Temporal variation of extreme precipitation events in Lithuania*

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Egidijus Rimkus*
Justas Kažys
Arūnas Bukantis
Aleksandras Krotovas

Department of Hydrology and Climatology,
Vilnius University,
M. K. Čiurlionio 21/27, Vilnius 03101, Lithuania;

e-mail: egidijus.rimkus@gf.vu.lt

*corresponding author

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Abstract

Heavy precipitation events in Lithuania for the period 1961–2008 were analysed. The spatial distribution and dynamics of precipitation extremes were investigated. Positive tendencies and in some cases statistically significant trends were determined for the whole of Lithuania.

Atmospheric circulation processes were derived using Hess & Brezowski's classification of macrocirculation forms. More than one third of heavy precipitation events (37%) were observed when the atmospheric circulation was zonal. The location of the central part of a cyclone (WZ weather condition subtype) over Lithuania is the most common synoptic situation (27%) during heavy precipitation events.

Climatic projections according to outputs of the CCLM model are also presented in this research. The analysis shows that the recurrence of heavy

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precipitation events in the 21st century will increase significantly (by up to 22%) in Lithuania.

1. Introduction

The total amount of precipitation provides only partial information, which is insufficient to correctly assess local conditions of humidity. Usually, changes in the total amount are not so obvious as compared with the strengthening and more frequent recurrence of extreme events. Changes in extremes can differ significantly even in neighbouring territories as a result of local factors (topography, distance from the sea, etc.).

Under changing climate conditions, a rise in the amount of global precipitation is anticipated. Increases in precipitation extremes are also very likely (IPCC 2007). The changes in these extremes suggest not only a more frequent recurrence of heavy precipitation events, but also more prolonged and intensive droughts. Such tendencies were already observed in large areas of the world in the 20th century (Groisman et al. 1999). However, in different regions the sign and significance of such changes can vary a lot (Haylock & Goodess 2004). The trends of precipitation extremes in Europe vary greatly and depend not only on the region but also on the indicator used to describe an extreme (Heino et al. 1999, Niedźwiedź 2003, Groisman et al. 2005).

The first investigations into the spatial distribution and synoptic conditions leading to the formation of extreme precipitation events in Lithuania were carried out by Pečiūrienė (1988) and Tylienė (1988), who analysed heavy rain and strong snowfall events. According to their results, the highest recurrence of extreme precipitation is associated with a cold front wave where a secondary depression forms. Bukantis & Valiuškevičienė (2005) found that daily heavy precipitation events had decreased in a large part of Lithuania in 1925–2003; only on the coast were positive tendencies observed.

Further changes in precipitation extremes are forecast for the 21st century. The majority of GCM and RCM simulation outputs show an increase in the recurrence of heavy precipitation events during the next one hundred years in Europe (Christensen & Christensen 2004), while negative changes in total precipitation are expected for the southern part of the continent. This means large changes in precipitation frequency rather than in intensity (Räisänen et al. 2004). Also, an increase in heavy precipitation events with a high return period is very likely in Europe (Beniston 2007). However, some investigations show that extreme precipitation events were still underestimated in RCM (Räisänen et al. 2003).

Statistical downscaling of GCM (HadCM3 and ECHAM5) outputs has shown that changes in the annual amount of precipitation in Lithuania will be insignificant. The decrease in summer and autumn precipitation will be compensated by a large increase during winter and spring (Rimkus et al. 2007). A significant increase in the unevenness of precipitation distribution in summer is very likely. More intensive and prolonged droughts will be often followed by very short-lived but extremely intensive rains.

The aim of this study was to analyse daily and 3-day heavy precipitation events in Lithuania from 1961 to 2008. The spatial distribution, long-term dynamics and changes in recurrence with a high return period were investigated, and the atmospheric circulation during extreme precipitation events was examined. In addition, possible changes in the recurrence of daily and 3-day heavy precipitation events in the 21st century were evaluated according to the CCLM (COSMO Climate Limited-area Model) model outputs.

2. Data and methods

Daily data from 17 meteorological stations were used for the analysis of heavy precipitation events in Lithuania (Figure 1). The research covers the period from 1961 to 2008. Stations with almost complete daily precipitation data sets were selected. At some stations, the observations had single gaps ($< 1\%$) which were filled using the ratio method.

Several indicators describing heavy precipitation were used: annual maximum values of daily and 3-day precipitation; the annual number of

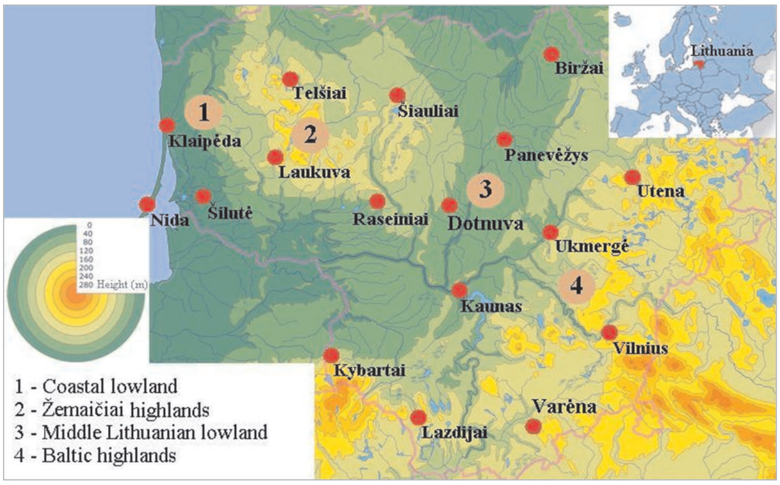

Figure 1. Locations of the meteorological stations from which data were used in the study

cases when the daily precipitation total exceeded 10 mm and 20 mm; the annual number of cases when the 3-day precipitation total exceeded 20 mm and 30 mm. Such threshold numbers are close to the 95th and 99th percentiles of the daily and 3-day precipitation values, but the exact values of the 95th and 99th percentiles vary (by up to 40%) in Lithuania.

2.1. Spatial and long-term variability

The main characteristics of heavy precipitation events, including the number of cases and the amounts of precipitation, were analysed. The spatial distribution of such cases was determined. Interpolation was carried out using regularized splines.

Daily and 3-day annual maxima probabilities were calculated using the Generalized Extreme Value (GEV) distribution. 10-, 30- and 100-year return periods were analysed. This continuous probability distribution combines the Gumbel, Frechet, and Weibull distributions used to model extreme events into a single one (Kotz & Nadarajah 2000).

The GEV distribution is widely used for the approximation of a short-term (up to several days) amount of extreme precipitation. Although the characterization of extreme precipitation remains elusive, mostly due to the lack of a generalizable model that can capture the statistical properties of precipitation distribution at both ends of the spectrum (Jutla et al. 2008), a number of studies in different countries have shown that the GEV distribution can describe an extreme precipitation event well enough, and it is one of the most relevant distributions (Kysely & Picek 2007, Wang & Zhang 2008, Hanel & Buishand 2009).

The GEV distribution has a cumulative distribution function:

$$G(z) = \exp\left\{ -\left[1 + \xi\left(\frac{z-\mu}{\sigma} \right) \right]^{\frac{-1}{\xi}} \right\}, \tag{1}$$

where μ, σ and ξ are the location, scale and shape parameters respectively (Coles 2001).

The long-term dynamics of daily and 3-day heavy precipitation events was also analysed in this study. Variations of annual maximum values and changes in the heavy precipitation percentage in the annual sum were calculated.

The sign and magnitude of changes as well as the statistical significance ($\alpha = 0.05$) of the observed tendencies were determined using the Mann-Kendall test. This test is a non-parametric one for detecting a trend in a time series. The Mann-Kendall test is widely used in environmental science, because it is simple, robust and can cope with missing values and values below a detection limit. Calculations were made using MULTMK/PARTMK software (Libiseller 2002).

2.2. Classification of atmospheric circulation

The Hess and Brezowski classification of circulation forms is used to link heavy precipitation events with prevailing synoptic situation schemes. The period from 1961 to 2004 was analysed in this study because the Gerstengarbe & Werner catalogue (Gerstengarbe & Werner 2005) provides data only up to this date. The classification designed for Central European synoptic patterns and circulation forms did not always correspond to the same situation over Lithuania. Therefore, the circulation forms (not circulation types or subtypes) were reviewed for Lithuania using sea-level pressure and 500 gpdm geopotential height schemes (the North Atlantic sector). Three circulation forms, six weather types and 29 weather condition subtypes were distinguished (Table 1). Weather subtype U was marked only under unclassified conditions. Macrocirculation forms could be zonal, mixed or meridional. Zonal circulation (weather type A) occurs when clear west-east moving air mass flows are formed between the subtropical high pressure zone over the North Atlantic and the low pressure zone over the subpolar regions. Mixed circulation (weather types B & C) is typical of both zonal and meridional air mass flows. Stationary and blocking high pressure (between lat. 50° and 60°N) processes form a meridional circulation (weather types D, E & F). All north-south oriented ridges are classified for this macrocirculation form.

Table 1. Weather types and conditions according to the Hess and Brezowski macrocirculation classification for Lithuania (after Gerstengarbe & Werner 2005)

Circulation form		Weather type	Weather conditions
zonal	**A**	westerly	WA, WS, WZ
mixed	**B**	south-westerly north-westerly high pressure centre	SWA, SWZ, TRW, WW; HNZ, NWA; BM, HM, SA, SEA
	C	low pressure centre	NWZ
meridional	**D**	northerly	HB, HNA, NA, NZ
	E	north-easterly easterly	HFNA, HFNZ, NEA, NEZ, TRM; HFA, HFZ
	F	south-easterly southerly	SEZ, TB; SZ, TM

Each heavy precipitation event was classified for the corresponding weather type (Table 1). A different coverage of Lithuania with heavy precipitation (more than 10 mm) was derived. Three possible situations were analysed: precipitation was recorded at ≤ 3, 4–10, ≥ 11 meteorological stations at the same time.

A detailed synoptic analysis was carried out for extreme heavy precipitation events: more than 80 mm per day for April-October and more than 30 mm for November–March. The sea level pressure field and 500 hPa geopotential height as well as cyclone trajectories during such events were investigated.

2.3. Modelling changes in the 21st century

This investigation is the first attempt to make a detailed climatic projection of precipitation extremity changes for Lithuania. In order to forecast a short-term weather extreme, analysis of daily data is necessary. In previous studies on Lithuanian climate projections, mean monthly data were used (Rimkus et al. 2007).

Output data of the regional climate model CCLM (COSMO Climate Limited-area Model) were used in this investigation. CCLM is the regional non-hydrostatic operational weather prediction model developed from the Local Model (LM) of the German Weather Service (Domms & Schättler 2002, Steppeler et al. 2003). This operational model was also applied to climate modelling.

Modelling outputs are presented for two periods: a control run (1960–2000) and two scenario runs (2001–2100) (Böhm et al. 2006). The modelling is based on A1B and B1 emission scenarios presented in a special IPCC report (Nakicenovic et al. 2000), in which B1 is a low-emission scenario (considered to be the 'best case') and A1B is a relatively high-emission scenario. The regional CCLM model covers a large part of Europe with a high spatial resolution (here, 20 km $\times$ 20 km) (Figure 2).

The regional CCLM model runs are driven by the initial and boundary conditions of the Global Circulation Model ECHAM5/MPI-OM. The ECHAM5/MPI-OM global model is a coupled atmospheric-ocean model developed at the Max-Planck-Institute in Hamburg. Realizations of the ECHAM5/MPI-OM model were dynamically downscaled to a smaller grid using the CCLM model. The CCLM model data outputs are available in the CERA data base which is driven by the WDCC (World Data Centre for Climate).

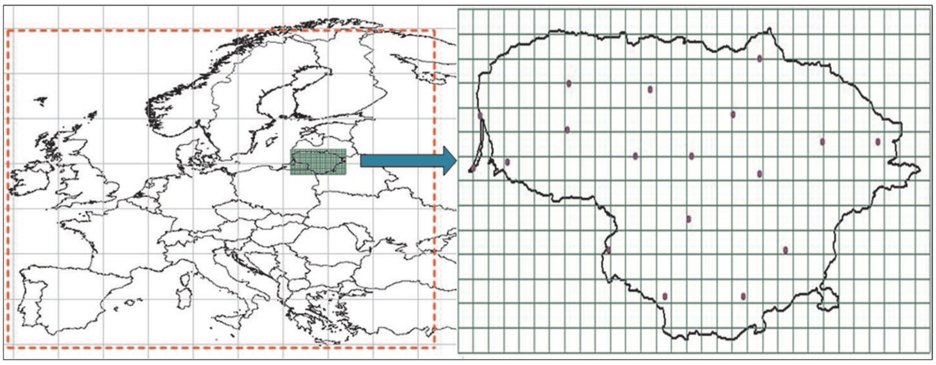

Figure 2. The CCLM model domain covering Lithuanian territory (dotted line on the left) and the regular grid (spatial resolution 0.2°) over the country (on the right). The black dots represent the meteorological stations from which data were used in this research

3. Results and discussion

3.1. Spatial variability

There is a significant unevenness in the spatial distribution of heavy precipitation events in Lithuania despite its relatively small area and quite negligible altitude differences. The mean annual number of cases when the daily precipitation amount exceeded 10 mm fluctuates from 12.4 to 21.9 (Figure 3a) and from 5.3 to 10.5 when 3-day precipitation exceeded 20 mm (Figure 3b). The largest number of heavy precipitation events during the observation period occurred in the Žemaičiai Highlands and coastal lowlands. The slight increase in heavy precipitation cases is determined by local microclimatic factors (extensive areas of forest, sandy soils). Another

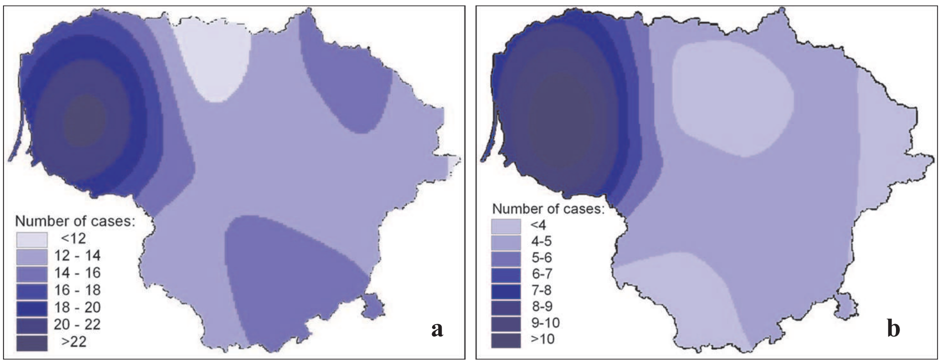

Figure 3. Mean number of cases when daily precipitation exceeded 10 mm (a) and 3-day precipitation exceeded 20 mm (b) in Lithuania in 1961–2008

possible reason is that some southerly cyclones bringing heavy precipitation affect only this part of the country.

The mean annual daily maximum amount of precipitation varied between 31 and 39 mm. The highest values were recorded in the southern part of the country and the Žemaičiai Highlands and the lowest in the Central Lithuanian plain. A noticeable urban effect on heavy precipitation formation was observed. The highest recurrence of events with precipitation in excess of 100 mm per 3 days was determined in the largest cities (Vilnius and Kaunas). Cities tend to increase the number of condensation nuclei. Moreover, the greater roughness of the land surface and the urban heat island accelerate vertical air movements and intensify convection processes over cities (Oke 1987).

The ten-year return levels of the precipitation maximum are very similar to the heavy precipitation distribution patterns. The highest values ($\sim$55–60 mm) per day were observed in western Lithuania and the lowest ones ($<$45–50 mm) in the central and eastern parts of the country (Figure 4a). The same distribution was found for 3-day periods (Figure 4b). Territorial differences for 30- and 100-year return levels of precipitation are very significant but hard to map. The 100-year return level of the daily precipitation maximum was exceeded at four meteorological stations and the 3-day maximum at six during the study period (1961–2008). The all-time record for 3-day precipitation (188.3 mm) noted at the Nida meteorological station in August 2005 satisfies the once-per-400-year recurrence ($p = 0.0025$) level.

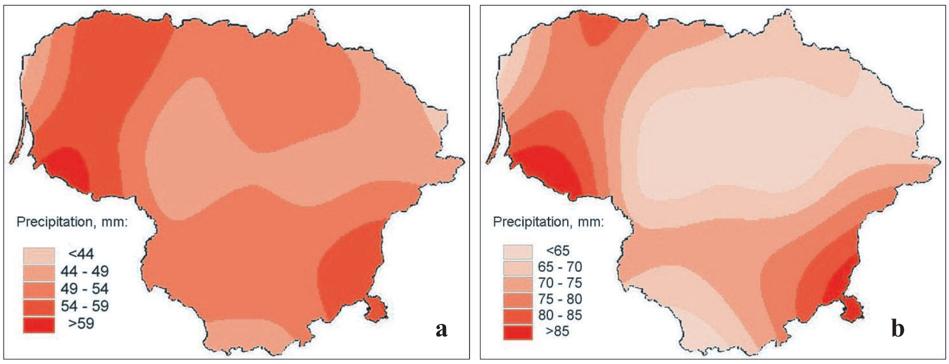

Figure 4. Ten-year return level of the daily (a) and 3-day (b) precipitation [mm] maximum in Lithuania

There is a significant difference in the annual distribution of heavy precipitation events in Lithuania. In much of the country, such events can be expected mostly in summer, whereas in autumn and winter heavy precipitation occurs mostly in the relatively warm coastal sector and on the windward slopes of the Žemaičiai Highlands because of the more intensive westerly air mass flows.

3.2. Atmospheric circulation

Extremely heavy precipitation (>30 mm per day) occurs mostly during cold wave fronts and local convectional processes. The atmospheric macrocirculation conditions favouring intensive convection occur when a cyclonic circulation prevails over Western Europe and Scandinavia, and at the same time anticyclones predominate over Eastern Europe. Over Lithuania, southerly airflows form in the mid-troposphere.

A more mixed synoptic situation occurs during heavy precipitation (>10 mm) events (Table 2). Heavy precipitation (at one meteorological station, at least) was measured for more than 1/5 (21%) of all days in 1961–2004. It was usually recorded at several stations (2/3 of all cases); only in 4% of cases did it cover a large part of Lithuania.

Table 2 shows that the frequency of weather type patterns for all days and days with precipitation is very similar (type B prevails). Meanwhile, the zonal circulation (type A weather) starts to dominate during heavy precipitation events. This dominance was especially clear when heavy precipitation was measured in a large part of the country. The recurrence of WZ (western cyclonic) weather conditions almost doubles (from 14 to 27 percent) during heavy precipitation events. The probability of such events also increases when the cyclone centre is situated over Lithuania (type C weather) or during northward (type D weather) air mass advection, when

Table 2. Frequency [%] of different weather types and the occurrence of the most frequent subtype (WZ) over Lithuania during heavy precipitation (>10 mm) events versus all day patterns in 1961–2004

Weather types	All days/ days with precipitation	Number of meteorological stations where >10 mm precipitation was observed		
		1–3	**4–10**	**≥11**
A	25/22	35	38	37
B	36/40	24	22	15
C	5/5	7	7	10
D	11/10	15	11	13
E	16/16	13	16	14
F	6/6	5	5	8
U*	1/1	1	1	3
All	100/100	100	100	100
WZ	16/14	24	27	27

*Subtype U was used for unclassified conditions.

conditions are favourable to convectional processes. During type B weather, conditions for heavy precipitation seem to be the least favourable.

Even greater differences between zonal and other circulation forms occur during the cold season (November–March). More than half (51%) the heavy precipitation events are explained by weather type A, as against 29% of the total occurrence. The dominant mixed circulation (weather types B and C) drops from 40% (all days) to 24% (heavy precipitation), but during the warm season (April–October) the dominance of zonal circulation (type A weather) over mixed (type B weather) circulation during heavy rains becomes less significant (31% and 26% respectively).

Only eight cases with precipitation exceeding 80 mm per day were recorded in the period 1961–2008. Such events occur only in summer (mostly in August). The highest amount of precipitation (103.8 mm) was measured on 9 August 1978 at the Telšiai meteorological station when the central part of a southerly cyclone (type D weather) was situated over Lithuania (Figure 5). As many as five meteorological stations recorded precipitation above 80 mm on 9 August 2005. During prolonged five-day rains, records of 3-day (188.3 mm) and 5-day (201.8 mm) precipitation were observed at the Nida weather station. Such a rainy period was formed by a southerly cyclone with a cold wave frontal system formed under very unstable hydrothermal conditions.

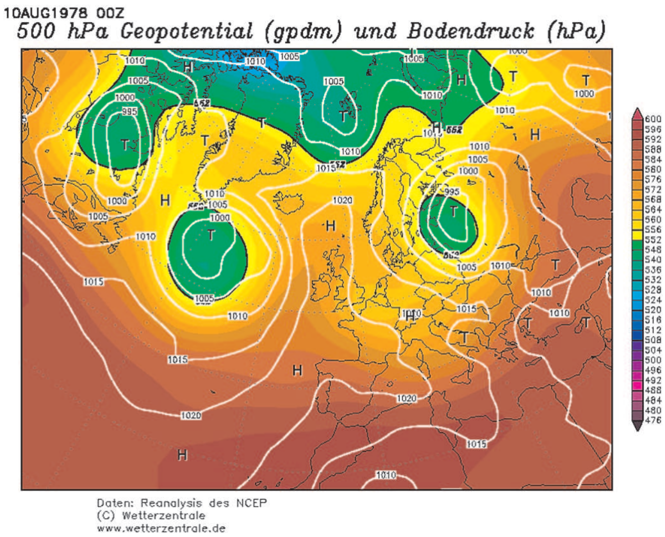

Figure 5. Reanalysis of the synoptic situation on 9 August 1978. Sea level pressure (white lines) and the 500 hPa geopotential height (coloured) pictured for the North Atlantic sector (Top Karten Kartenarchiv 2010)

It is quite difficult to determine the prevailing macrocirculation processes in summer, because heavy precipitation events are determined by various weather conditions. In November–March, however, the circulation was zonal (type A weather) in more than 2/3 of all cases.

3.3. Long-term variability

The annual number of heavy precipitation events varies a lot in Lithuania. The highest number of cases when daily precipitation exceeded 10 mm was observed in 1981 (37 cases in Klaipėda and Šilutė) and the lowest one in 2005 (only two cases in Šiauliai). Positive tendencies of the recurrence of daily heavy precipitation events were determined in the whole of Lithuania. However, it is quite difficult to distinguish the regions where the changes are the most intensive. According to the Mann-Kendall test significant changes were observed at separate meteorological stations representing different regions of Lithuania (Figure 6a).

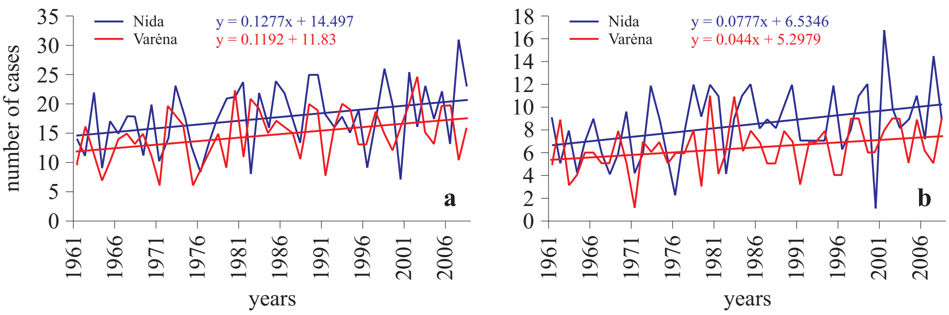

Figure 6. Changes in the number of heavy precipitation events (> 10 mm daily precipitation (a) and 20 mm 3-day precipitation (b)) at Nida and Varėna in 1961–2008. All trends are statistically significant according to the Mann-Kendall test

The recurrence trends of 3-day heavy precipitation are less clear and significant. Despite the prevailing positive tendencies (Figure 6b), at some locations the changes were negative. The number of cases when 3-day precipitation exceeded 20 mm varied from 0 in 1979 (Vilnius) to 20 in 1980 (Telšiai).

An important indicator of an extreme precipitation event is the percentage of heavy precipitation in the total annual amount. Mean percentages of daily heavy precipitation vary from 33 to 44% in Lithuania and can approach 60% in some years. The average 3-day heavy precipitation percentage varies from 27 to 41% and can exceed 60% in single years. In summer and autumn, the percentage of heavy precipitation is much higher than during the rest of the year. Analysis of the dynamics shows positive but mostly insignificant tendencies in a large part of Lithuania during the study period. This means that during recent decades the temporal unevenness of precipitation has increased. This tendency is especially clear in the summer months, when extreme precipitation events increase against the background of neutral or negative trends in the total summer precipitation.

An increase in daily and 3-day annual maximum values was determined during the study period. Moreover, positive tendencies of the mean annual precipitation maximum were calculated for all meteorological stations by splitting the 1961–2008 year period into two parts (Figure 7). The period from the middle of the 1980s to the end of the 1990s was very abundant in heavy precipitation events.

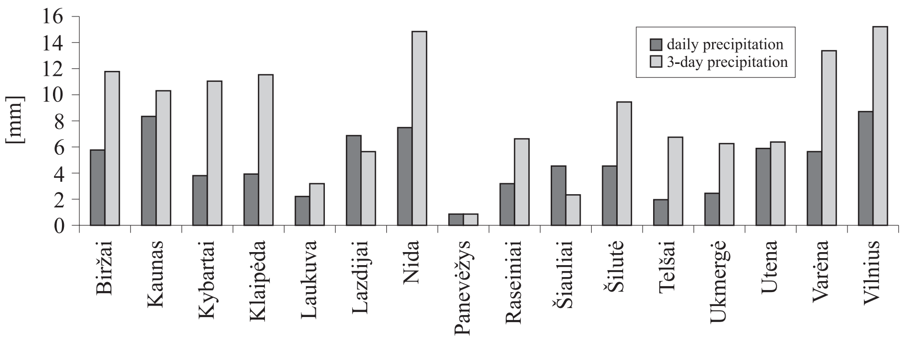

Figure 7. Mean annual daily and 3-day maxima of precipitation differences between two periods (1985–2008 average minus the 1961–1984 average) at 16 meteorological stations in Lithuania. Positive changes show a precipitation increase

Long-term variability data from neighbouring countries are quite similar to our findings. In the western part of Russia an increase in the number of days with heavy precipitation was recorded in 1936–2000 (Bogdanova et al. 2010). There was also an increase in the number of days with heavy precipitation and in the intensity of heavy precipitation in 1925–2006 in Latvia (Avotniece et al. 2010). Most of the positive significant trends were observed in the cold season, particularly in winter, and no overall long-term trend in extreme precipitation was detected in summer (Lizuma et al. 2010). In Estonia there is a rising trend of extreme precipitation events (Tammets 2010) and of the total number of extremely wet days (Tammets 2007) in 1957–2006. In contrast, another study did not reveal any significant long-term trend of heavy precipitation in 1961–2005 in Estonia (Mätlika & Post 2008). In Poland, moreover, decreasing trends in extreme precipitation prevailed in both the warm and cool seasons of the year in 1951–2006 (Lupikasza 2010a,b).

3.4. Modelling of extreme precipitation events for the 21st century

The CCLM model control run outputs (1961–2000) were compared with measurement data at 17 meteorological stations. Three main discrepancies between the two data sets were found. Firstly, the modelled total amount of precipitation exceeded the measured value by 10–20 percent. The smallest difference between the measured and modelled data was found in the highlands, which receive the largest amounts of precipitation. This means that, despite the high spatial model resolution, the impact of the relatively small highland area on the redistribution of the amount of precipitation is inaccurately represented. Other studies also show that the CCLM model outputs exceed measurement data in the whole of Europe (Roesch et al. 2008).

Secondly, there are different numbers of days with precipitation. The output data of a control run gave 30% higher values for almost the whole country. The most significant inequality was obtained in summer. The model generated slight precipitation (0.1–0.5 mm) much more often. The possible reason for this is that the model calculates precipitation according to water content in the atmosphere, but precipitation does not always reach the ground. Furthermore, some precipitation can evaporate (especially in summer) from the gauges. Besides, the model provides average data from a grid (400 km^2); therefore, despite the spatial unevenness of precipitation, a small amount of precipitation is generated for the whole cell.

Finally, extreme precipitation also differs. Heavy precipitation ($>$ 15 mm per day) was measured more often compared with the modelled results. This is usually a very local phenomenon and its spatial distribution field is very uneven. Meanwhile, the model showed only average values (less precipitation) for the grids. The measured and the modelled annual maximum mean values of precipitation were much more similar, however, the measured values being only up to 20% higher than the modelled ones. The biggest difference was located in the Žemaičiai Highlands (more frequent and intensive events).

For the above reasons, only relative changes, i.e. deviations from the control period (1971–2000) run, were used in this study. According to the CCLM model outputs, annual precipitation will increase in Lithuania in the 21st century. Simulations according to both scenarios predict a rise of 5–22% by the end of the century. The largest and statistically significant changes (above 15%) are anticipated for the Žemaičiai Highlands and coastal lowlands.

The rate of change of all the precipitation indices will be uneven during the 21st century. A large increase was simulated for the first part of the century (a rise in precipitation of up to 10%). Minor changes are expected for the middle of the century; finally, positive changes are very likely to intensify in the last thirty years. Changes according to the A1B scenario will be much more significant for the last part of the century.

According to the A1B scenario, the largest changes are predicted for winter (by up to 30%) and spring. Although particularly large shifts are expected in western Lithuania, statistically significant changes will be observed in almost all the country. Precipitation during the cold period of the year will rise more rapidly owing to the more frequent advection of warm, moist air masses. The summer rise in precipitation in western Lithuania will be insignificant, but a decrease (by 10%) in precipitation is very likely for the remaining part of the country. A decrease in the amount of precipitation and a rise in air temperature may well intensify periods of drought during the growing season. Scenario B1 forecasts the largest statistically significant changes for autumn (by up to 25%), whereas hardly any changes are expected for summer.

The outputs of the CCLM model anticipate only a minor increase in the number of days with precipitation in the 21st century. This means that the increase in precipitation will be achieved as a result of a larger number of extreme precipitation events. According to both scenarios, the largest positive changes are expected for spring.

The recurrence of daily heavy precipitation events (>10 mm) will increase in the 21st century. The changes will be statistically significant in almost the whole of Lithuania (Figure 8). The A1B scenario forecasts greater changes (22%) than scenario B1 does (18%) (Figure 9a). The number

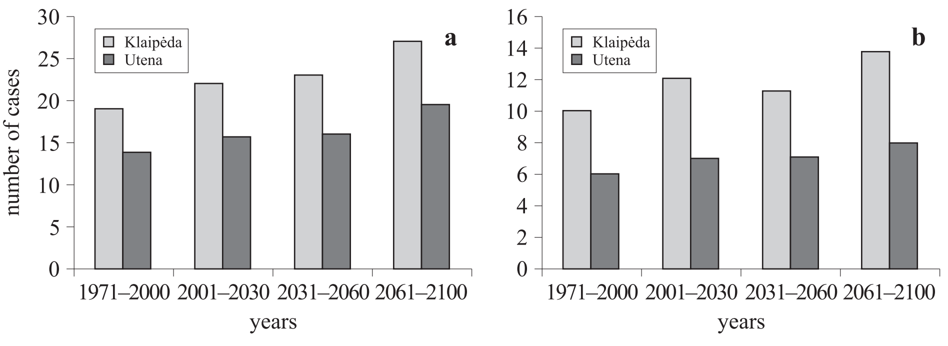

Figure 8. Dynamics of the number of cases (per year) when daily precipitation exceeds 10 mm (a) and 3-day precipitation exceeds 20 mm (b) for the 21st century, simulated by CCLM model output data according to the A1B emission scenario

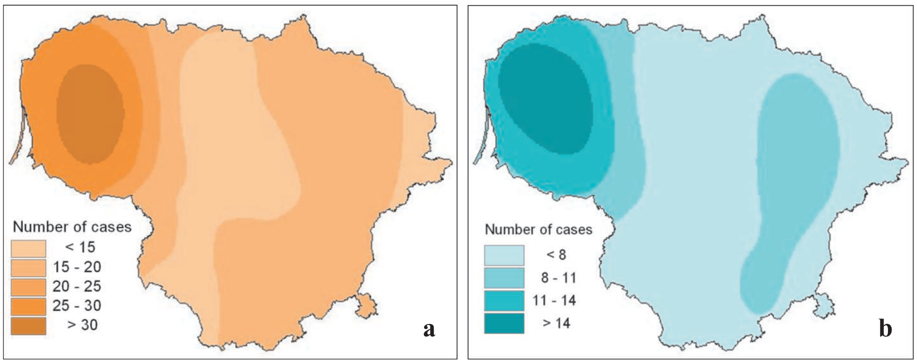

Figure 9. The number of cases with daily precipitation exceeding 10 mm (a) and 3-day precipitation exceeding 20 mm (b) for the year 2100, simulated using CCLM model output data according to the A1B emission scenario

of such events will change most significantly in the Žemaičiai Highlands and coastal lowlands (by up to 30%).

The A1B emission scenario envisages larger changes in almost the whole country, and only in the northern part will the changes be greater according to the B1 emission scenario. The changes in the west will be most significant in autumn, but in eastern Lithuania in winter. The recurrence of heavy summer precipitation events will increase in western Lithuania, but a decrease of such events is very likely elsewhere in the country. The modelled changes will not be statistically significant, however. Both scenarios anticipate an increase in the percentage of heavy precipitation in the annual total. The largest changes are expected for autumn.

According to the CCLM model outputs, the recurrence of 3-day heavy precipitation events (>20 mm) will also increase significantly (by up to 50%) (Figure 9b). Both scenarios envisage large positive and statistically significant changes in the easternmost and western parts of Lithuania. In autumn, the rise will be the most intensive, but the recurrence of such heavy precipitation events will probably remain the same during the 21st century as in summer.

The daily precipitation maximum probability will remain almost unchanged in the major part of Lithuania. Only the shifts in western Lithuania will be more obvious. Positive changes are expected according to the A1B scenario, but the B1 scenario anticipates a decrease in these values. The 100-year return level of 3-day precipitation amounts will increase according to the A1B scenario in a large part of Lithuania. The greatest changes are expected in the coastal area and in the Žemaičiai Highlands.

4. Conclusions

During the study period from 1961–2008, the highest recurrence of annual heavy precipitation events as well as daily and 3-day annual maximum values was observed in western Lithuania. Heavy precipitation in this part of the country prevails in late summer and early autumn, while summer precipitation extremes predominate in the remainder of the country.

The changes in all the precipitation indices analysed show predominantly positive tendencies during the study period. At some locations, the changes are statistically significant according to the Mann-Kendall test. The number of cases where daily precipitation exceeds 10 mm and the 3-day annual precipitation maximum increased especially prominently, but the trends of 3-day heavy precipitation recurrence are less clear and significant. Despite the prevailing positive tendencies, changes were negative in some locations.

More than one third of heavy precipitation events were observed when the atmospheric circulation was zonal (type A weather). The location of the centre of a cyclone over Lithuania is the most common synoptic situation during heavy precipitation events. The repeatability of the WZ (western cyclonic) subtype of weather conditions increases sharply during heavy precipitation events. Mixed circulation (type B weather) seems to be the most unfavourable condition for heavy precipitation. The dominance of zonal circulation increases in winter but decreases in summer during heavy precipitation events.

According to CCLM model outputs, the annual amount of precipitation will increase in the 21st century by up to 22%. The largest shifts were simulated for the winter months (by up to 30%), whereas changes in summer precipitation will be insignificant. The modelled changes will be statistically significant in western Lithuania. The recurrence of daily heavy precipitation events (>10 mm) will increase in the 21st century. The modelled changes will be statistically significant in almost the whole of Lithuania. The number of such events will change most significantly in the Žemaičiai Highlands and coastal lowlands (by up to 30%).

The recurrence of 3-day heavy precipitation events (>20 mm) will also increase significantly (by up to 50%). Both scenarios (A1B and B1) foresee large positive and statistically significant changes in the easternmost as well as the western parts of Lithuania.

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