Temporal variability of precipitation extremes in Estonia 1961–2008*

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Abstract

Daily precipitation data from 40 stations are used to investigate the temporal variability of precipitation extremes in Estonia. The period covered is 1961–2008, characterized by a uniformity of observational practice. Precipitation extremes are quantified by yearly and seasonal values of two different parameters: day-count indices based on 95th and 99th percentile thresholds. Trend significance was assessed with the Mann-Kendall test. Results show that the frequency of both indices has increased. No significant negative trends were found. An increase of 15.8 events over the 99th percentile per decade was observed for Estonia. The indices selected for this study may be called 'soft' climate extremes, but the number of such events is large enough to allow for meaningful trend analysis in a roughly half-century long time series.

1. Introduction

In recent years extreme precipitation events have generated a lot of media attention. According to the latest report from the Intergovernmental

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Panel on Climate Change (IPCC) (Trenberth et al. 2007), the Earth's surface temperature has been rising and that rise is accelerating. In line with the characteristics of global temperature rise, Klein Tank et al. (2002) note that the European rate of change was also the highest in the last quarter of the 20th century. A warmer climate results in an increase in extreme weather events (Hennessy et al. 1997, Watterson 2005, Tebaldi 2006). This is partly because warmer air holds more water vapour, which is directly connected to the amount of precipitation (Trenberth 2003), and partly due to the increased energy budget. Even more so, Karl & Knight (1998) showed that extreme precipitation events are increasing at a relatively faster rate than moderate precipitation events. The same results are seen in the study by Groisman et al. (1999), who showed that the changes in heavy precipitation are disproportionately high compared to the rise in the monthly mean. Extreme weather in turn causes great economic damage (Nutter 1999): extreme precipitation events cause floods, mudflows and erosion.

Significant increasing trends in Estonian air temperature (1951–2000) were found not only for the cold season monthly means but also for the whole cold period (NDJFM) by Jaagus (2006). As a rule, however, the trends in monthly mean precipitation differ from station to station, displaying no clear tendency to rise or fall in any month or season (Jaagus 2006). Researchers investigating Estonian precipitation extremes have obtained contradictory results. Tammets (2007) found that the annual number of the sum of extreme wet and dry days indicated a rising trend of extremes in the precipitation regime of Estonia in 1957–2006. Merilain & Post (2006) and Mätlik & Post (2008) investigated heavy precipitation (>= 50 mm per 24 h) events recorded at Estonian stations in 1961–2005 but did not find any conspicuous trend in the number of events. One reason for the different conclusions lies in the different definition of extremely wet days: 50 mm for daily precipitation is a very high threshold for the Estonian climate and does not provide a sufficient number of cases for proper statistical study. Moreover, there are stations where 50 mm was not exceeded in the period under investigation.

Therefore, in this study, we have used indices of extremes that have a return period typically of the order of weeks, rather than once in 20 years. This ensures that the annual and seasonal number of extremes is sufficiently high to allow for a meaningful trend analysis in a half-century time series. The indices of precipitation extremes considered in the present study were selected from the list of indices for surface data recommended by the joint working group on climate change detection of the World Meteorological Organization-Commission for Climatology (WMO-CCL) and the Research Programme on Climate Variability and Predictability (CLIVAR) (Peterson et al. 2001). These day-count indices, based on the daily precipitation distribution with the 95th and 99th percentiles as thresholds, show anomalies relative to local (station) climatology. Therefore it is possible to investigate the geographical distribution of the thresholds themselves in addition to a temporal statistical analysis of indices.

The approach of using percentiles as thresholds of precipitation extremes was used widely before by numerous authors like Klein Tank & Können (2003) and Zolina et al. (2004). Klein Tank & Können (2003) investigated the trends in the indices of daily precipitation extremes in the whole of Europe using the European Climate Assessment (ECA) daily dataset, but many Estonian stations are missing from that database.

The purpose of this paper was to find out whether extreme precipitation events are becoming more frequent in Estonia, whether the trends are statistically significant, and whether there are different trends for the warm and cold seasons. This was achieved by calculating a threshold for every station from its daily precipitation density distribution and then counting the number of events over that threshold for every year. Groisman et al. (2005) suggest that to obtain statistically significant estimates, the characteristics of heavy precipitation should be averaged over a spatially homogeneous region; otherwise, the noise of the spatial scale of daily weather systems masks changes and makes them very difficult to check. Therefore, trends for three regions in Estonia were assessed.

2. Data and methods

This study is based on the dataset of daily precipitation from the Estonian Meteorological and Hydrological Institute (EMHI). The dataset covers 40 stations (see Figure 1, page 249) and the period from 1961 to 2008. There were data missing at 17 stations but in no case did the gap exceed 2.1% of records during 1961–2008. All the measurements were made manually with a Tretyakov precipitation gauge (Mätlik & Post 2008). After 1966 a wetting parameter of 0.2 mm was added, and in 2005 the time of accumulation for 24 hour sums of precipitation was changed from 18:00 UTC to 06:00 UTC. Although this means that the dataset is not completely homogeneous, it does not affect precipitation extremes too much.

The precipitation indices used in this study are defined in terms of counts of days crossing variable thresholds (percentiles). The day-count indices based on percentile thresholds are site-specific. Here we use four indices: the 95th ($R95p$) and the 99th ($R99p$) percentiles of precipitation distribution of the daily measurements, and $R95$ (or $R99$) for the counts of days when at the station the measured precipitation rate RR exceeds the 95th (or the

99th) percentile threshold. The definitions of extremes indices are available online at http://eca.knmi.nl/indicesextremes/indicesdictionary.php. Days with $RR > R95p$ are referred to as 'very wet' days and days with $RR > R99p$ are 'extremely wet' days. Percentiles were found for the cold and warm seasons and for the whole year. The cold season is defined as lasting from November to April and the warm season from May to October. We divided the year into two seasons in this way on the basis of the analysis of percentiles of monthly precipitation distributions. The one-month shift of the beginning of the seasons compared to the astronomical ones can be explained by the inertia in the sea surface temperature and consequent evaporation and atmospheric humidity levels. Once the percentiles had been found, values exceeding those thresholds were counted for each season and each year.

We investigated the temporal variability of precipitation extremes by assessing linear trends in $R95$ and $R99$. We assessed trend significance in extreme precipitation events with the Mann-Kendall test and used Sen's method to estimate slope (Salmi et al. 2002); this latter method is applicable in cases where the trend is assumed to be linear.

To obtain the slope estimate Q, the slopes of all possible value pairs in the data

$$Q_i = \frac{x_j - x_k}{j - k} \tag{1}$$

are calculated. Here $j > k$. For n values of x_i in the time series we get $\mathrm{N} = \mathrm{n}(\mathrm{n}-1)/2$ slope estimates. The Sen slope estimator is the median of these N values of Q_i. These values are then ranked from the smallest to the largest, and the Sen slope estimator is

$$Q = Q_{[(\mathrm{N}+1)/2]}, \text{ if N is odd}$$

or (2)

$$Q = \frac{1}{2}(Q_{[\mathrm{N}/2]} + Q_{[(\mathrm{N}+2)/2]}), \text{ if N is even.}$$

The results given in Table 1 (see page 252) are the slope estimator multiplied by one hundred to obtain the slope percentage for the whole period.

Trends in extreme precipitation events were also found for three different regions in Estonia. Precipitation regionalization is a method for grouping meteorological stations with similar precipitation regimes. In this work we applied manual regionalization based on daily precipitation distribution percentiles. We separated Estonia into three regions – western, central and eastern. Figure 1a shows the geographical distribution of $R99p$ in the

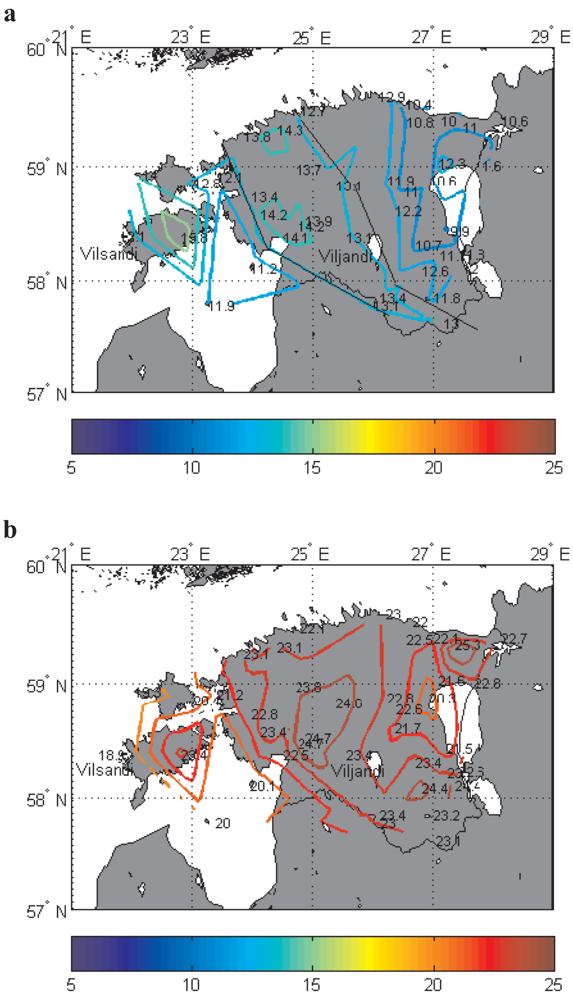

Figure 1. Geographical distribution of $R99p$ (in mm) for 40 stations in Estonia. a) for the cold season and b) for the warm season. The numerical value of the threshold ($R99p$) is shown by the locations of the stations. The two black broken lines in Figure a) mark the borders between the eastern, central and western regions. The isohyets are drawn for a better overview of the spatial pattern

cold season: three regions are clearly distinguishable – the western and eastern regions with lower threshold values and the central region (between them) with higher ones. The same geographical separation is valid for the distribution of the $R95p$ for the cold season and for the whole year. The other three percentiles (both for the warm season and $R99p$ for the whole year) depend more on small-scale influences and therefore do not provide a reasonable basis for regionalization. An example of this situation is shown in Figure 1b – $R99p$ for the warm season. The regional time series of $R95$ and $R99$ are produced by summing the numbers of events at all stations in the region: 7 stations belong to the western region, 13 to the central region and 20 to the eastern region.

3. Results

3.1. Indices of precipitation extremes at Estonian stations

The 99th percentiles of daily precipitation distributions for Estonian stations vary between 18.9 mm and 25.3 mm in the warm season (Figure 1b) and 9.9 mm and 15.8 mm in the cold season (Figure 1a); the corresponding 95th percentiles are 9.3–13.1 mm and 5.2–8.8 mm. The $R99p$ and $R95p$ for the whole year fall into the 15.7–20.6 mm and 7.7–10.4 mm ranges respectively. Approximately the same values can be seen in Figures 2a and 2b, which show histograms of the daily precipitation distributions at the Viljandi and Vilsandi stations, together with the annual values $R95p$ and $R99p$. These stations were selected as examples of typical stations with low (Vilsandi) and high (Viljandi) percentile values.

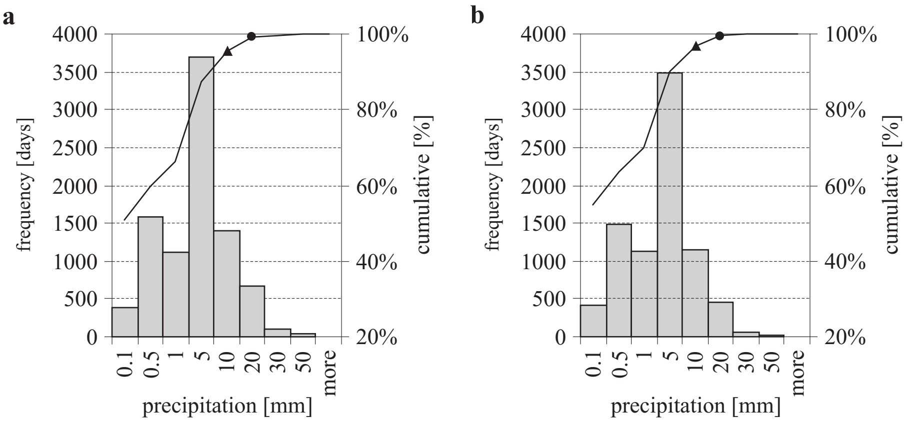

Figure 2. Histogram of daily precipitation sums a) at the Viljandi station and b) at the Vilsandi station for the period 1961–2008. The number of dry days at Viljandi is 8505 (48.5%); $R95p = 9.7$ mm and $R99p = 19.1$ mm; the number of dry days at Vilsandi is 9015 (52.4%); $R95p = 7.9$ mm and $R99p = 15.7$ mm. The triangle and circle on the 'cumulative %' line show the approximate amount of precipitation for $R95p$ and $R99p$. The label is the upper boundary of the bin. Note the change in scale on the x-axis

Figures 3a, 3b and 3c show the interannual variability of $R99$ and $R95$ at Viljandi. The $R95$ and $R99$ usually go hand in hand from one year to the next. The reason for this synchronous movement is that during years with a lot of extreme events, both very wet days and extremely wet days occur more often, and also that extremely wet days are counted among the very wet days.

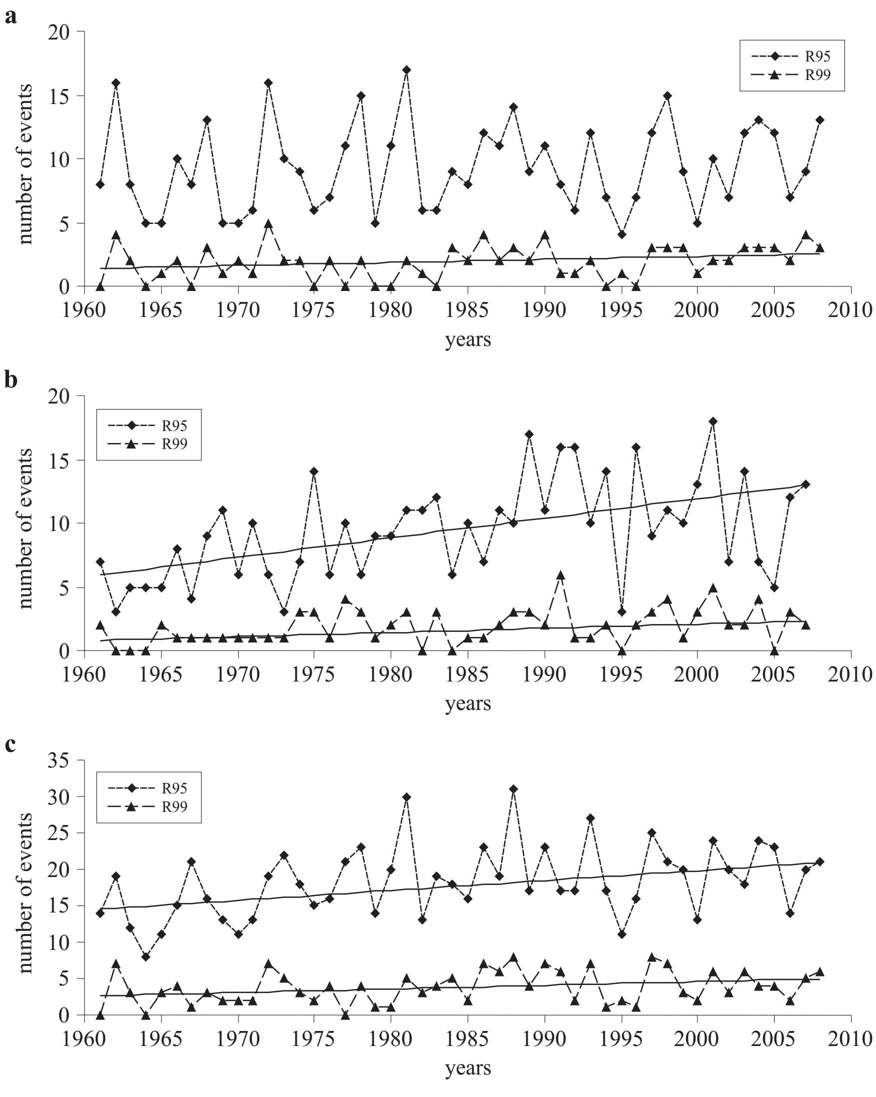

Figure 3. Time series of the precipitation extremes indices from 1961–2008 at the Viljandi station. a) For the warm season the $R99$ slope is 2.4% at a significance level of 0.05 (the $R95$ trend slope is not significant); b) for the cold season the $R99$ trend slope is 3.2% ($\alpha = 0.01$) and the $R95$ trend slope is 15.4% ($\alpha = 0.001$); c) for the year the $R99$ trend slope is 5% ($\alpha = 0.05$) and the $R95$ trend slope is 3.6% ($\alpha = 0.01$)

In Figure 3, especially in Figure 3b for the cold season, two different periods between 1961 and 2008 can be distinguished: one with lower values beginning from 1961 (or before) and ending around 1980, and the other with higher values beginning in the 1980s and lasting till the present day. This pattern is also apparent in the other time-series.

3.2. Trends of very wet and extremely wet days in Estonia

Among the temporal changes in the series from individual stations, tendencies were evident in both directions as regards very wet and extremely wet days, but none of the falling trends was significant. Whereas summing the events over the whole country yields more stable trends (see Table 1), grouping the stations in regions allows us to refer to regions where these trends are more pronounced.

Table 1. Trends (in %) in the occurrence of the precipitation extremes indices in 1961–2008. The significance of the trend is given by the following signs: $^{+}0.1$, $^{*}0.05$, $^{**}0.01$, $^{***}0.001$

Region	Warm season		Cold season		Year	
	$R99$	$R95$	$R99$	$R95$	$R99$	$R95$
Viljandi	2.4^{*}	4.6	3.2^{**}	15.4^{***}	5.0^{*}	13.6^{**}
mean of 40 stations	2.2^{**}	5.2^{*}	2.2^{*}	8.6^{**}	4.2^{**}	10.3^{**}
eastern region	2.7^{**}	7.7^{*}	1.3^{+}	6.7^{*}	4.5^{**}	10.0^{*}
central region	1.5^{+}	2.9	3.8^{***}	11.0^{***}	3.5^{**}	10.5^{*}
western region	2.4^{**}	3.0	1.5	7.4^{*}	4.0^{**}	5.8

If we look at the trends of the Estonian mean, then they are all significant at least at the 5% level. The trends for very wet days are always larger than for extremely wet days. This is also the case in all the regions taken separately.

As we can see in Figure 4a, the number of very wet days in the warm season has increased by 5.2% at a significance level of $\alpha = 0.05$. On average, events over $R95p$ take place 9.3 times during the warm season, so the 5% increase is relatively small in absolute terms. Even more so, the same scenario applies to values over $R99p$ during the warm season. As on average there are 1.9 events over $R99p$ per station during the warm season, its 2.2% increase at $\alpha = 0.01$ is not especially remarkable. However, as Figure 4c shows, if we sum all the extremely wet events from all the stations for every year, we perceive an increase of about 16 events per decade at 40 Estonian stations, which implies a rising probability of economic losses. The overall trends of $R99$ in the warm season are affected more by the increase in events in the eastern and western regions and, correspondingly, the trends of $R95$ in the eastern region (Table 1).

For the cold season the Estonian mean $R95$ trend slope is higher than for the warm season with 8.6% at a significance level of 0.01 (Figure 4b).

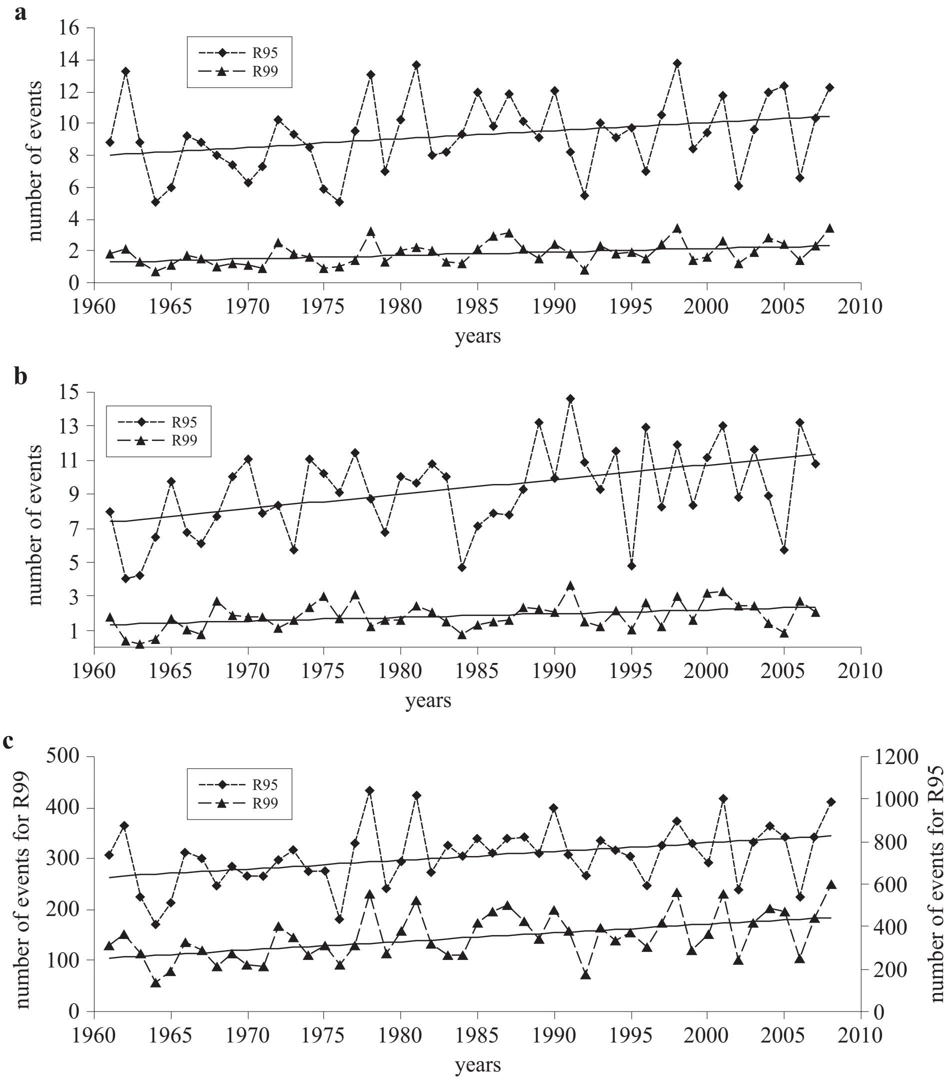

Figure 4. Time series of the precipitation extremes indices in 1961–2008 for all stations. a) For the warm season $R99$ and $R95$ averaged over all stations, b) for the cold season $R99$ and $R95$ averaged over all stations, c) the annual sum of events exceeding $R99p$ and $R95p$ at all stations. The $R99$ increase is 15.8 events per decade ($\alpha = 0.01$) and the $R95$ increase is 35.9 events per decade ($\alpha = 0.01$). The numerical values of the trend slopes and their significances are listed in Table 1

The central region's stations account for the cold season's large overall trend with a regional 11.0% for the period for $R95$ and the quite small 3.8% for $R99$. The other two regions, separated by the central region, have rather similar increasing trends for very wet days in the cold season, but these are only 6.7% and 7.4% for the eastern and western regions respectively.

Figure 4b also shows that in the 1980s there was a regime shift in cold season precipitation extremes in Estonia.

4. Discussion and conclusion

We investigated the temporal variation in precipitation extremes at 40 Estonian stations in the period 1961–2008. We used variable threshold-based precipitation extremes indices: the 95th and the 99th percentiles of the precipitation distribution in daily measurements, and counts of the days when the measured precipitation at a station exceeded the 95th (or the 99th) percentile threshold. All these indices were calculated for all 40 stations for two seasons (the cold and warm half-year) and for the whole year. Temporal variability was investigated by calculating the linear trend slopes for the day-counts with Sen's slope estimator and significances with the Mann-Kendall test. To ensure better stability of trends, the counts of days were summarized over all stations and over three regions in Estonia: western, central and eastern region. This regionalization was performed on the basis of the geographical distribution of the 99th percentile threshold in the cold season.

The main conclusion is that the frequency of precipitation extremes has gone up. Our study shows a statistically significant increase in extreme precipitation in Estonia for the 1961–2008 period, which coincides with the research done by Groisman (2005) for the European part of the former USSR, by Rimkus et al. (2010) for Lithuania and by Venäläinen et al. (2009) for Finland. The trends had similar signs for the warm and cold seasons, which is a different result from that obtained in similar studies done for other parts of Europe (Klein Tank et al. 2002, Zolina et al. 2005, Moberg et al. 2006, Zolina et al. 2008). Zolina et al. (2008) showed that estimates of climate variability in precipitation characteristics based on annual time series result from the unequal changes of opposite signs in different seasons. Our results showed consistently positive trends for both seasons. Although there were some negative trends, none of them were statistically significant. An explanation for the difference may be that in this study, we divided the year into two seasons (cold and warm), whereas Zolina used four seasons. Another reason could be that Estonia is farther north than the locations where the other studies were carried out and that it really does get more intense precipitation events in both seasons. Nevertheless, the increase in the warm season was less than in the cold season. This would also support the idea that the higher latitudes are experiencing a greater increase in climatic extremes of precipitation. For example, Karagiannidis et al. (2009) demonstrated negative trends in extreme precipitation for Europe – the dataset used in that study included stations from Denmark to the Mediterranean Sea.

This research also showed that Estonia is a region where the mean precipitation has not noticeably changed (Jaagus 2006), but where the number of heavy precipitation events has done so. Such regions also include Siberia, South Africa, northern Japan (Easterling et al. 2000) and the eastern Mediterranean (Alpert et al. 2002).

The spatial distribution of the 99th percentile threshold in winter is similar to the spatial distribution of Estonian annual precipitation (Jaagus et al. 2010), with a belt of maximum values expanding from the south to the north nearly parallel to the coastline at an average distance of 10–60 km from the sea. To the east and west of this belt the precipitation rates are lower. For our study this regionalization of extreme precipitation fields was justified by giving clearly different trends of precipitation indices for neighbouring regions in different seasons. The largest rising trends of very wet and extremely wet day counts were also recorded in this central region in the cold season. This may be due to the high positive NAO index period during 1972–2007, which brought a more zonal circulation to north-eastern Europe with an increasing number of cyclones from the SW to Estonia. The trajectories of these cyclones force the frontal precipitation to fall in this near-coastal belt, but not in the islands or the inner Estonian uplands.

References

Alpert P., Ben-Gai T., Baharad A., Benjamini Y., Yekutieli D., Colacino M., Diodato L., Ramis C., Homar V., Romero R., Michaelides S., Manes A., 2002, *The paradoxical increase of Mediterranean extreme daily rainfall in spite of decrease in total values*, Geophys. Res. Lett., 29 (11), 1536, doi: 10.1029/2001GL013554.

Easterling D. R., Evans J.-L., Groisman P. Y., Karl T. R., Kunkel K., 2000, *Observed variability and trends in extreme climate events: A brief review*, Bull. Am. Meteorol. Soc., 81 (3), 417–425.

Groisman P. Y., Karl T. R., Easterling D. R., Knight R. W., Jamason P. F., Hennessy K. J., Suppiah R., Page C. M., Wibig J., Fortuniak K., Razuvaev V. N., Douglas A., Førland E., Zhai P., 1999, *Changes in the probability of heavy precipitation: Important indicators of climatic change*, Climatic Change, 42 (1), 243–283.

Groisman P. Y., Knight R. W., Easterling D. R., Karl T. R., Hegerl G. C., Razuvaev V. N., 2005, *Trends in intense precipitation in the climate record*, J. Climate, 18 (9), 1326–1350.

Hennessy K. J., Gregory J. M., Mitchell J. F. B., 1997, *Changes in daily precipitation under enhanced greenhouse conditions*, Clim. Dynam., 13 (9), 667–680.

Jaagus J., 2006, *Climatic changes in Estonia during the second half of the 20th century in relationship with changes in large-scale atmospheric circulation*, Theor. Appl. Climatol., 83 (1), 77–88.

Jaagus J., Briede A., Rimkus E., Remm K., 2010, *Precipitation pattern in the Baltic countries under the influence of large-scale atmospheric circulation and local landscape factors*, Int. J. Climatol., 30 (5), 705–720.

Karagiannidis A., Karacostas T., Maheras P., Makrogiannis T., 2009, *Trends and seasonality of extreme precipitation characteristics related to mid-latitude cyclones in Europe*, Adv. Geosci., 20, 39–43.

Karl T. R., Knight R. W., 1998, *Secular trends of precipitation amount, frequency, and intensity in the United States*, Bull. Am. Meteorol. Soc., 79 (2), 231–241.

Klein Tank A. M. G., Können G. P., 2003, *Trends in indices of daily temperature and precipitation extremes in Europe, 1946–99*, J. Climate, 16 (22), 3665–3680.

Klein Tank A. M. G., Wijngaard J. B., Können G. P., Böhm R., Demarée G., Gocheva A., Mileta M., Pashiardis S., Hejkrlik L., Kern-Hansen C., Heino R., Bessemoulin P., Müller-Westermeier G., Tzanakou M., Szalai S., Pálsdóttir T., Fitzgerald D., Rubin S., Capaldo M., Maugeri M., Leitass A., Bukantis A., Aberfeld R., van Engelen A. F. V., Forland E., Mietus M., Coelho F., Mares C., Razuvaev V., Nieplova E., Cegnar T., López J. A., Dahlström B., Moberg A., Kirchhofer W., Ceylan A., Pachaliuk O., Alexander L. V., Petrovic P., 2002, *Daily dataset of 20th-century surface air temperature and precipitation series for the European Climate Assessment*, Int. J. Climatol., 22 (12), 1441–1453.

Mätlik O., Post P., 2008, *Synoptic weather types that have caused heavy precipitation in Estonia in the period 1961–2005*, Est. J. Eng., 14 (3), 195 –208.

Merilain M., Post P., 2006, *Heavy rainfall – is it only a feature of recent years' summers in Estonia?*, Publ. Geophys. Univ. Tartuensis, 50, 144–154.

Moberg A., Jones P. D., Lister D., Walther A., Brunet M., Jacobeit J., Alexander L. V., Della-Marta P. M., Luterbacher J., Yiou P., Chen D., Klein Tank A. M. G., Saladié O., Sigró J., Aguilar E., Alexandersson H., Almarza C., Auer I., Barriendos M., Begert M., Bergström H., Böhm R., Butler C. J., Caesar J., Drebs A., Founda D., Gerstengarbe F.-W., Micela G., Maugeri M., Österle H., Pandzic K., Petrakis M., Srnec L., Tolasz R., Tuomenvirta H., Werner P. C., Linderholm H., Philipp A., Wanner H., Xoplaki E., 2006, *Indices for daily temperature and precipitation extremes in Europe analyzed for the period 1901–2000*, J. Geophys. Res., 111, D22106, doi: 10.1029/2006JD007103.

Nutter F. W., 1999, *Global climate change: Why U.S. insurers care*, Climatic Change, 42 (1), 45–49.

Peterson T. C., Folland C., Gruza G., Hogg W., Mokssit A., Plummer N., 2001, *Report on the activities of the Working Group on Climate Change Detection and Related Rapporteurs 1998–2001*, World Climate Data and Monitoring Progr., Geneva, WMO, 47.

Rimkus E., Kažys J., Bukantis A., 2010, *Recent dynamics and prediction of heavy precipitation events in Lithuania*, 6th Study Conf. BALTEX, Poland.

Salmi T., Määttä A., Anttila P., Ruoho-Airola T., Amnell T., 2002, *Detecting trends of annual values of atmospheric pollutants by the Mann-Kendall test and Sen's slope estimates – the Excel template application MAKESENS*, Finnish Meteorol. Inst. Rep., 31.

Tammets T., 2007, *Distribution of extreme wet and dry days in Estonia in last 50 years*, Proc. Estonian Acad. Sci. Eng., 13 (3), 252–259.

Tebaldi C., Hayhoe K., Arblaster J., Meehl G., 2006, *Going to the extremes*, Climatic Change, 79 (3), 185–211.

Trenberth K. E., Dai A. G., Rasmussen R. M., Parsons D. B., 2003, *The changing character of precipitation*, Bull. Am. Meteorol. Soc., 84 (9), 1205–1217.

Trenberth K. E., Jones P. D., Ambenje P., Bojariu R., Easterling D., Klein Tank A. M. G., Parker D., Rahimzadeh F., Renwick J. A., Rusticucci M., Soden B., Zhai P., 2007, *Observations: surface and atmospheric climate change*, [in:] *Climate Change 2007: The physical science basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, S. Solomon, D. Quin, M. Manning, M. Marquis, K. Averyt, M. M. B. Tignor, H. L. Miller & Z. Chen, Cambridge Univ. Press, Cambridge, 236–336.

Venäläinen A., Jylhä K., Kilpeläinen T., Saku S., Tuomenvirta H., Vajda A., Ruosteenoja K., 2009, *Recurrence of heavy precipitation, dry spells and deep snow cover in Finland based on observations*, Boreal Environ. Res., 14 (1), 166–172.

Watterson I. G., 2005, *Simulated changes due to global warming in the variability of precipitation, and their interpretation using a gamma-distributed stochastic model*, Adv. Water Resour., 28 (12), 1368–1381.

Zolina O., Kapala A., Simmer C., Gulev S. K., 2004, *Analysis of extreme precipitation over Europe from different reanalyses: a comparative assessment*, Global Planet. Change, 44 (1–4), 129–161.

Zolina O., Simmer C., Kapala A., Bachner S., Gulev S. K., Maechel H., 2008, *Seasonally dependent changes of precipitation extremes over Germany since 1950 from a very dense observational network*, J. Geophys. Res., 113, D06110, doi: 10.1029/2007JD008393.

Zolina O., Simmer C., Kapala A., Gulev S. K., 2005, *On the robustness of the estimates of centennial-scale variability in heavy precipitation from station data over Europe*, Geophys. Res. Lett., 32, L14707, doi: 10.1029/2005GL023231.