Long-term changes of precipitation in Latvia

Lita Lizuma, Agrita Briede and Maris Klavins

ABSTRACT

This study investigated long-term variability and trends in Latvia's annual, seasonal, monthly and daily precipitation using data from 10 meteorological stations for the period 1925–2006 and from station Riga University for the period 1850–2006. The obtained results indicate that during the 20th century a significant increase in precipitation has occurred in the cold season while the warm period showed a decreasing tendency. The annual precipitation totals showed a slight decrease, at half of the studied stations, due to opposite tendencies in cold season and warm season. The long-term trend in the annual precipitation in Riga (from 1850) was positive with large interannual and interdecadal variability. The extreme precipitation events were evaluated using a set of nine climate change indices. Of these, number of wet days, 1-day and 5-days maximum precipitation, moderate wet days and very wet days showed a well pronounced positive tendency in the cold period of the year particularly in winter. No overall long-term trend was detected in extreme precipitation in summer. As in the case of 150-year precipitation pattern, extreme precipitation exhibited cyclic fluctuations that were more pronounced than linear changes. The close correlation between North Atlantic oscillation (NAO) and extreme precipitation was found for winter season.

Key words | Latvia, long-term changes, precipitation indices, series homogeneity

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INTRODUCTION

Global land mean annual precipitation shows a small, but uncertain, upward trend over the 20th century of approximately 1.1 mm per decade (Trenberth *et al.* 2007). Changes in global mean precipitation over land mask large regional variations.

Precipitation has generally increased over land north of 30°N during the period 1900 to 2005, but downward trends have dominated the tropics since the 1970s (Trenberth *et al.* 2007). In Europe mean winter precipitation over the period 1900 to 2005 is increasing in most of Atlantic and northern Europe, while in the Mediterranean area yearly precipitation trends are negative in the east and are non-significant in the west (Alcamo *et al.* 2007).

The countries of the Baltic region report higher precipitation in the period 1976–2000 compared to the years 1951–1975. The changes are therefore different throughout the region, being higher in Sweden and the Eastern Baltic especially in winter, autumn and spring (Heino *et al.* 2008).

The studies carried out in Estonia detected an annual precipitation increase by 80–180 mm (10–25%) at 8 stations out of 9 during the second half of the 20th century (Jaagus 1998, 2006). In the period 1922–2003, Latvia, Estonia and Lithuania have received higher precipitation in winter with an abrupt increase in the second part of the 20th century (Jaagus 2006; Reihan *et al.* 2007).

Today there is a growing interest in extreme weather events such as food- or flood-producing rains and droughts (Easterling *et al.* 2000). For many impact applications and decisions, extreme events are much more important than the mean climate. Changes in extremes may be due to the mean effect, the variance effect or the structural change in

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shape of distribution (Heino *et al.* 2008). Determining changes in the behaviour of precipitation extreme events in Europe is the main topic of several international projects e.g. European Climate Assessment and Dataset (ECA&D) (Klein Tank *et al.* 2002; Klein Tank & Könen 2003), European and North Atlantic daily to MULtidecadal climATE variability (EMULATE) (Moberg *et al.* 2006) and Statistical and regional dynamical downscaling of extremes for European regions (STARDEX) (Haylock & Goodess 2004). Extreme climate events can be identified in different ways. One of these methods is using internationally agreed, predefined indices e.g. day count exceeding a fixed threshold, percentile threshold, extreme event duration, etc. In the frame of the CCl (Commission for Climatology of WMO), CLIVAR (research programme on CLImate VARiability and predictability) and JCOMM Expert Team on Climate Change Detection and Indices, the primary focus was extreme events. A range of climate indices were defined to detect probable changes.

Studies have provided evidence that the increase in abundant precipitation is more significant than the increment in the precipitation amount. In some cases, when seasonal precipitation totals remain unchanged, extreme precipitation amounts showed increased values (Easterling *et al.* 2000). Most of the observation stations in Europe have shown a significant increasing trend in the number of days of mean and extreme precipitation over the later part of the 20th century (Klein Tank & Können 2003).

The number of heavy precipitation events over most land regions (even in areas where there has been a decrease in total amount of precipitation) is likely to have increased; this is consistent with a warming climate and observed significant increases in atmospheric water vapour. Climatological data show that the most intense precipitation occurs in warm regions (Easterling *et al.* 2000). Analyses have shown that even without any change in total precipitation, higher temperatures lead to a greater proportion of total precipitation in heavy and very heavy precipitation events (Groisman *et al.* 1999; Katz 1999; Karl & Trenberth 2003).

To date, studies of the climate change in Latvia have mostly been conductedt using monthly data. In order to carry out more rigorous study, especially in assessing extreme values, daily data are of the highest importance. For the territory of Latvia, uninterrupted daily precipitation data are available since the 1920s and for the station Riga University since 1850.

The aim of the study is to determine long-term variability and trends in the time series of total precipitation, extreme precipitation events and to analyze changes in seasonal distribution of precipitation in Latvia.

MATERIALS AND METHODS

The present study used daily, monthly and annual precipitation data series (1925–2006) for 10 meteorological stations (Figure 1) obtained from Latvian Environment, Geology and Meteorology Agency. At the Riga University station, the daily, monthly and annual precipitation data were used to investigate the changes in precipitation over a period of 156 years.

Basic quality and homogeneity control was undertaken for all of the series. Inhomogeneities in precipitation series have mainly formed as a result of the use of different instruments and observation methods. During the long-term observation period, there have been a number of important changes in the network operation. At the end of the 19th century the height of the precipitation gauges was standardized to 2 m above ground level and a so-called Nipher wind shield around the gauge orifice was installed. The study showed that data recorded at Riga University station during the period 1851–1876 had lower values than those measured in later periods. Based on the practices of other countries (Moberg *et al.* 2003), to avoid the uncatch effect of the change in measuring instruments on the quality of data, the monthly means derived from data for years 1851–1870, 1876–1900, 1901–1920, 1921–1940, 1941–1960 were compared. Based on this procedure, definite monthly multiplication factors (1.5–1.2) for each individual month were introduced. These factors were used to calculate daily precipitation totals for the period 1851–1875.

Another important change in the operation of the precipitation network over the territory of Latvia started in 1953 when the old-style gauges were replaced with the Tretyakov-type rain gauges. Studies were conducted in the former USSR and also in Latvia, aimed at comparing data acquired with both measuring instruments (Groisman *et al.* 1991; Groisman & Legates 1995). The correction

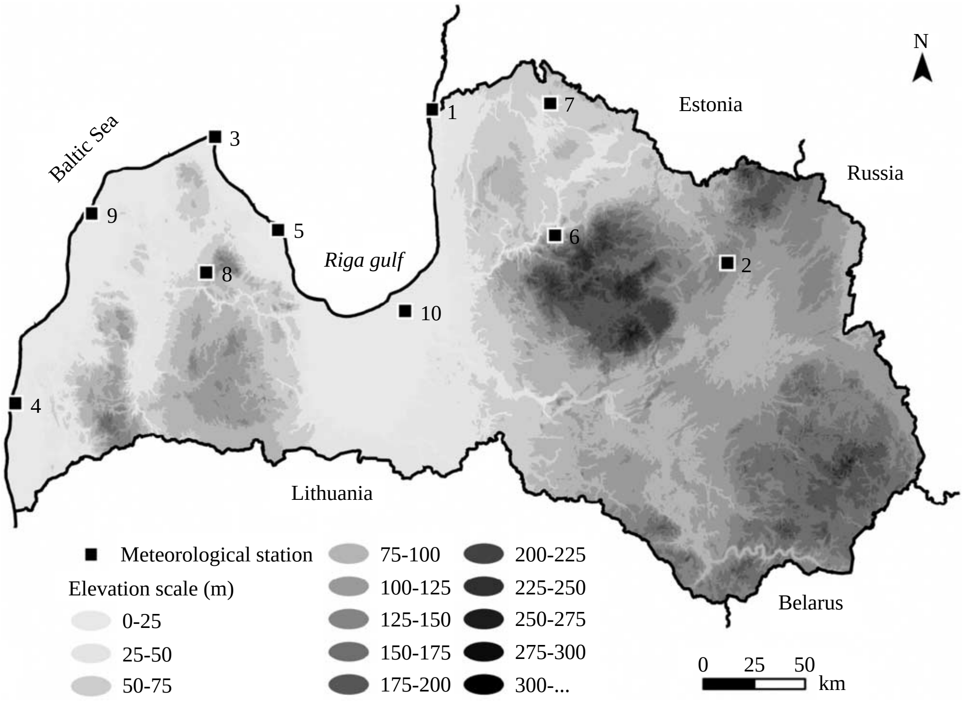

Figure 1 | Location of meteorological stations selected for the study (1: Ainazi; 2: Gulbene; 3: Kolka; 4: Liepaja; 5: Mersrags; 6: Priekuli; 7: Rujiena; 8: Stende; 9: Ventspils; 10: Riga).

coefficients were developed and applied to daily precipitation data acquired in the period before the new rain gauge was introduced.

The quality of daily measured data has been improved by the bucket moisture compensating factor introduced in 1966. The daily precipitation totals obtained before 1966 were corrected by adding 0.1 mm (solid precipitation) or 0.2 mm (wet or mixed precipitation).

Homogeneity of the created precipitation and air temperature series was tested using two statistical homogeneity tests: standard normal homogeneity test (SNHT) (Alexandersson & Moberg 1997) for monthly, seasonal and annual data series, and multiple analyses of series for homogenization (MASH) (Szentimerey 1996) for daily data series as well as for monthly, seasonal and annual data series.

In this study, only homogeneous data series were used. The seasonal means were calculated as arithmetic means from monthly records. Trends in the precipitation time series were analyzed using the non-parametrical Mann-Kendall test (Libiseller & Grimvall 2002). The Mann-Kendall test was applied separately to each variable at each site at a significance level of $p \leq 0.01$. The trend was considered statistically significant if the test statistic was greater than 2 or less than -2. The slope of linear regression was obtained by multiplying the slope with the number of observation years.

An ensemble of climate change indices, derived from daily precipitation data, describe changes in the mean indices or extremes of climate. The indices follow the definitions recommended by the CCl/CLIVAR/JCOMM Expert Team on Climate Change Detection and Indices (www.knmi.nl/samenw/eca) with a primary focus on extreme events (Table 1).

The possible connection between large-scale atmospheric circulation and climate change indices was investigated using NAO monthly and seasonal indices (Jones *et al.* 1997; Osborn 2006; www.cru.uea.ac.uk/~timo/projpages/nao_update.htm).

RESULTS AND DISCUSSION

Climate in Latvia is affected by its location in the northwest of the Eurasian continent and by its proximity to the Atlantic Ocean. Latvia has a fully humid snow climate (type Dfb) with warm summers in the Köppen-Geiger climate

Table 1 | List of indices used in this study

Index name	Definition	Unit
RR	Precipitation total	mm
RR1	Number of wet days (number of days with precipitation >1 mm)	days
RR10 mm	Heavy precipitation days (number of days with precipitation ≥ 10 mm)	days
RR20 mm	Very heavy precipitation days (number of days with precipitation ≥ 20 mm)	days
RX1	Highest 1-day precipitation amount	mm
RX5	Highest 5-day precipitation amount	mm
R75p	Moderate wet days (days with precipitation >75th percentile of daily amounts of precipitation at wet days in the 1961–1990 period)	days
R95p	Very wet days (days with precipitation >95th percentile of daily amounts of precipitation at wet days in the 1961–1990 period)	days
R99p	Extremely wet days (days with precipitation >99th percentile of daily amounts of precipitation at wet days in the 1961–1990 period)	days

classification system (Kottek *et al.* 2006). Because of frequent cyclonic activity over Latvia, precipitation occurs about 170–200 days per year. The prevailing westerlies bring significant precipitation to Latvia and the mean annual precipitation (1961–1990) over the territory is 670 mm. The highest amount of precipitation (750 to 850 mm) is typical for the western slopes of Vidzeme Upland and Western Kursa Upland, whereas the lowest annual amount of precipitation (500–600 mm) is observed in the western part of Zemgale Plain and Lubana plain. Convective and stratiform precipitation, associated with atmospheric fronts, occurs in all seasons and can produce a significant amount of daily and monthly precipitation. During summer, convective precipitation is also induced by land surface heating that leads to significant upward motion.

Contrary to the winter situation, summer precipitation is more intense and of a shorter duration. The largest amount of precipitation (>80 mm per month) falls during the summer season; the cold period typically has a low monthly precipitation (about 20 mm). Heavy and very heavy precipitation occurs mostly in the warm period (April–September), induced by intensive convection processes and usually local phenomena. The maximal diurnal precipitation, 160 mm, has been measured in the western part of Latvia in 1973. The average (1961–1990) number of the days with precipitation exceeding 10 mm and 20 mm are 13–26 days and 2–7 days, respectively.

Precipitation totals

The trend analysis of the precipitation totals discloses temporal and seasonal variability (Figure 2). In general, the amount of precipitation in Latvia has a tendency to increase in the cold period.

During the cold half of the year (October–March), a statistically significant increase ($p \leq 0.01$ test statistic ≥ 2) in precipitation has been observed at 6 out of 10 stations (1925–2006), but the rest of stations exhibited an increasing tendency. In contrast, the warm period (April–September) precipitation exhibited a decreasing tendency (Figure 2). At 4 out of 10 stations, the increased precipitation during the cold season is negated by the decrease of warm season precipitation that leads to the increase of annual

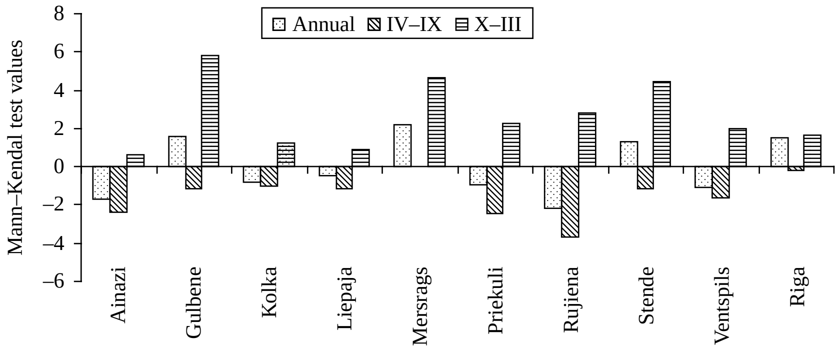

Figure 2 | Mann-Kendall test statistics of annual precipitation and precipitation in warm (IV–IX) and cold (X–III) periods (1925–2006).

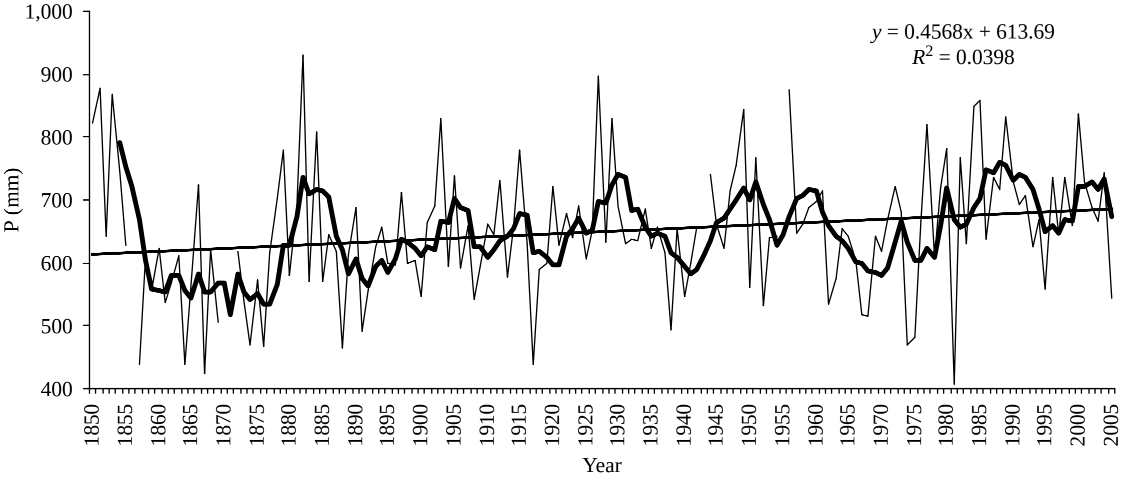

Figure 3 | Annual precipitation totals with 5-year smoothed data and trend line for Riga.

precipitation. The remaining six stations showed a weak decreasing trend of the annual precipitation. Similar patterns of changes in winter–summer precipitation balance during the same time period have been found in other Baltic States (Reihan *et al.* 2007) and Eastern Germany. Franke *et al.* (2004) demonstrated a marked decrease in summer rainfall (−10 to −30%) and significant increase in winter precipitation (10 to 20%) for Saxony, Eastern Germany.

Overall, the long-term trend in the annual precipitation in Riga (from 1850) shows a positive sign (Figure 3). The linear trend is statistically significant at the $p \leq 0.01$ level. Standardized residuals fell within the range −2.6 to 2.8 with zero mean; the residuals were almost normally distributed. The Mann-Kendall test value of trend was 3.13. It should be noted that over the entire observation period, a large interannual variability and (in some periods) interdecadal variability was noted. The driest period was between 1858 and 1877 (average annual precipitation 550 mm), while the period after 1977 stands out as rather wet (average annual precipitation 700 mm).

Investigating changes in monthly precipitation series can provide a more detailed overview of the timing of significant changes in annual precipitation. Precipitation has a pronounced tendency to increase in December, January, February and March with a significant decrease in September and July (Table 2).

The total changes in the amount of precipitation were considered by using the slope of linear regression for the 10 stations having 81 years of observation (Figure 4). Standard errors associated with the slopes varied in winter season

Table 2 | Mann-Kendall test values for the monthly precipitation (1925–2006) (statistically significant values, $p \leq 0.01$, in bold)

Meteorological station	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Ainazi	−0.2	0.2	0.3	−0.6	−1.6	1.1	**−2.1**	−1.7	−1.6	0.0	0.8	1.7
Gulbene	**5.1**	**3.5**	**2.6**	−0.4	0.0	1.4	**−2.6**	−0.9	−1.3	1.4	2.0	**4.6**
Kolka	−0.3	0.3	0.4	−0.3	−1.7	0.9	0.1	−1.2	−1.7	−0.3	0.9	1.2
Liepaja	0.1	0.6	1.8	−1.0	−1.8	1.2	−0.1	−0.1	−1.7	−0.2	0.6	0.5
Mersrags	**3.6**	**3.5**	1.7	0.0	−1.2	0.5	−0.5	−0.2	−1.1	0.3	1.3	**2.9**
Priekuli	**2.2**	1.4	0.8	−0.9	−1.0	−0.9	−1.7	−0.9	−1.6	−0.2	0.4	**2.4**
Rujiena	**2.4**	1.5	0.5	−1.4	−1.7	0.6	**−2.5**	−1.7	**−2.4**	−0.2	0.0	**2.6**
Stende	**2.5**	**2.8**	**2.4**	0.0	−0.8	1.4	−1.9	−1.5	−1.2	0.6	1.0	**3.1**
Ventspils	−0.2	0.2	0.3	−0.6	−1.3	1.5	−0.9	−0.9	**−2.0**	−0.9	0.8	1.7
Riga	0.1	0.6	−0.2	−0.2	−1.0	0.5	−0.1	0.7	−0.4	0.1	0.9	1.9

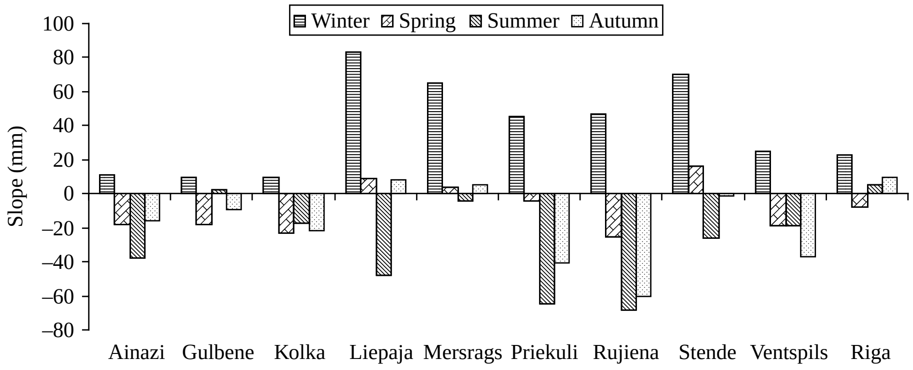

Figure 4 | Slope of seasonal precipitation (mm) for the period 1925–2006.

from 10 mm to 18 mm, in spring from 13 mm to 15 mm, in summer from 25 mm to 30 mm and in autumn from 17 mm to 25 mm. Statistically significant slopes ($p \leq 0.01$) in winter precipitation have been observed at 4 out of 10 stations. It is evident that during the winter period the increase in precipitation occurred with varying amplitude at selected stations. Decreasing patterns have been found for summer and autumn seasons, and these are indicative of a decreasing contribution of summer and autumn precipitation to the annual total. However, the decrease in summer and autumn precipitation in most of the stations was not statistically significant. Only two stations demonstrated the decrease of the summer and autumn precipitation at level $p \leq 0.05$. This is consistent with the tendencies found in northeast Europe (Schonwiese & Rapp 1997; Alcamo *et al.* 2007; www.knmi.nl/samenw/eca).

The earlier study (Treiliba 1995) showed that precipitation during the cold period in Latvia has become more abundant and was more evident in areas where the prevailing winds and terrain facilitated ascending air masses.

Number of wet days

The number of days with daily precipitation exceeding 1 mm has increased significantly in winter and two upland stations also exhibited a springtime increase (Table 3) For Riga University station, the increase in the number of wet days on record at the beginning the 1890s was due to the use of a rain gauge with a wind shield (Figure 5). This is a good illustration of the effect of the instrument on the precipitation measurements. The analysis of data has shown no dramatic changes in the annual number of wet days since the 1890s (Figure 5). However, there is a clear evidence of significant increase in a number of wet days during the winter season. Trends of wet days index for the winter season over the period 1925–2006 for the studied 10 stations have increased from 5 to 14 days; most of these values are statistically significant (Table 3).

Heavy and very heavy precipitation

The heavy precipitation days (>10 mm) show a positive trend and a strong interdecadal variability. For very heavy precipitation days (>20 mm) there was no clear long-term trend, but interannual and also interdecadal variability was high (Figure 6).

Highest 1-day and 5-day precipitation

Heavy precipitation within a short period of time may bring flooding, generating huge losses in agriculture and the

Table 3 | Mann-Kendall test values for number of wet days (RR1) (1925–2006) (statistically significant values, $p \leq 0.01$, are in bold)

Station	Winter	Spring	Summer	Atumn	Year
Ainazi	1.83	0.44	0.20	−0.54	0.97
Daugavpils	**4.70**	1.58	−0.49	1.48	**3.74**
Gulbene	**5.41**	**2.11**	−0.90	**2.18**	**4.52**
Kolka	**4.24**	1.45	1.93	1.01	**3.86**
Liepaja	**2.78**	1.03	1.21	1.11	**2.57**
Mersrags	**5.34**	1.37	−0.15	0.13	**3.66**
Priekuli	**4.11**	0.18	−0.78	0.20	**2.85**
Riga	**2.74**	−0.09	−0.39	0.63	1.92
Stende	**4.34**	**2.38**	0.28	0.78	**3.72**
Ventspils	0.90	0.63	0.08	−0.42	0.96

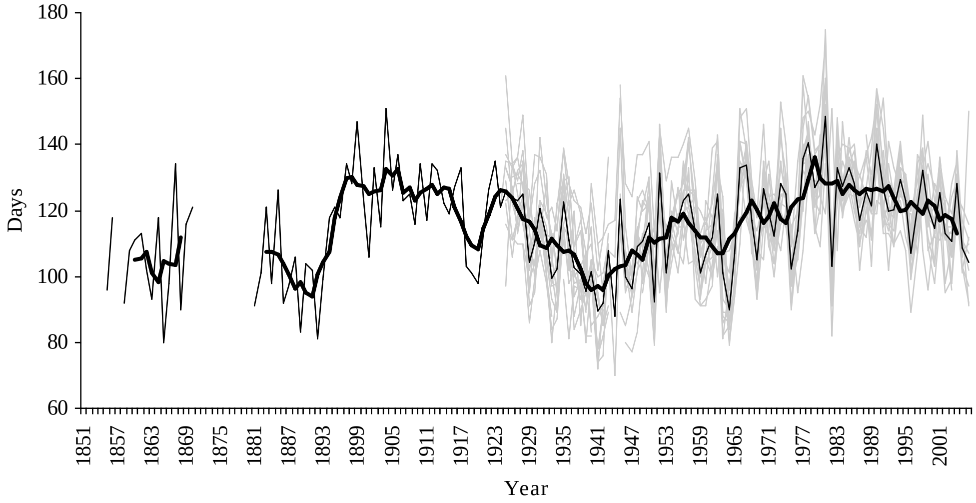

Figure 5 | Time series for the annual RR1 index for 10 stations. Shaded lines indicate individual stations, solid line indicates the Riga University data (1851–1924) and the average for individual stations (1925–2006) and the smoothed solid line indicates 5-year smoothed data.

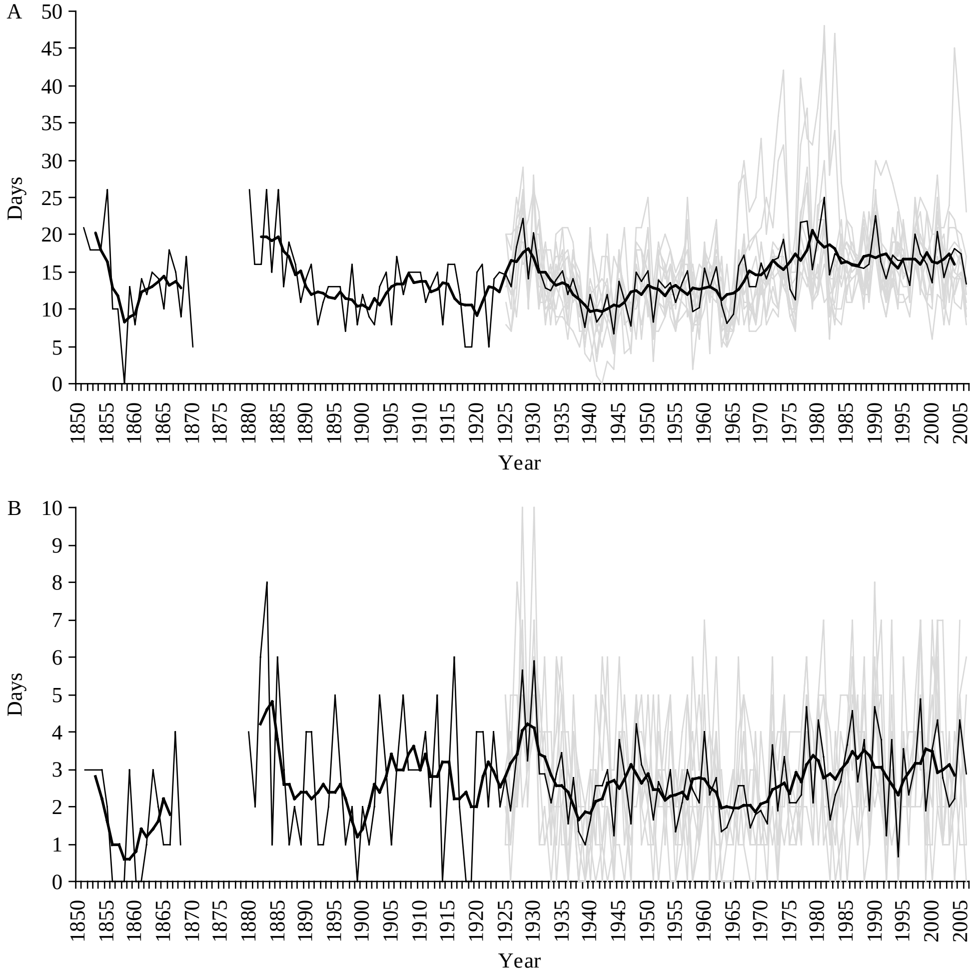

Figure 6 | Time series for the annual RR10 (A) and RR20 (B) index for 10 stations (lines as for Figure 5).

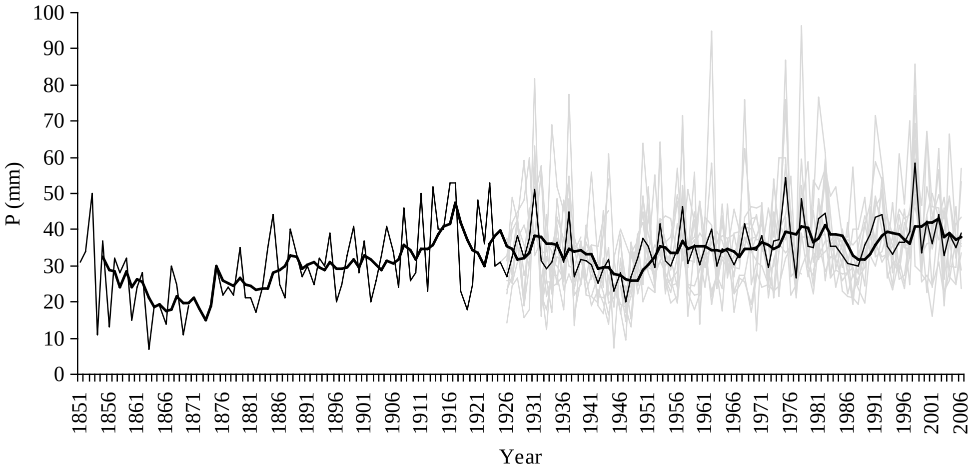

Figure 7 | Time series for the cold season RX5 index for 10 stations (lines as for Figure 5).

national economy. The Riga University instrumental record of observations showed a lower daily precipitation maximum in earlier periods of the observations. Daily precipitation maxima at the Riga University station was found to have gradually decreased from the 1880s to the early 1900s and increased from the 1950s to 1990s. Five-day precipitation maxima showed a significant 18 mm increase in the cold period of the year (Figure 7) throughout the period from 1851 (Mann-Kendall test value 5.73). For the warm period, linear changes were not typical. The graphic representation of data is a good illustration of the rapid increase in the 5-day precipitation totals at the end of the 19th century until the beginning of the 20th century that has affected the general positive trend (Figure 7).

Overall, significant positive trends in 1-day and 5-day maximum precipitation during the period 1925–2006 were only found for the winter season (Table 4).

Extremely wet, very wet and moderate wet days (R99p, R95p and R75p)

The analysis of Riga University time series showed that days of precipitation exceeding the 99th percentile have been observed at least 1–2 times per year, both in the cold and the warm period of the year (sometimes 3–4 times per

Table 4 | Mann-Kendall test values for number highest 1-day (RX1) and 5-days (RX5) precipitation amount (1925–2006) (statistically significant values, $p \leq 0.01$, are marked in bold)

	Winter		**Spring**		**Summer**		**Autumn**		**Year**	
Station	**RX1**	**RX5**	**RX1**	**RX5**	**RX1**	**RX5**	**RX1**	**RX5**	**RX1**	**RX5**
Ainazi	**2.67**	**3.94**	−1.02	−1.30	−0.58	1.35	−1.02	0.72	−1.32	0.98
Riga	**4.85**	**4.70**	0.49	0.82	1.27	1.15	1.74	**2.45**	1.83	1.28
Daugavpils	**1.90**	**3.67**	0.55	1.39	**−2.17**	−0.86	−0.54	1.01	−1.66	−0.33
Gulbene	**5.12**	**6.57**	0.65	0.71	−0.30	0.01	−0.33	1.73	−0.45	0.14
Jelgava	**2.36**	**3.82**	0.65	1.28	0.76	0.43	1.30	1.36	0.86	0.89
Kolka	1.21	**2.85**	0.07	−0.10	−1.12	0.18	1.87	1.15	−0.70	0.61
Liepaja	1.54	1.99	−0.71	0.72	0.66	0.39	0.99	−0.53	0.89	−0.48
Mersrags	**4.38**	**5.16**	1.64	1.97	0.42	0.28	1.25	1.65	1.37	0.75
Priekuli	**4.13**	**3.93**	1.20	0.85	0.03	0.43	1.36	−0.35	1.53	0.28
Stende	**4.11**	**4.74**	−0.46	1.24	−1.14	−1.24	0.77	0.57	−1.49	−1.84
Ventspils	**2.71**	**2.77**	−0.57	0.55	0.07	1.29	0.54	0.55	0.89	0.30

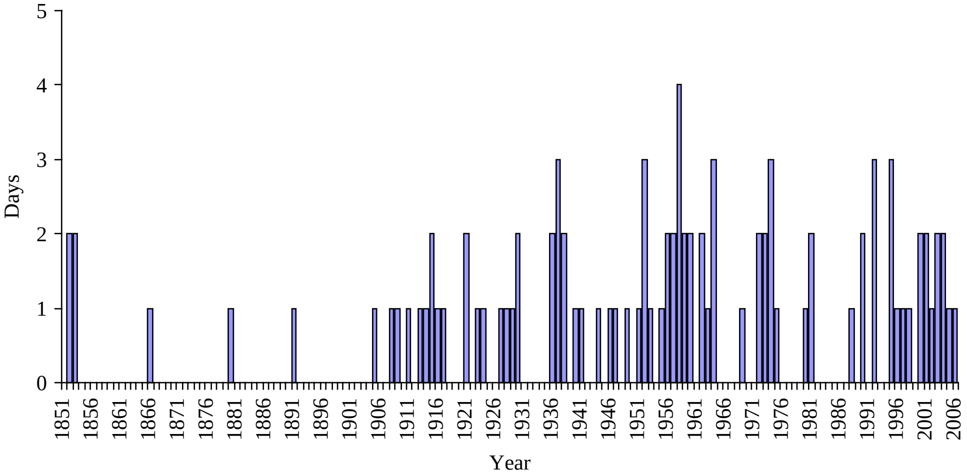

Figure 8 | Number of extremely wet days at Riga University.

year). No significant tendency in the changes was identified, yet it was noted that the number of days with extreme precipitation was higher in the 20th century than in the 19th (Figure 8).

The Riga University station showed a significant positive trend in the time series of the number of days of very wet days, both in the warm (Mann-Kendall test value 1.69) and the cold (Mann-Kendall test value 6.65) period during the 150-year period (Figure 9). Against year-to-year variations, the trends in R95p for 10 stations for the period 1925–2006 have been similar only for the cold period (Mann-Kendall test values for individual station 1.60–4.65). In the warm period of the year, periodical variations in the number of days of very wet precipitation occurred and no significant trend was found.

The number of moderate wet days (index R75p) at the Riga University station has also increased in both the cold and warm periods of the year, being more pronounced in the cold period (Figure 10). There is a small amount of days for the R75p index prior to the 1890s, demonstrating the effect of a change in the instrument on the measured precipitation totals. The period from the 1890s reported a significant increase of 2.5 days in the number of moderately wet days (Mann-Kendall test value 3.39) with cyclic variations in the warm period of the year and no changes of statistical significance. Over the period 1925–2006,

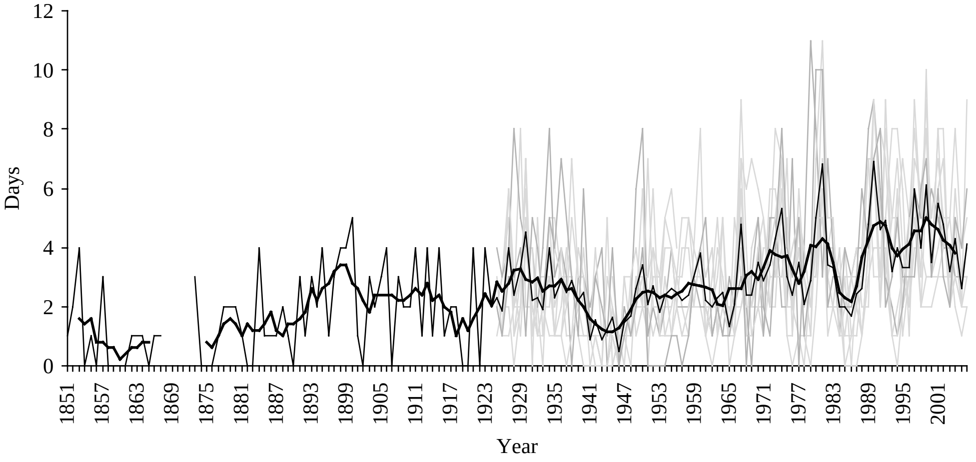

Figure 9 | Time series for the cold season R95p index for 10 stations (lines as for Figure 5).

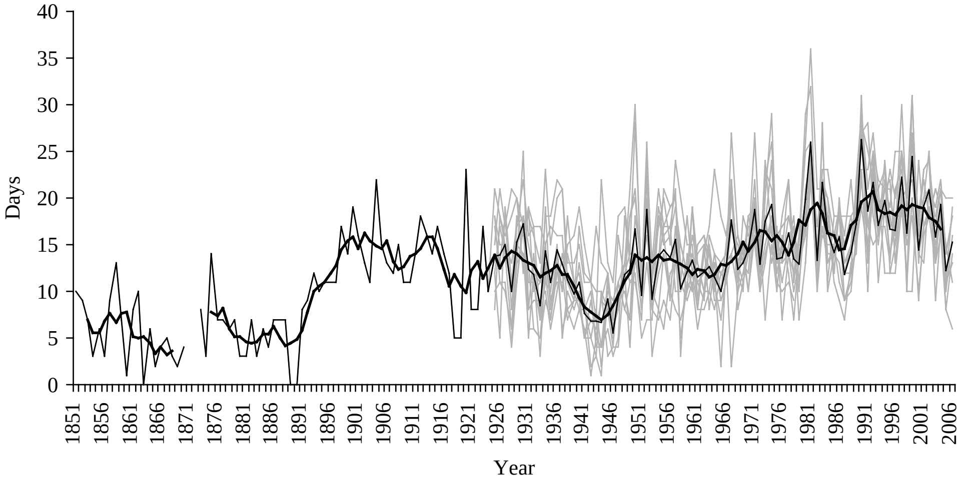

Figure 10 | Time series for the cold season R75p index for 10 stations (lines as for Figure 5).

the average trends at the 10 stations were positive only for the cold season (Figure 10) when the Mann-Kendall test value varied from 1.82 to 6.27.

Both precipitation totals and extreme precipitation indices showed a well-pronounced positive tendency in the cold period of the year, particularly in winter. This is consistent with the tendencies found in northeast Europe. Several authors (Groisman *et al.* 1991; Førland & Hanssen-Bauer 2000; Moberg *et al.* 2006) hypothesize that climate warming may cause more measured liquid precipitation in winters due to the reduction of well-known uncatch bias of precipitation that falls as snow. Apart from this, analyses of the long-term trends of main atmospheric circulation types demonstrate significant changes in the main circulation patterns, which have an important influence upon climate in Latvia (Klavinš *et al.* 2007). Previous studies have shown the increasing tendency of precipitation in winter to be closely related to positive North Atlantic oscillation (NAO) phase. Monthly correlation coefficients of precipitation and NAO indexes are statistically significant for January, February, March and December (Briede & Lizuma 2007). The study found a significant positive relationship between NAO and precipitation indexes for winter season, which indicates an increase of extreme precipitation during the winter period in the case of positive NAO phase (Table 5).

Table 5 | Correlation coefficients between NAO indexes and precipitation indices for the winter (statistically significant correlation coefficients, $r_{\alpha 0.05;\ n82} = \pm 0.22$, are marked in bold)

Station	RR1	RR10	RX5	R75p	R95p
Ainazi	**0.28**	**0.32**	**0.22**	**0.32**	**0.41**
Riga	**0.21**	0.13	0.15	**0.24**	0.19
Daugavpils	0.15	0.13	0.13	**0.36**	**0.32**
Gulbene	**0.31**	**0.29**	**0.24**	**0.25**	**0.35**
Jelgava	**0.26**	0.11	**0.28**	**0.24**	0.18
Kolka	0.04	0.09	**0.30**	**0.26**	0.12
Liepaja	**0.24**	0.18	**0.21**	**0.24**	**0.26**
Mersrags	0.06	0.04	0.11	0.17	**0.22**
Priekuli	**0.30**	**0.38**	**0.35**	**0.30**	0.11
Stende	**0.25**	**0.37**	**0.36**	**0.28**	**0.32**
Ventspils	0.13	**0.31**	**0.27**	0.17	**0.21**

However, a more systematic study of how observed trends and long-term variations in precipitation in Latvia are related to variations in atmospheric circulations and other regional factors should be initiated for future study.

CONCLUSIONS

Analysis of the annual and seasonal precipitation data in Latvia show pronounced intra-seasonal and inter-station variations. Overall, increasing trends are evident in precipitation series for the cold period, and monthly precipitation series at most of the stations show increasing trends from December to March. The time series analysis of monthly precipitation found a statistically significant decreasing trend only in September and July. A comparatively similar decrease in summer and autumn seasons contributes to a slight decrease of annual total at half of the stations. The time series of selected ten precipitation stations show an increased number of wet days, 1-day and 5-day maximum precipitation, moderate wet days and very wet days during the 81-year period. These indices show a well-pronounced positive tendency in the cold period of the year, particularly in winter. As in the case of the 150-year long-term precipitation pattern, extreme precipitation is subject to long-term cyclic fluctuations that are more pronounced than the linear changes. This is evidence of the fact that long-term data series, especially extreme values, provide more detailed and precise information about changes in climatic parameters concerned with global climate change.

The close correlation between NAO and precipitation indicates that dominating atmospheric circulation has a significant influence on the precipitation in winter season. Continuing efforts are necessary to identify the main regional and local factors that cause the variations in precipitation.

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