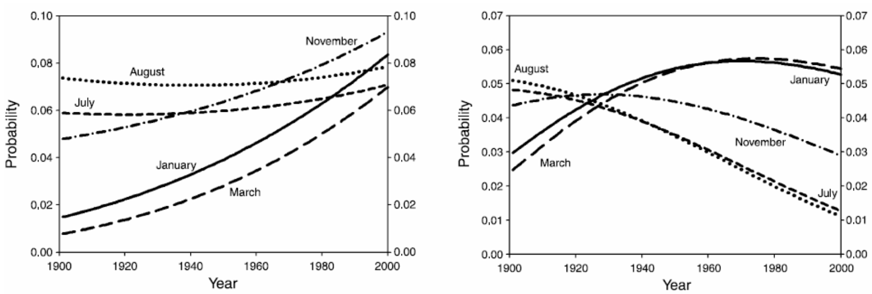

Fig. 1.2.10. Change 1901-2000 of the probability of occurring extremes (a, left) above the 95th percentile and (b, right) below the 5th percentile of precipitation in selected months at station Eppenrod, Germany (from Trömel and Schönwiese, 2007).

lows. If one defines the lower 5 % of the total data set (5th percentile) to be extreme dry and the upper 5 % (95th percentile) to be extreme moist, the shaded areas in Fig. 1.2.9 (illustrating the integral of the PDF below or above these percentile boundaries, respectively) represent the related occurrence probabilities. In this case we see that both probabilities have increased: occurrence of extreme dryness from

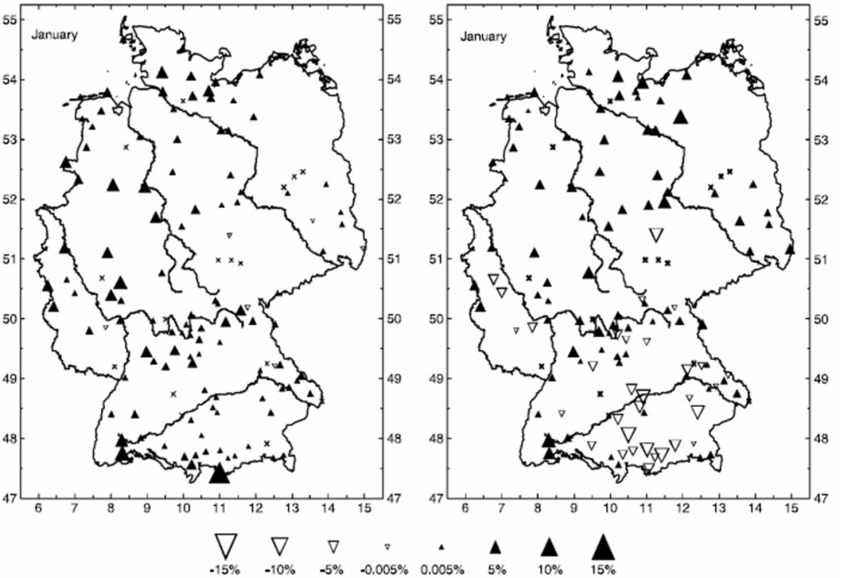

Fig. 1.2.11. Changes 1901-2000 of the probability of extreme January precipitation occurring above the 95th, left, or below the 5th percentile, right, at 132 stations in Germany. Upward black triangles indicate an increase and white downward triangles an decrease of this probability. The caption denotes the related magnitude (from Trömel and Schönwiese, 2007).

3.0 % (grey shaded area) to 5.3 % (grey plus black shaded area) and occurrence of extreme moistness from 1,5 to 8.4 % (again grey or grey plus black shaded areas, respectively).

Fig. 1.2.10 shows that this probability change of occurring extremes is a systematic process, however different in different months. From Fig. 1.2.10a where the development of the probability of occurring extremes exceeding the 95th percentile is indicated for a selection of months, it can concluded that this probability increases systematically in November, January, and March whereas it remains nearly constant in the summer months July and August. In contrast, the probability of occurring extremes falling under the 5th percentile (Fig. 1.2.10b) decreases gradually in November, July, and August but increases in January and March where, however, this increase seems to come to an end roughly around 1970 (results for all months and more stations see Trömel, 2005; see also Trömel and Schönwiese, 2007).

Just for one example, namely January precipitation, the distribution in space of such probability changes of occurring extremes is presented, see Fig. 1.2.11. It arises that the probability increase of occurring extremes above the 95th percentile is a wide-spread effect in Germany, however with relatively small magnitude at some stations, especially in the east. In case of extremes falling below the 5^{th} percentile the probabilities have different signs, mostly positive at the majority of northern stations but mostly negative in the south (especially Bavaria). By the way, if both probabilities of extremes occurring below the 5^{th} percentile and above the 95^{th} percentile decrease (or one of these probabilities remaining nearly constant), this means a decrease of variability and, in turn, a less extreme climate. This points to the fact that the behaviour of extremes is complicated. As far as Germany is concerned and with a focus on winter months, however, the precipitation behaviour indicates a more extreme climate (see again Fig. 1.2.11).

1.2.6 Conclusions

Global climate change is reality. The same holds for anthropogenic forcing as an additional climate factor although some quantitative uncertainties remain (IPCC, 2007; Schönwiese, 2003). Again it is a fact, that this change has its impact on the global water cycle.

However, there are complicated regional and seasonal peculiarities. So, whereas there is no confident prove that the global water cycle may have accelerated in land areas due to global warming in industrial time, we see a complicated precipitation trend pattern with striking regional and seasonal peculiarities. On a global scale, most of the subtropical zones like Central America and the Mediterranean area suffer from a precipitation decease, in addition – *inter alia* – most of Africa, India and Indonesia (reference period 1951-2000). Simultaneously, in other regions a precipitation increase is recorded, again *inter alia* in major parts of America and Australia such as in the northwest of Europe.

As far as Europe is concerned, detailed precipitation trend analyses have been performed and the results are available for different seasons or months, respectively, and for different observation periods. Again with reference to 1951-2000, the most outstanding winter effects are an increase in northern parts (maximum trends in Scandinavia and Scotland) and a decrease in the Mediterranean area (maximum trends in Italy and the western part of the Black Sea area). In summer, increasing dryness appears also in England and Central Europe. A case study concerning the probability change of occurring precipitation extremes in Germany shows the most interesting effect in winter with simultaneously more low and much more high precipitation rates (reference period 1901-2000). This means a more extreme climate with respect to precipitation. However, even in such a small country like Germany there are a lot of (sub-)regional and seasonal (monthly) peculiarities.

The recent IPCC Report (2007) expects that much of the ob served climate trends observed so far may continue at least for some decades, broadly independent from mitigation measures due to the inertia effects of the climate system. As late as roughly in the second half of this century, mitigation measures, predominately reductions of GHG emissions, may slow down anthropogenic climate change

(IPCC, 2007). In the mean time there is no chance than to adopt on unavoidable climate change. For the Mediterranean and North Africa the main challenge is to meet the problems of water stress (aridity) with all its ecological and socio-economic consequences.

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