3.1.6 Variability of European precipitation within industrial time

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***SUMMARY:** Precipitation variability as observed from 1901 to 2000 in Europe is analysed on a 147 stations monthly data base. In addition, for the 1951–2000 subperiod a 521 stations network was used. This analysis is focussed on linear trend patterns and extremes. The most outstanding results of trend analysis are a precipitation decrease in southern parts of Europe and an increase otherwise, especially in winter and autumn. This increase is often combined with a more extreme behaviour leading to both more extreme high and more extreme low precipitation rates. However, there are a lot of regional and seasonal peculiarities.*

The observed global warming of the lower atmosphere within industrial time (roughly since 1850; see IPCC 2001, SCHÖNWIESE 2003, HOUGHTON 2004) involves pronounced regional and seasonal peculiarities. Actually even more pronounced, this holds also for precipitation. The assumption that in a warmer world the hydrological cycle is intensified, in principle a reasonable idea, proves to be by far too simple if it is concluded that precipitation generally increases. Instead, we have to realise that complicated variations in time and space take place. To describe this behaviour in some overview for Europe for the recent century, is the intention of this contribution.

Usually, long-term climate variations are described by means of the linear trends of the variables under consideration derived from the related time series. However, this is just one aspect of climate variability because, for example, also variance my vary. In addition, trends may be non-linear. So, a more appropriate technique of data analysis is the computation of the related frequency distribution and adaptation of a suitable probability density function (PDF). This is a smoothed standardised theoretical version of the observed frequency distribution and may be of Gaussian, Gumbel, Weibull or any other type (von STORCH & ZWIERS 1999, SCHÖNWIESE 2000). Such distributions are characterised by their location, scale and eventually shape parameters where in the Gaussian case the location parameter is identical with the average and the scale parameter quantifies the standard deviation.

Trömel (2005; see also Trömel & Schönwiese 2005) has evaluated an innovative technique which allows to compute from time step to time step the variations of the PDF parameters where the variation of the average describes the trend. In addition, this generalised method of time series modelling allows, again from time step to time step, the computation of the probability that defined upper or lower thresholds are exceeded by the data. This contributes to the analysis of extremes on a non-stationary basis. Thereby, both the underlying PDF and the thresholds chosen are optional.

In the following we refer to a monthly precipitation data network of 147 stations covering the period 1901-2000 and 521 stations covering 1951-2000 (Janoschitz, 2006). We show a few examples of time series and PDFs but focus on linear trends (for reasons of comparison with other studies favouring this aspect), in particular spatial trend patterns; furthermore, we focus on the varying probability of occurring extremes.

Variability as seen in time series

We start with three examples of observed annual total precipitation time series from three European countries: Norway, station Barkestad; Germany, station Frankfurt/ Main; and Italy, station Milano, see *Fig. 3.1.6-1*. Evidently, the dominating impression is pronounced interannual variability although some relatively long-term fluctuations may have occurred, too. In case of Barkestad and Frankfurt there are also some weak indications of increasing variance where in case of Milano variance seems to fluctuate. First, however, we focus on linear trends.

This trend is outstanding in case of Barkestad, Norway: increase of 302 mm which corresponds to 21.5% (confidence > 95%, corresponding to an error probability of < 5% where here and in the following all confidence statements are based on the Mann-Kendall trend test, see e.g. Sneyers 1990). Also in case of Frankfurt/Main, Germany, an increasing trend is detectable which, however, is much smaller: 23 mm corresponding to 3.4% (not confident). In contrast, the Italian station Milano shows a considerable decreasing trend: 116 mm corresponding to 12.2% (confidence, however, only weak: > 80%). There are no stringent indications that these trends may be non-linear.

However, such trends of annual data do not necessarily reflect the seasonal trends or to say in other words: Weak trends of annual data may be the result of outstanding trends of different signs in different seasons (detailed analysis for Germany see Schönwiese & Janoschitz 2005). Moreover, as already seen from *Fig. 3.1.6-1*, trends vary from station to station. So, a view is necessary which takes account for both spatial and seasonal trend peculiarities.

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Some trend patterns

This view is realised by the assessment of spatial trend patterns. First, *Fig. 3.1.6-2a* shows such patterns of annual precipitation trends as revealed by a spatial interpolation (ordinary kriging) leading to contour lines within the area 35°–70° N, 10° W–45° E (from Janoschitz 2006 in actualisation of the European Climate Trend Atlas by Schönwiese & Rapp 1997; see this book for all technical details). The upper plot is based on the period 1901–2000 (147 stations) and shows decreasing precipitation in the Mediterranean region including a region roughly south of the East Sea. Thereby, maxima exceed 100 mm (confidence > 95%) around the Isles of Corsica and Sardinia such as in southern Spain. Otherwise an increase prevails with maxima exceeding 200 mm roughly north of Scotland and along the Norwegian coast (confidence again > 95%).

Based on the 1951–2000 network (521 stations), see *Fig. 3.1.6-2b* the trend patterns look much more chaotic and a confidence level of > 95% is reached only in some small areas. Nevertheless, decreasing trends are again detected in the Mediterranean region (maximum now in southern Italy) and maxima of increasing trends appear in Scotland and Scandinavia (with some »island structure« which points to some subregional fluctuation effects).

Then, *Fig. 3.1.6-3* specifies the seasonal trend patterns for the period 1901–2000. In summer (*Fig. 3.1.6-3b*) a weak decrease is found covering nearly all European regions except Scandinavia north of roughly 60° N and eastern Europe roughly east of 30° E reaching their maxima of approximately 20–30 mm, corresponding to approximately a 10% decrease, within the British Isles, south-western France, the Baltic countries and around the Bosporus (only weak confidence). In the subperiod 1951–2000 (plot not shown) this decrease pattern is slightly intensified within the British Isles, propagates from France to Germany and Denmark and arises also in eastern Spain, in all these cases exceeding a 20% decrease. In spring, see *Fig. 3.1.6-3a*, roughly southern and eastern parts of Europe are characterised by

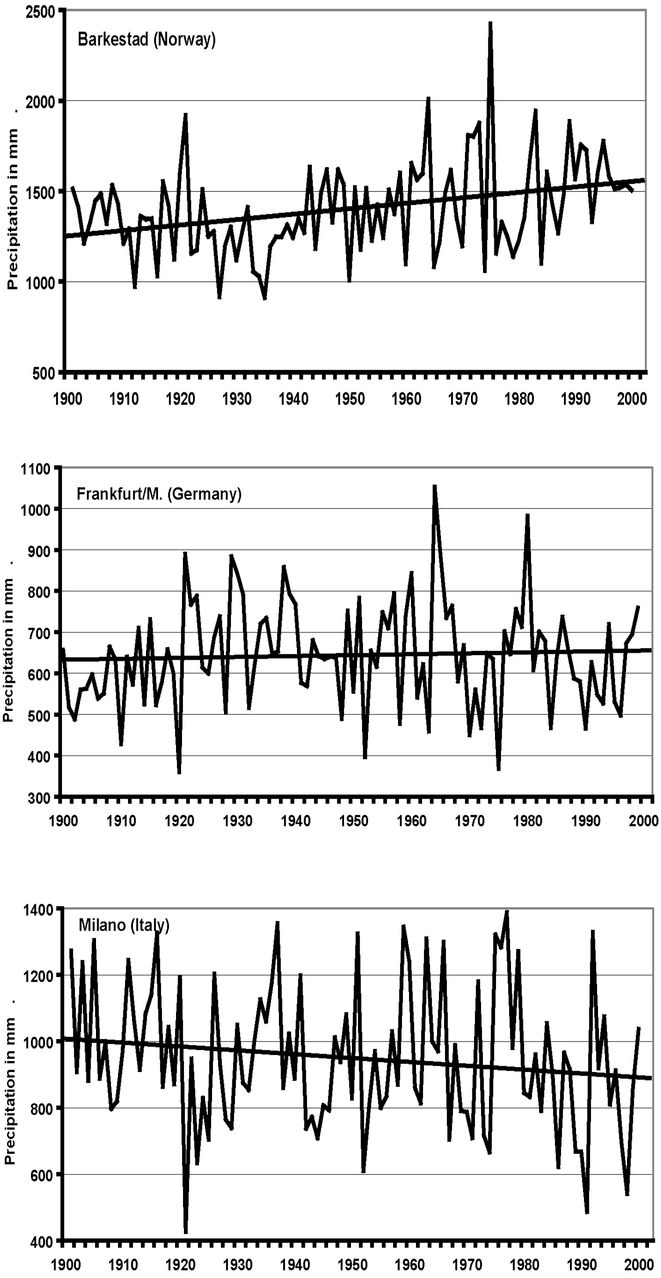

Fig. 3.1.6-1: Time series of annual precipitation totals 1901–2000 at stations Barkestad (Norway, 68.8° N 14.8° E), Frankfurt/Main (Germany, 50.1° N 8.6° E) and Milano (Italy, 45.5° N 9.2° E) along with linear trends (for details see text).

a slight decrease of precipitation whereas within the other regions a slight increase prevails intensifying towards the north-west so that the Norwegian coast is the region of maximum increase (approximately 50 mm or 20%; around c. 65–70° N, 30–35° E even until c. 50% with a confidence of > 95%; otherwise only weak confidence).

The winter trend pattern 1901–2000, see *Fig. 3.1.6-3d*, is quite similar to the annual one (*Fig. 3.1.6-2*) with a maximum decrease of approximately 50 mm (20%, weak confidence) near Corsica and maxima of increase in relatively small regions of the Alps, Denmark and more extended in northern Scandinavia (approximately again 50 mm, confidence mostly > 95%, near the North Cape roughly 100 mm, corresponding to 20–40% increase, confidence > 95%). Again, these trends have intensified in the 1951–2000 subperiod (plot not shown) where the dryness has propagated also to eastern Mediterranean regions and southern Scandinavia shows an increase now similar to northern Scandinavia. The autumn pattern (*Fig. 3.1.6c*) is more or less similar to the winter or annual one with some relatively pronounced regions of increase reaching from the North Sea via Denmark to major parts of Scandinavia (approximately 50 mm or 20%, confidence > 95%). Note, however, that due to a poor data coverage all trends in eastern Europe such as the Atlantic sector adjacent to the British Isles and Scandinavia are very uncertain.

Analysis of extremes

As already mentioned in the introduction, the analysis of extremes and their changing occurrence in time needs the adaptation of an appropriate PDF to each time series and a computation of the PDF parameter variations. This procedure is illustrated in *Fig. 3.1.6-4* using the example of January (from TRÖMEL & SCHÖNWIESE 2006) and August precipitation variations 1901–2000 at the German station Eppenrod (near Limburg, c. 60 km north-west of Frank-

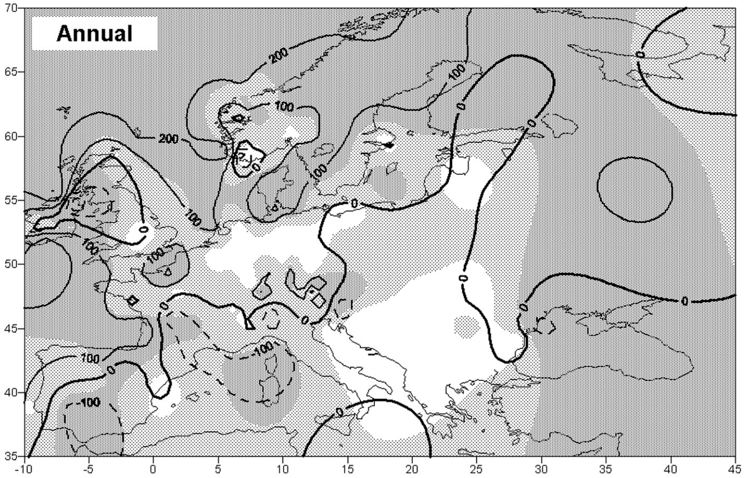

Fig. 3.1.6-2a: Linear trend pattern of annual precipitation totals 1901–2000 in mm, Europe, based on 147 stations. Light shading indicates confidence > 80%, dark shading > 95%.

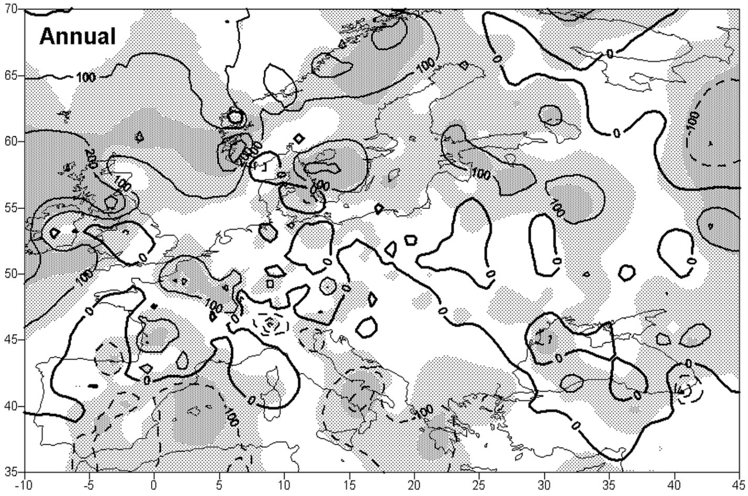

Fig. 3.1.6-2b: Similar to *Fig. 3.1.6-2a*, but period 1951–2000 based on 521 stations.

furt) where a Gumbel PDF revealed to be most appropriate. In January (*Fig. 3.1.6-4a*), not only the average has increased (from 55 to 70 mm) but also variance. So, the PDF has »broadened« leading to the effect that the occurrence probability of both extreme low and extreme high precipitation has increased. Oriented to the 5% percentile (lower threshold, corresponding to 17 mm in this case) the probability that monthly precipitation rates occur below this threshold has increased from 3.0% in 1901 to 5.3% in 2000; simultaneously, the probability that monthly precipitation exceeds the 95% percentile (upper threshold, corresponding to 131 mm in this case), has increased, too: even from 1.5% in 1901 to 8.4% in 2000, i.e. by a factor of 5.6. This means, the situation in January has become considerably more extreme.

In contrast to that, at the same station and within the same period, but in August (see *Fig. 3.1.6-4b*), the variance has decreased. In consequence, the probability of monthly precipitation below the 5% percentile has decreased from 5.1% to 1.1%, whereas near the upper threshold (95% percentile) only a weak probability change is detected. So, in August the situation has become less extreme. There are other examples available showing up that in summer both low and high extremes have become less probable (for Germany see Trömel 2005, Trömel & Schönwiese 2006).

Note, that in *Fig. 3.1.6-4* only the PDF in 1901 and 2000 is shown. The analysis technique used (Trömel 2005), however, allows to assess also the PDF in all years in between, similarly the computation of the probability of occurring extremes. Thereby, all time series 1901–2000 analysed so far show a gradual increase or decrease, respectively, of this probability. However, on longer time scales, also fluctuations of this probability may take place (see, for example, analysis of hot summers in Germany 1761–2003, Schönwiese et al. 2004).

In a final step, we show charts for the European region 35°–72° N, 26° W–60° E, where the changes of the probabilities are

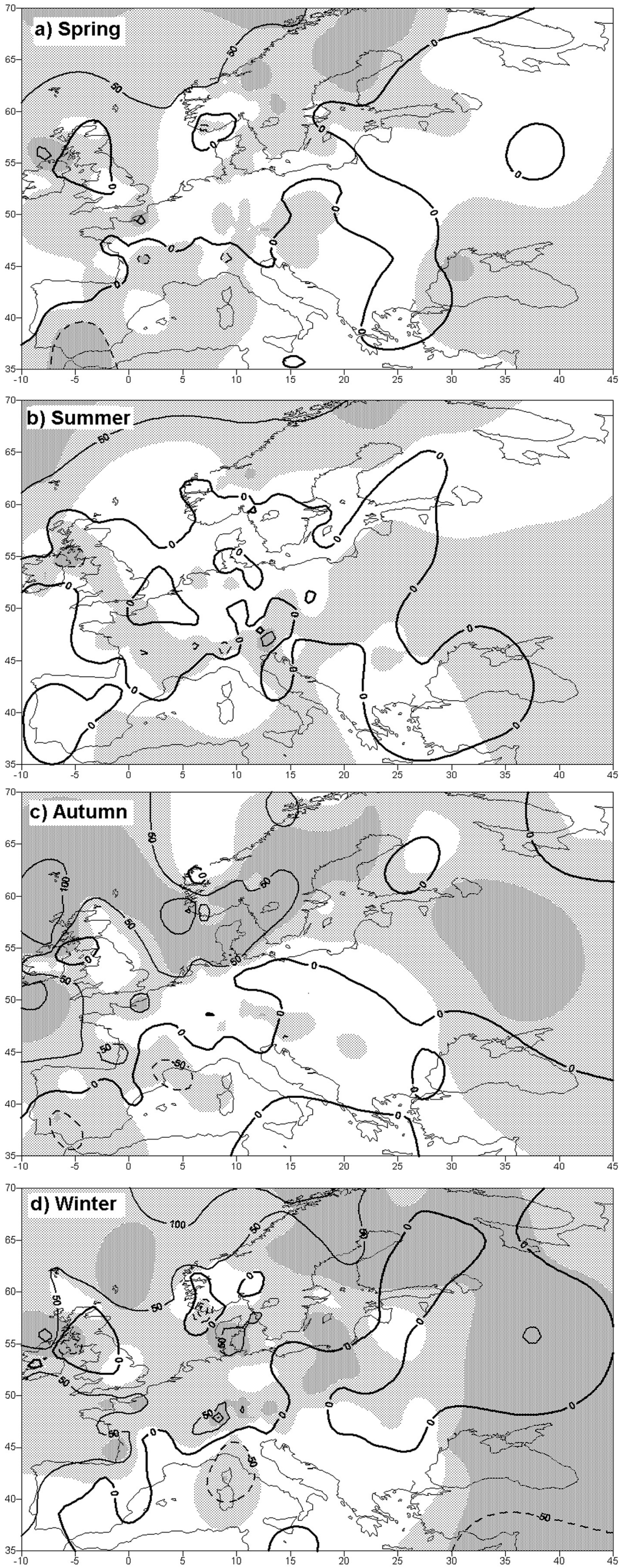

Fig. 3.1.6-3: Linear trend patterns of seasonal precipitation totals 1901–2000 in mm, Europe, based on 147 stations. Light shading indicates confidence > 80%, dark shading > 95%.

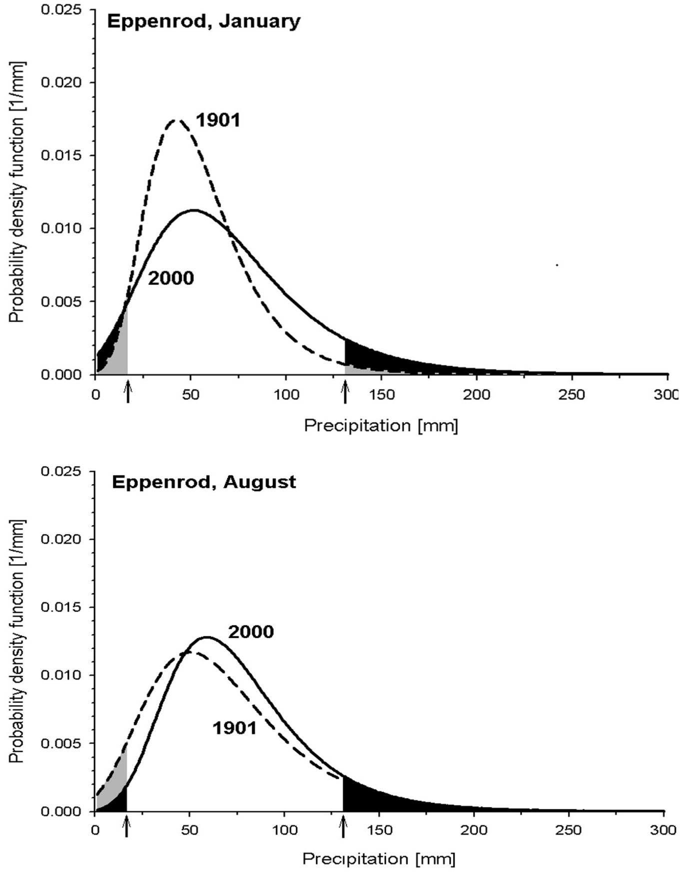

Fig. 3.1.6-4: Probability density functions (PDF) of a) January and b) August precipitation totals, station Eppenrod (Germany, 50.4° N 8.0° E), as snapshots for the year 1901, dashed line, and 2000, solid line. The 5% and 95% percentiles (lower and upper threshold for occurring extremes) are marked by asterisks and the related areas representing the probability that data exceed these thresholds are given in black or grey colour, respectively (from TRÖMEL AND SCHÖNWIESE 2006, modified and supplemented). For details see text.

shown that extremes occur below the 5% percentile or above the 95% percentile, respectively. This is done for the examples of the months of January and August. To start with January, see *Fig. 3.1.6-5*, a wide-spread probability increase of occurring extreme high precipitation (above the 95% percentile) is observed, especially in Scotland, Germany, Poland, Benelux countries, major parts of France and Spain such as in Scandinavia except Finland. However, a corresponding probability increase of occurring extreme low precipitation rates is observed only in Germany, some adjacent countries in the east, and only small subregions of northern France and northern Spain.

In August, a probability increase of occurring extreme high precipitation (above the 95% percentiles), see *Fig. 3.1.6-6*, is observed in the Alpine regions, Benelux countries and north Germany, Scandinavia except Finland, Ireland, Romaia, and a few subregions like northern France and northern Spain. A probability increase of occurring extreme low precipitation in August is a wide-spread phenomenon in Europe except Scandinavia, Central Germany, Ireland and a few relatively small regions in northern Spain, western France and southern Poland. Similar to trend analysis, the data base roughly east of 25–30° E is very poor.

Conclusions

It is a well-known fact that precipitation, in contrast to – for example – temperature, is a relatively problematical climate variable due to errors of measurement, poor representativeness, and outstanding variability in space and time. In the context of climate diagnostics and related to human affairs, relatively long-term trends and extremes may be most important. Within industrial time and Europe, a precipitation decrease in southern parts and an increase otherwise, especially in winter and autumn, are the most outstanding observational results of a trend analysis. However, a weak trend to more summer dryness in Central Europe is also worth to mention.

As far as extremes are concerned, only a few examples are presented here using January as an representative of winter and August as an representative of summer. To summarise the outcome of this aspect of analysis, a trend to more extreme conditions (increasing probability of both extreme high and extreme low precipitation monthly totals) took place predominantly in January in Central and some parts of western Europe, in August predominantly in the Alpine region, northern Germany, the Benelux countries, Romania and some parts of France. Otherwise, a trend to less extreme precipitation behaviour prevails♦

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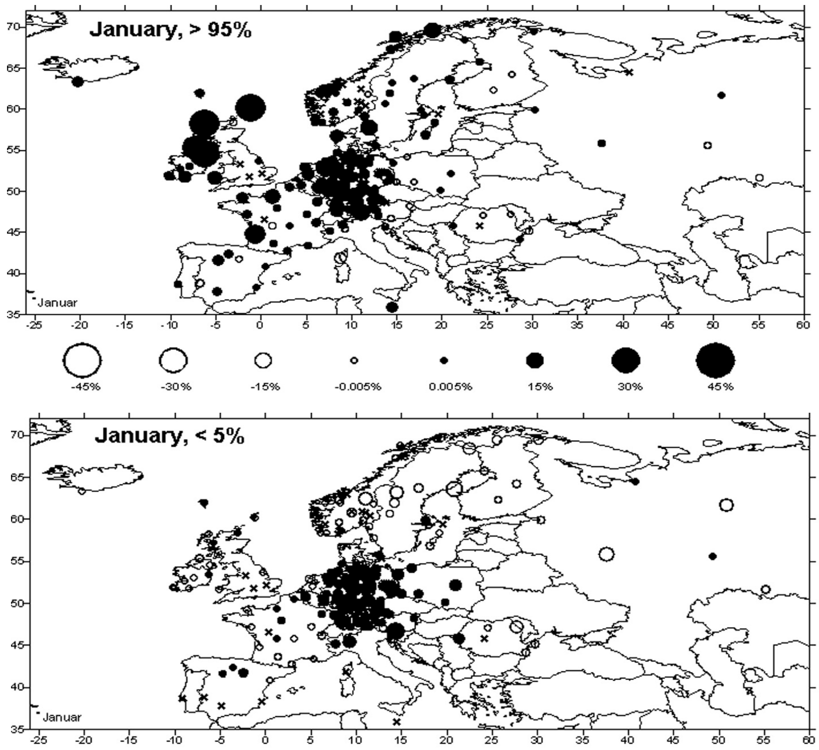

Fig. 3.1.6-5: Change in percent of the probability that extremes of precipitation exceed the 95% percentile in January, upper plot, or fall below the 5% percentile, lower plot, Europe. *Black circles* point to an increase, *white circles* to an decrease of this probability where the magnitude of change is characterised by the size of the circles. Crosses indicated that no significant change has been detected (from TRÖMEL 2005, modified and supplemented).

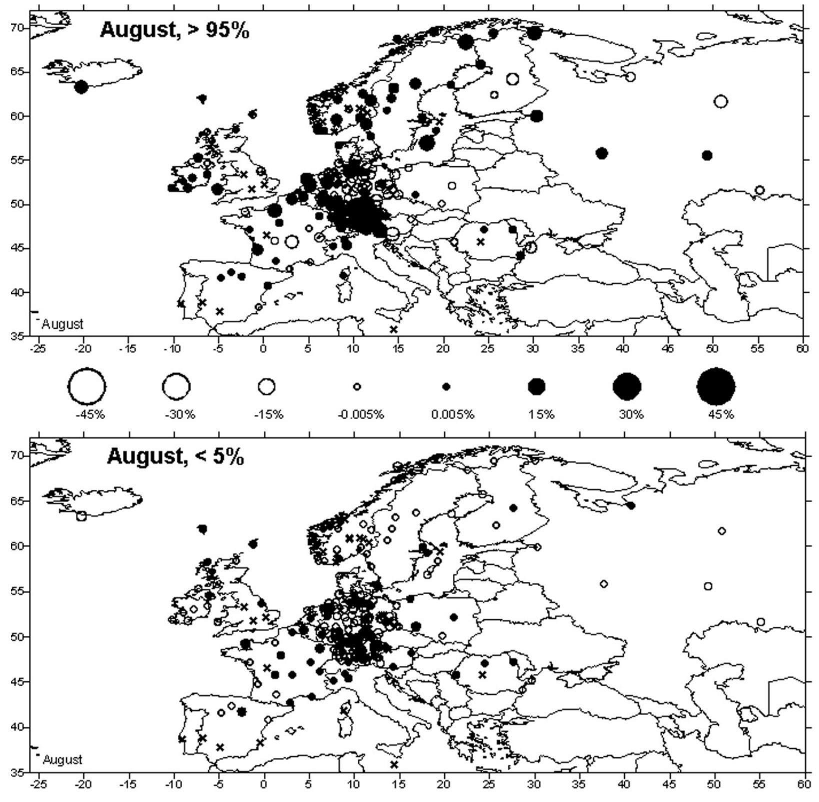

Fig. 3.1.6-6: Similar to *Fig. 3.1.6-5*, but August.