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Variability in temperature, precipitation and river discharge in the Baltic States

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The climate change impact on water resources is observed in all the Baltic States. These processes became more evident in the last decades. Although the territory of the Baltic States (Lithuania, Latvia, Estonia) is not large (175 000 km^2), the climatic differences are quite considerable. We performed a regionalization of the territory of the Baltic States depending on the conditions of river runoff formation which can be defined according to percentages of the river feeding sources (precipitation, snowmelt, groundwater). Long-term series of temperature (40 stations), precipitation (59 stations) and river discharge (77 stations) were used to compose ten regional series. This paper addresses: (1) variability in long-term regional series of temperature, precipitation and river discharge over a long period (1922–2007); (2) changes in regional series, comparing the periods 1991–2007 and 1931–1960 with the reference period (1961–1990), and (3) the impact of temperature and precipitation changes on regional river discharge.

Introduction

Precipitation (P), air temperature (T) and river discharge (Q) vary in space and time. This variation can be very pronounced, especially for precipitation, even over a small region. According to IPCC (2007), since the end of the 19th century, the global average annual temperature at the end of the 20th century increased by about 0.6–0.9 °C.

Air temperature changes have been studied in the Baltic States as well. Bukantis and Rimkus (2005) reported warming of winters and the contrast between seasons decreasing in the last decades of the 20th century in Lithuania. Jaagus (1998) analyzed climatic fluctuations and trends in Estonia in the 20th century and the possible climate change scenarios. In Latvia, Lizuma (2000) investigated air temperature trends, and Draveniece (2009) detected an increase of temperature in winter.

Precipitation variations in Europe are under intensive research. Schmidli and Frei (2005) discovered statistically significant trends (1901–2000) in precipitation during winter and autumn in Switzerland. Similar results were found in England (Phillips and Denning 2007) and in northern Europe (Uvo 2003). Jaagus (2009)

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found clear relationships between the atmospheric circulation and precipitation in the Baltic Sea drainage basin.

River discharge time series were extensively studied in many countries (Great Britain: Arnell and Reynard 1996, United States: Lins and Slack 1999, Ziegler *et al*. 2002, Canada: Dery 2005), and in the Baltic Sea drainage-basin area (Lindström *et al*. 2006, Hisdal *et al*. 2007). There are many studies on river discharge changes and variability in northern Europe (Finland: Vehviläinen and Huttunen 1997, Nordic and Baltic region: Hisdal *et al*. 2003, 2007, Sweden: Lindström and Alexandersson 2004, Denmark: Thodsen 2007). Klavins *et al* (2002) concluded that changes in the discharge in Latvia were minimal and the discharge increased considerably only in the main rivers (Venta, Gauja, Barta, Irbe and Tulija). Kilkus *et al* (2006) investigated changes in precipitation and runoff of Lithuanian rivers, whereas Kriauciuniene *et al* (2006) carried out an analysis of variability in Lithuanian river discharge series. However, only few papers analyzed changes in river discharge in all the Baltic States by using a common methodology (Reihan *et al*. 2007, Klavins *et al*. 2008).

In order to evaluate changes in the meteorological and hydrological parameters in large territories (for example the Nordic countries or the Baltic States), it is necessary to perform a regionalization. Regional variability in river discharge in the Nordic countries was examined by analyzing 13 regions with similar behaviour of annual runoff (Roald *et al*. 1997). Lindström *et al* (2006) compiled monthly regional series of temperature, precipitation and river discharge for 8 regions in the Nordic countries. For the analysis of discharge trends in 1807–2002, Sweden was divided into a northern region, with rather stable winter conditions, and a southern region with milder winters (Lindström and Bergström 2004). Austria was divided into five hydroclimatic regions with respect to climate and catchment characteristics (Merz and Blöschl 2009). Depending on the discharge regime, river basins in Latvia were grouped into 4 hydrological regions (Klavins *et al*. 2002). Lithuania was divided into three hydrological districts according to the different types of river feeding sources and hydrological regimes (Gailiusis *et al*. 2001, Kriauciuniene *et al*. 2008). However, regionalization of the main meteorological and hydrological parameters for the entire territory of the Baltic countries by a common methodology is still lacking.

In this paper we study: (1) variability in long-term regional series of temperature, precipitation and river discharge over the period 1922–2007, (2) changes in regional series, comparing the periods of 1931–1960 and 1991–2007 with the reference period 1961–1990, and (3) the impact of temperature and precipitation changes on river discharge.

The World Meteorological Organisation (http://www.wmo.int/pages/index_en.html) defines 1961–1990 as the official normal period of 30 years to be used as a reference, and therefore the same reference period was selected in this study. For the analysis of changes in regional series, the thirty-year period (1931–1960) was selected for comparison with standard normals (1961–1990).

Material and methods

Description of hydrological regions in the Baltic States

The Baltic States are three countries in eastern Europe: Estonia, Latvia and Lithuania; their total area is 175 117 km^2. Even though the area of the Baltic States is relatively small, hydrometeorological differences are distinct. We divided the Baltic States into 10 hydrological regions (Fig. 1) according to the conditions of river discharge formation defined according to percentages of river feeding sources (Table 1). Geographical and hydrometeorological characteristics were also taken into account.

In Lithuania, three hydrological regions — (1) western, (2) central and (3) southeastern — were established based on the differences in the hydrological regime (Fig. 1). A marine type of climate prevails in the western region characterized by the largest amount of precipitation, the highest winter temperature, and the least number of days with snow cover (Table 1). The main source of river feeding in western Lithuania is precipitation (53%). The maximum discharge of rain

Table 1. Geographical description of the Baltic State regions.

	Estonia			Latvia				Lithuania		
	N	E	W	NE	SE	Central	W	W	Central	SE
Lake cover (%)	0	9	0	2	3	1	1	1	0	7
Forest cover (%)	38	41	35	40	40	30	20	25	20	60
Wetland cover (%)	18	18	26	10	15	10	5	12	8	11
Average density of river network (km km^{-2})	0.22	0.23–0.29	0.27	0.35–0.40	0.35–040	0.40–0.45	0.20–0.50	0.64–0.75	0.61–0.82	0.33–0.47
Monthly average temperature (°C) (January–July)	−4.8–16.7	−6.4–17.4	−4.9–17.8	−6.2–16.4	−7.0–16.7	−5.1–16.7	−3.6–16.1	−4.0–16.4	−4.7–16.4	−5.0–16.2
Annual precipitation (mm)	550–660	600–660	550–720	620–730	590–660	580–630	590–690	735–810	600–680	600–670
Snow cover duration (days)	95–120	100–125	95–100	85–135	105–120	90–95	70–100	68–94	71–97	86–106
Feeding										
Snowmelt (%)	40	50	40	35	50	50	40	29	43	27
Groundwater (%)	20	30	19	40	32	5	10	18	16	45
Precipitation (%)	40	20	41	25	18	45	50	53	41	28

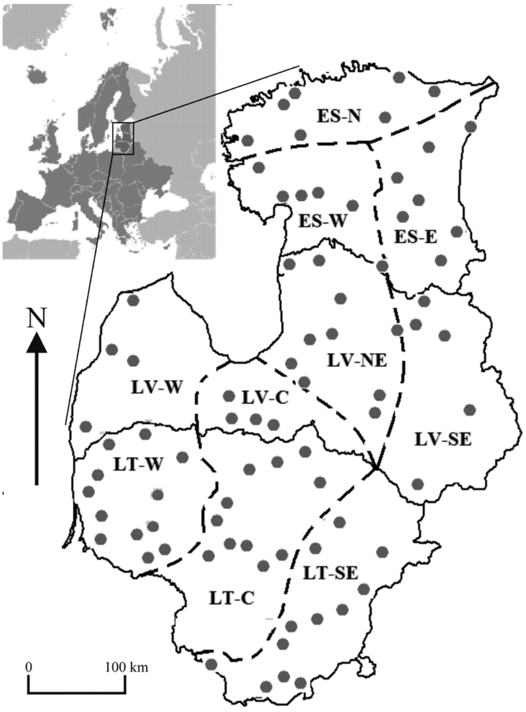

Fig. 1. Hydrological regions of western (W), central (C) and southeastern (SE) Lithuania (LT); western (W), central (C), northeastern (NE) and southeastern (SE) Latvia (LV); and northern (N), western (W) and eastern (E) Estonia (ES).

floods often exceeds discharges of spring floods. The type of river feeding in central Lithuania is mixed. Feeding from the groundwater accounts for only 16%, therefore, smaller rivers dry out in summer. A very irregular discharge distribution during the year is the main feature of the rivers in central Lithuania. A continental type of climate is typical for southeastern Lithuania where the snow-cover duration is the longest, and winters are coldest. Subsurface feeding of the rivers prevails in this region (45%). Permeable sandy soils, which are widespread here, effectively absorb snowmelt and later gradually release it, supplying rivers in the low-water period. Annual discharge of southeastern Lithuanian rivers is distributed rather equally.

We grouped the river basins of Latvia into four hydrological regions: (1) western, (2) central, (3) northeastern, and (4) southeastern (Fig. 1). A marine type of climate (warmer winters and the shortest duration of snow cover) prevails in the western region, which is under the influence of polar maritime air masses from the North Atlantic. The main river feeding source in western Latvia is precipitation (50%). Rivers have two flood peaks: during the spring snowmelt period and in late autumn during intensive rainfalls.

The main part of the landscape in central Latvia is flat. A particular phenomenon in the region is the karst area in the vicinity of the Latvian–Lithuanian border. It is the driest region both in Latvia and Lithuania. More than 50% of the total water discharge comes from spring floods, and the smallest part of the discharge is generated from groundwater (up to 5%).

The climate is most continental in the southeastern part of Latvia, where the winters are coldest and snow seasons are long. The main river feeding sources are snowmelt (50%) and groundwater (32%). High spring floods, summer and winter low-flow periods, and winter floods caused by ice jams characterize the hydrological regime.

The main river feeding sources in northeastern Latvia are snowmelt (35%) and groundwater (40%). High spring floods and smaller rain floods are typical for this region.

There are three hydrological regions in Estonia: (1) northern, (2) eastern and (3) western (Fig. 1). The rivers of northern Estonia (drainage basin of the Gulf of Finland) flow in the north-northwest direction. The main river feeding sources are snowmelt (40%) and precipitation (40%).

The rivers in the eastern part of the drainage basin are in karst terrains where feed from groundwater can exceed precipitation. Snowmelt floods and rain floods dominate in this region. Eastern Estonia is distinguished by the Lake Peipsi drainage basin. This is the most continental part of Estonia with coldest winters and longest duration of snow cover. Additionally, this region has the largest number of lakes (9% of the area) and the greatest forest coverage (41% of the area). The main river feeding sources are snowmelt (50%) and groundwater (30%). Spring floods are typical for this hydrological region. The rivers of the Gulf of Riga (hydrological region of western Estonia) have a great variety of relief, geology and hydrogeology. A marine type of climate prevails in this region characterized by largest amount of precipitation, the highest winter temperature and the least number of days with snow cover. The main source of river feeding in western Estonia is precipitation (41%). Rain floods often exceed the discharge of spring floods.

Data and methods

For the calculation of regional time series of the river discharge, we used historical data series from 77 gauging stations (32 stations in Lithuania, 23 in Latvia and 22 in Estonia) (Fig. 1). Regional series of temperature and precipitation were compiled from the data from 59 meteorological stations (17 stations in Lithuania, 32 in Latvia and 10 in Estonia). We carried out homogeneity tests of the data series of the annual Q, P and T from all the hydrological and meteorological stations: a double-mass plot technique was used to assess the hydrological data series homogeneity from Latvia and Lithuania, and the Standard Normal Homogeneity Test (SNHT) (Alexandersson and Moberg 1997) was used for the Estonian data.

Annual and seasonal anomalies in P and Q (%) were calculated by dividing each member of the series by the mean values of P and Q for the reference period (1961–1990), whereas annual and seasonal T anomalies were calculated by subtracting the mean of the reference period from each member of the series and dividing the result by the standard deviation of the time series. The resulting anomaly value is, therefore, a dimensionless standard score. Regional anomalies in T, P and Q were averages of the standardized individual series. To study long-term variations in P and Q, cumulative 5-year moving average curves were used. A cumulative curve is the sum of anomalies in P or Q relative to the reference period 1961–1990.

Results

Regional variations in temperature, precipitation and discharge

In all the Baltic States, the annual temperature variations were synchronic (*see* Fig. 2),

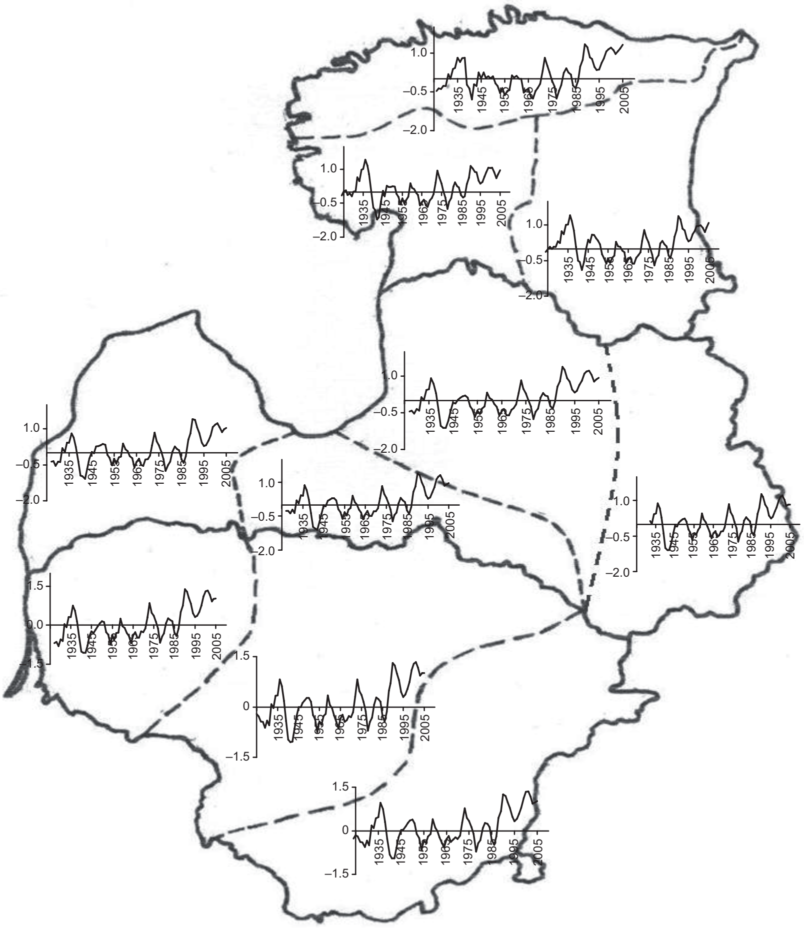

Fig. 2. Temperature anomalies (5-year moving averages, dimensionless standard scores) in relation to the reference period of 1961–1990.

and an increase in *T* has been observed since 1988. During 1988–2007, negative *T* anomalies occurred only in 1996 (in Lithuania and Latvia –0.7, and in Estonia –0.5). The years 1989, 1990, 1999, 2000, 2006 and 2007 were exceptionally warm in all the Baltic States, as the *T* anomalies were 1.4–1.9.

In 1922–1987, winter *T* fluctuated around the reference-period mean. Cold winters, when *T* anomalies were below –1.0, were repeated on average every 4 years, while warm winters (*T* anomalies above 1.0) occurred every 6 years. We found the largest negative *T* anomalies in Lithuania (1922–1987), while the least noticeable changes were in Estonia. A considerable rise in winter *T* was found for 1988–2007. In this period, there were only 3 negative winter *T* anomalies in Latvia and Lithuania, and only 1 in Estonia.

During 1922–1987, *T* anomalies in spring were both positive and negative. The largest positive *T* anomalies reached 1.2–1.3. During 1988–2007, positive spring *T* anomalies were found for 15 out of 20 years. The maximum positive *T* anomalies were 1.6–1.8.

Until 1988, positive and negative anomalies in the summer *T* series were of similar size (±0.7–0.8). Only in the summers of 1939 and 1972, which were exceptionally warm in all countries, anomalies were 2.6 and 2.4. In 1988–2007, the *T* anomalies were > 1.4 during 7 summers and > 2.0 during 4 summers. Only 4 summers had negative *T* anomalies. The positive anomalies in summer *T* were the largest in Lithuania and the smallest in Estonia. In 1922–2007, autumn temperature anomalies were evenly distributed between both sides of the reference-period mean. The autumns of 1941

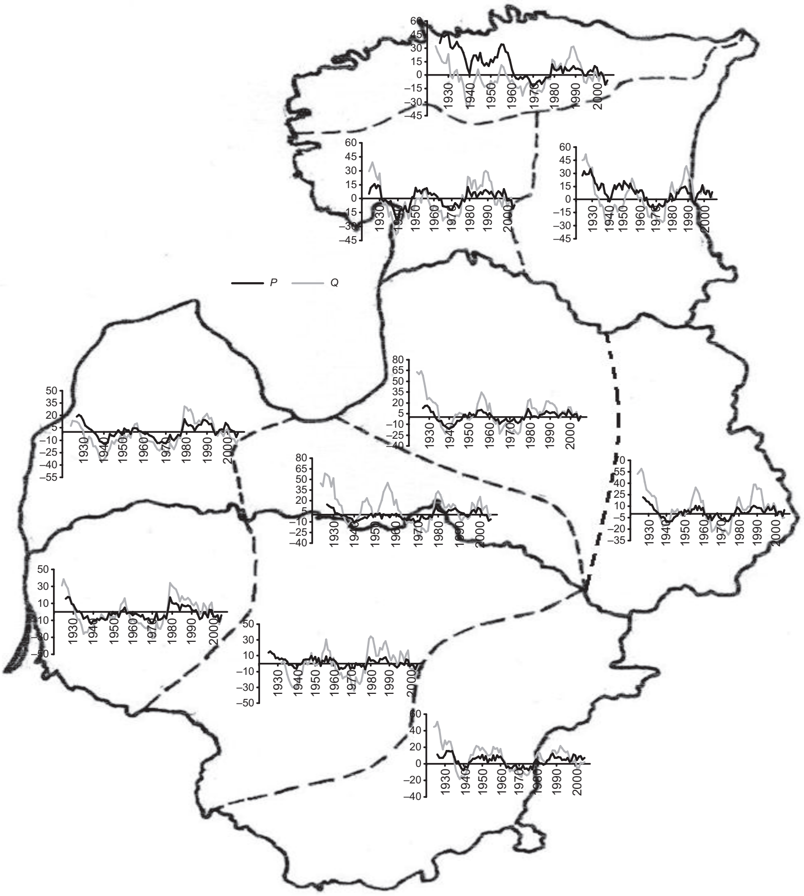

Fig. 3. Precipitation (*P*, %) and discharge (*Q*, %) anomalies (5-year moving averages) in relation to the reference period of 1961–1990.

(with anomalies from –1.9 to –4.3 depending on the region) and 1993 (from –2.4 to –4.2) were extremely cold in all the Baltic States, whereas the autumns of 1934 (2.0 to 3.4) and 2006 (1.5 to 3.6) were very warm.

The changes in anomalies in long-term series (1922–2007) of precipitation were almost synchronic in the Baltic States (Fig. 3). An analysis revealed that the average length of long-term *P* variations is 26–30 years which comprise wet and dry periods of 13–15 years each (Table 2). However, 1991–2007 was an exception; instead of the dry *P* phase, a marginally positive *P* (2%) anomaly in *P* occurred. The years of conversion from wet to dry usually coincided in most of the Lithuanian and Latvian hydrological regions, but there were some discrepancies in Estonia. Long-term *P* variations also existed in seasonal (spring, summer and autumn) precipitation series, although cycle durations were more variable: 24–32 years for spring, 21–33 years for summer, and 26–29 years for autumn. There were no long-term variations in the winter *P* regional series. In 1922–1980, negative *P* anomalies dominated. During 1981–2007, winter *P* was on average 18% above the mean for 1961–1990 in all the Baltic States.

The change in river discharge (*Q*) was almost synchronic in the Baltic States (Fig. 3). When analyzing the anomalies in the regional annual discharge series of 1922–2007, an alternation of wet and dry periods emerged (Table 3).

In the Baltic States, there are three periods with dry and wet phases in the regional *Q* time series with an average duration of 28 years. The period with the highest *Q* was 1922–1932 (average anomaly of 32% in all regional series), and the one with the lowest *Q*, 1963–1976 (average anomaly of –21%). Since 1996, river discharge in the Baltic States may have been in the dry phase; however, the river discharge differed only by –3% from the average discharge of the whole period (1922–2007).

Long-term seasonal variations in river discharge were found for spring, summer and autumn but not for winter. In 1922–1980, negative anomalies (–15%) dominated in the winter series in comparison with the average of the series 1922–2007, while during 1981–2007, the discharge in winter increased by 42%.

Changes in regional *T*, *P* and *Q* series of 1931–1960 and 1991–2007 relative to the reference period

We compared the regional mean values of *T*, *P* and *Q* for 1931–1960 and 1991–2007 with the data for the reference period 1961–1990.

The regional average annual temperature anomalies in 1931–1960 were from –0.2 to 0.1 (Table 4). The winter *T* anomalies were negligible in all the Baltic States Regional series, whereas the spring *T* anomalies were negative (–0.2 to –0.6). The most negative anomalies were found in Latvia. In Lithuania and Latvia, the summer temperature anomalies were around 0.1–0.5, and in Estonia 0.1–0.7. Insignificant autumn *T* anomalies (0–0.1) occurred in Estonia, whereas negative *T* anomalies (–0.1 to –0.3) were found in Lithuania and Latvia.

Temperature anomalies relative to the reference period were greater (almost 1) in 1991–2007. Positive temperature anomalies occurred in all seasons (Fig. 4). The winter *T* anomalies were similar in all the Baltic States (0.5–0.6). Regional series of the spring *T* slightly differed depending on the latitude. In Lithuania and western and central Latvia, the winter temperature anomalies were around 0.7–0.8, and in Estonia 0.4–0.5. Greater *T* anomalies occurred in summer.

Table 2. Wet and dry periods in the regional series of annual precipitation (average anomaly of all regional series).

Wet phase			Dry phase		
Period	Duration (years)	Average anomaly (%)	Period	Duration (years)	Average anomaly (%)
1922–1932	11	17	1933–1948	16	–8
1949–1962	14	6	1963–1976	14	–9
1977–1995	19	6	1996–2007	12	2

Table 3. Wet and dry periods in the regional series of annual discharge (average anomaly of all regional series).

Wet phase			Dry phase		
Period	Duration (years)	Average anomaly (%)	Period	Duration (years)	Average anomaly (%)
1922–1932	11	32	1933–1948	16	–13
1949–1962	14	11	1963–1976	14	–21
1977–1995	19	17	1996–2007	12	–3

Table 4. Regional annual temperature anomalies (dimensionless standard score) in 1931–1960 and 1991–2007 relative to the reference period (1961–1990) mean.

	Lithuania			Latvia				Estonia		
	W	Central	SE	SE	NE	Central	W	N	E	W
1931–1960	–0.2	–0.1	0	–0.1	–0.2	–0.1	–0.1	0	0.1	0.1
1991–2007	0.9	0.9	0.9	0.8	0.9	0.9	0.9	0.8	0.8	0.9

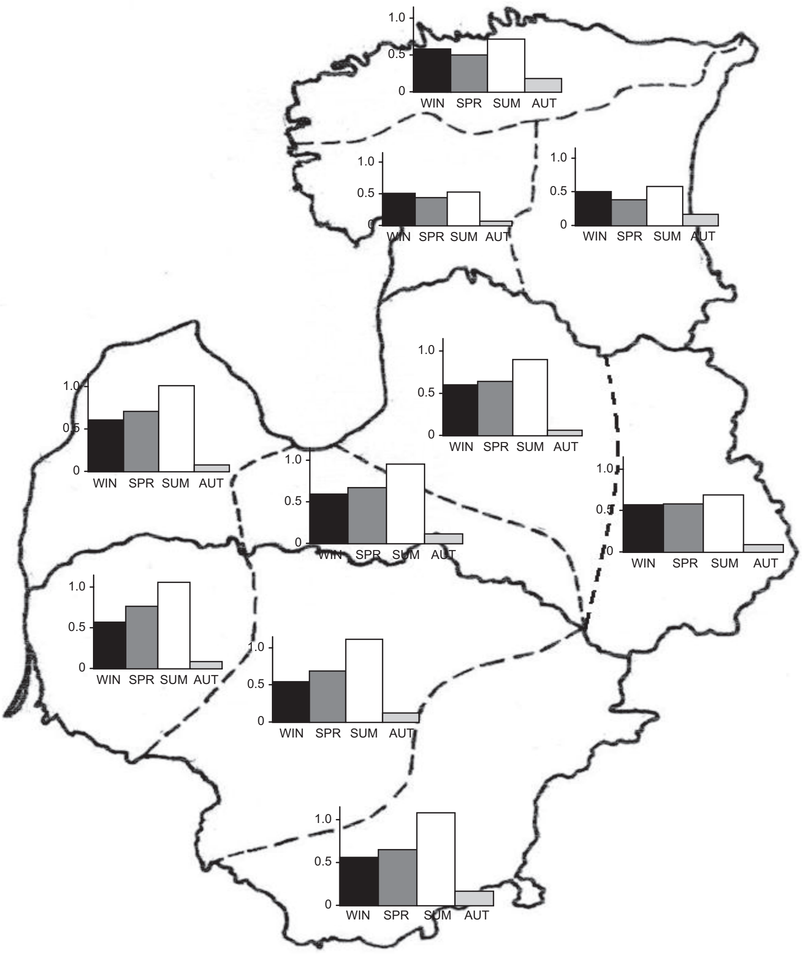

Fig. 4. Regional anomalies in seasonal temperature (dimensionless standard score) in 1991–2007 relative to the mean of 1961–1990. WIN = winter, SPR = spring, SUM = summer, AUT = autumn.

Temperature anomalies were the highest (0.9–1.1) in Lithuania and Latvia (except the southwestern part), whereas in Estonia they were not that high (0.5–0.7). Temperature anomalies in autumn were small in all the Baltic States (0.1–0.2).

There were no considerable changes in annual *P* in any of the ten regions in either of the two studied periods in comparison with the reference period (Table 5).

We compared the regional *P* means for the seasons of 1931–1960 with those of the reference period. In winter, *P* showed clear regional differences. In Lithuania, *P* anomalies were negative (from –7% to –1%) and in Estonia positive (5% to 19%). In spring, *P* was close to the values of the reference period in Lithuania and Latvia, whereas in Estonia *P* anomaly ranged from –8%

Table 5. Regional annual precipitation anomalies (%) in 1991–2007 and 1931–1960 relative to the reference period (1961–1990) mean.

	Lithuania			Latvia				Estonia		
	W	Central	SE	SE	NE	Central	W	N	E	W
1931–1960	–5	3	6	1	–2	–2	–2	5	6	–2
1991–2007	–3	–1	6	4	3	0	2	1	5	1

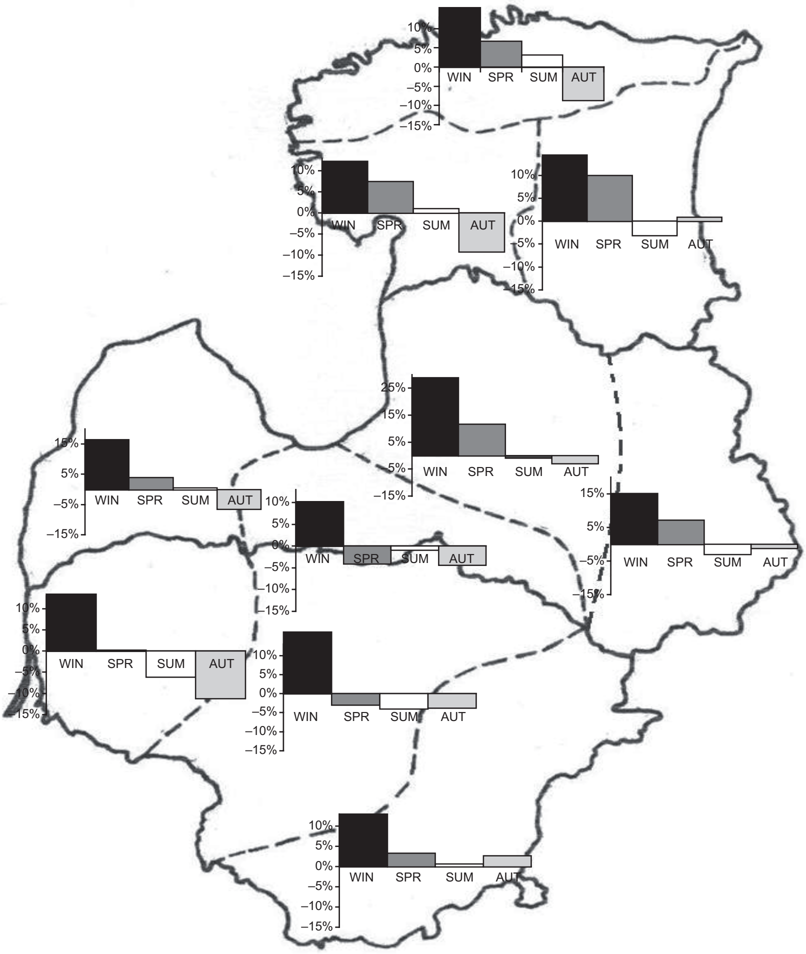

Fig. 5. Regional anomalies in seasonal precipitation in 1991–2007 relative to the mean of 1961–1990. WIN = winter, SPR = spring, SUM = summer, AUT = autumn.

to 10%. In the Baltic States, the summer *P* anomalies were positive (7% to 22%) and higher than the anomalies during the other seasons, except in the western part where summer anomalies were insignificant. In autumn, *P* anomalies were mostly negative (–3% to –13%) throughout the territory. One exception was the northern and eastern Estonia, where autumn *P* anomalies were positive.

We compared the regional *P* means for the seasons of 1991–2007 with those of the reference period (Fig. 5). In winter, *P* increased in all the Baltic States. In the western and central regions, *P* increased by 10%–16%, while in the eastern regions it increased by as much as 15%–29%. The anomalies in spring *P* differed regionally. In western Lithuania, *P* was close to the values of the reference period, whereas in central Lithuania and Latvia it was smaller by 3%–4%. In whole Estonia, spring *P* increased by 8%–10%.

In 1991–2007, summer *P* decreased the most in the western and central parts of Lithuania (by 6% and 4%, respectively) and in the eastern region of Estonia (by 4%). In the remaining regions, summer *P* differed only slightly from the values of the reference period. In 1991–2007, autumn *P* decreased the most in the western regions of all the countries (by 6%–11%), while the decrease in the central regions was around 4%. In eastern Estonia and Latvia, *P* differed only slightly from the values of the reference period.

We compared the annual discharge (*Q*) in 1931–1960 and 1991–2007 with the data for the reference period (Table 6). In 1931–1960, annual

Q in all Estonia, western Latvia, and western and central Lithuania was smaller by 2%–12% than Q during the reference period, whereas in the remaining regions it was higher by 5%–15%. In 1991–2007, negative anomalies in annual Q occurred only in western Latvia and the western and northern parts of Estonia (from –1% to –4%), while in other parts of the area the anomalies were positive (1%–7%). In 1991–2007, the absolute values of the anomalies in Q were smaller than in 1931–1960.

In 1931–1960, *Q anomalies* in winter were negative in all the Baltic States (by –2% to –29%), except in central Latvia (13%). Spring Q anomalies were mostly positive in all the Baltic States (1%–3%) with an exception in the western part, where negative anomalies (–3% to –4%) were found. The summer Q anomalies differed regionally. In autumn, Q anomalies were positive (15%–17%) in the southeastern Lithuania and Latvia but negative (–5% to –20%) elsewhere.

In 1991–2007, Q in winter increased considerably in all the Baltic States (by 20%–65%) (Fig. 6). In spring, the least changes in Q occurred in the eastern regions of all the countries, as Q was close to that of the reference period. In the remaining regions, Q decreased by 6%–17% in 1991–2007. In summer in comparison with the reference period, both positive (up to 30% in northern Estonia) and negative (down to –11% in western Lithuania and western Latvia) anomalies in Q occurred. In 1991–2007, Q anomalies in autumn were negative (from –3% in southeastern Lithuania to –34% in northern Estonia).

We analysed annual and seasonal relationships between T and Q, and P and Q anomalies (Fig. 7). The most obvious tendency was detected in the relationship between the annual anomalies in T and Q (Fig. 7a). We noticed an increase in T anomalies and a smaller scatter of Q anomalies in all regional 1991–2007 series. More positive anomalies in T and Q were found for winters 1991–2007 than for winters 1931–1960 (Fig. 7c). The same tendencies were found for P and Q anomalies (Fig. 7d): in 1991–2007, a considerable increase in T and P resulted in an increase in winter Q. In 1931–1960, negative anomalies in spring T and anomalies in *P that varied from negative to positive* resulted in a increase in Q (Fig. 7e and f). We did not find any clear tendencies in the relationship between anomalies in T, P and Q in summer. In 1991–2007, slightly positive anomalies in T and negative anomalies in P caused a decrease in autumn Q.

We determined that in 1991–2007, the differences in annual Q in all the hydrological regions of the Baltic States became even more pronounced because of the increase in winter Q and the decrease in spring Q.

Conclusions

Geographical position (from south to west, from the Baltic Sea to the continent) and hydrometeorological factors (snow cover, temperature and precipitation) have a considerable influence on the patterns of river discharge in different regions of the Baltic States.

The ten studied hydrological regions of the Baltic States include two end-member groups according to the variability in regional series of temperature, precipitation and river discharge. The first group consists of regions of western Lithuania and Latvia, the territory of which is close to the Baltic Sea. The climate of these regions is marine and the main source of river feeding is precipitation. The second group consists of southeastern Latvia and Lithuania and eastern Estonia: the continental part of the Baltic

Table 6. Regional annual discharge anomalies (%) in 1991–2007 and 1931–1960 relative to the reference period (1961–1990) mean.

	Lithuania			Latvia				Estonia		
	W	Central	SE	SE	NE	Central	W	N	E	W
1931–1960	–8	–2	10	7	5	15	–12	–8	–3	–11
1991–2007	1	1	6	5	5	5	–1	–4	7	–2

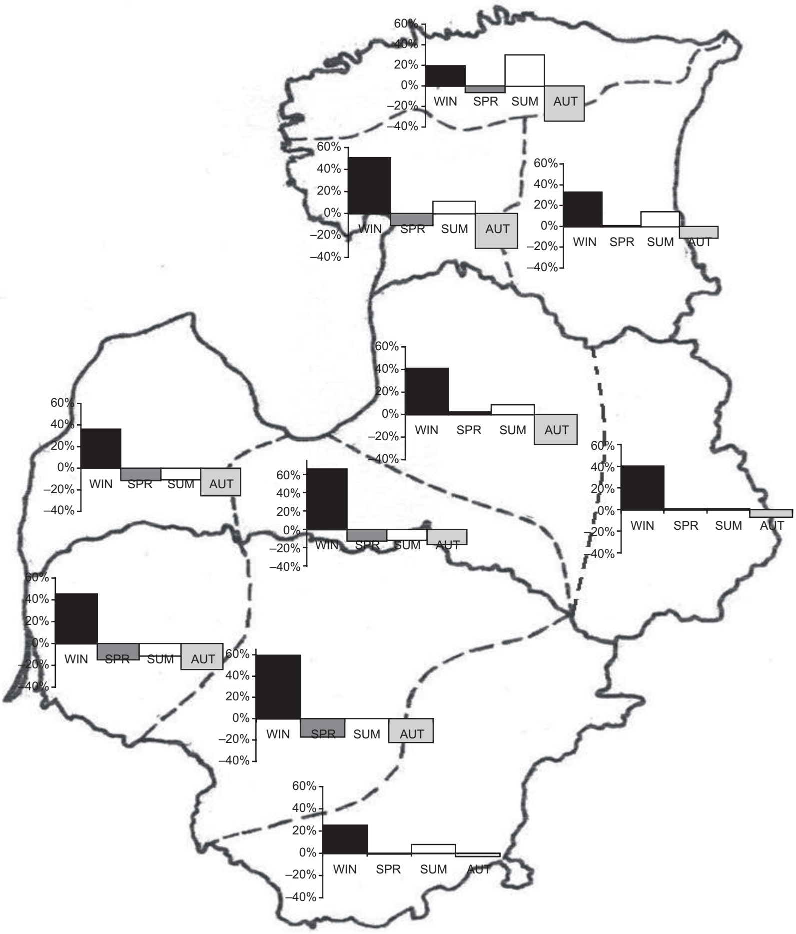

Fig. 6. Seasonal, regional anomalies in river discharge in 1991–2007 relative to the mean of 1961–1990. WIN = winter, SPR = spring, SUM = summer, AUT = autumn.

States. The rivers of this territory are fed by snowmelt and subsurface sources, and the annual discharge of these rivers is distributed rather equally. The remaining five hydrological regions of the Baltic States are characterized by more individual patterns of river discharge.

An analysis of long-term regional series of temperature, precipitation and discharge revealed that variations in precipitation and discharge are typical for all regions. The average length of the wet and dry phases is 27–30 years, including the average wet period of 15 years and the dry period of 14 years.

We made a comparison of all regional series of 1991–2007 with the data of the reference period (1961–1990), and determined the increase in annual and seasonal temperatures in all regions of the Baltic States. The temperature anomaly depends on the geographical position of a region. In the northern part of the Baltic States (Estonia) relative to 1961–1990, the temperature anomaly was 0.8, while in Lithuania it was 1.1. Comparing the precipitation of 1991–2007 with the reference period, we found a considerable increase of 10%–29% in winter in all the Baltic States. Changes in spring precipitation differed regionally. The amount of precipitation in summer decreased the most in the western and central parts of Lithuania and in the eastern region of Estonia. In autumn, precipitation decreased the most in the western regions of all the countries (by 6%–11%).

The anomaly of regional discharge series depends on the type of climate (marine or continental) and sources of river feeding. As compared with the reference period, in 1991–2007 the winter

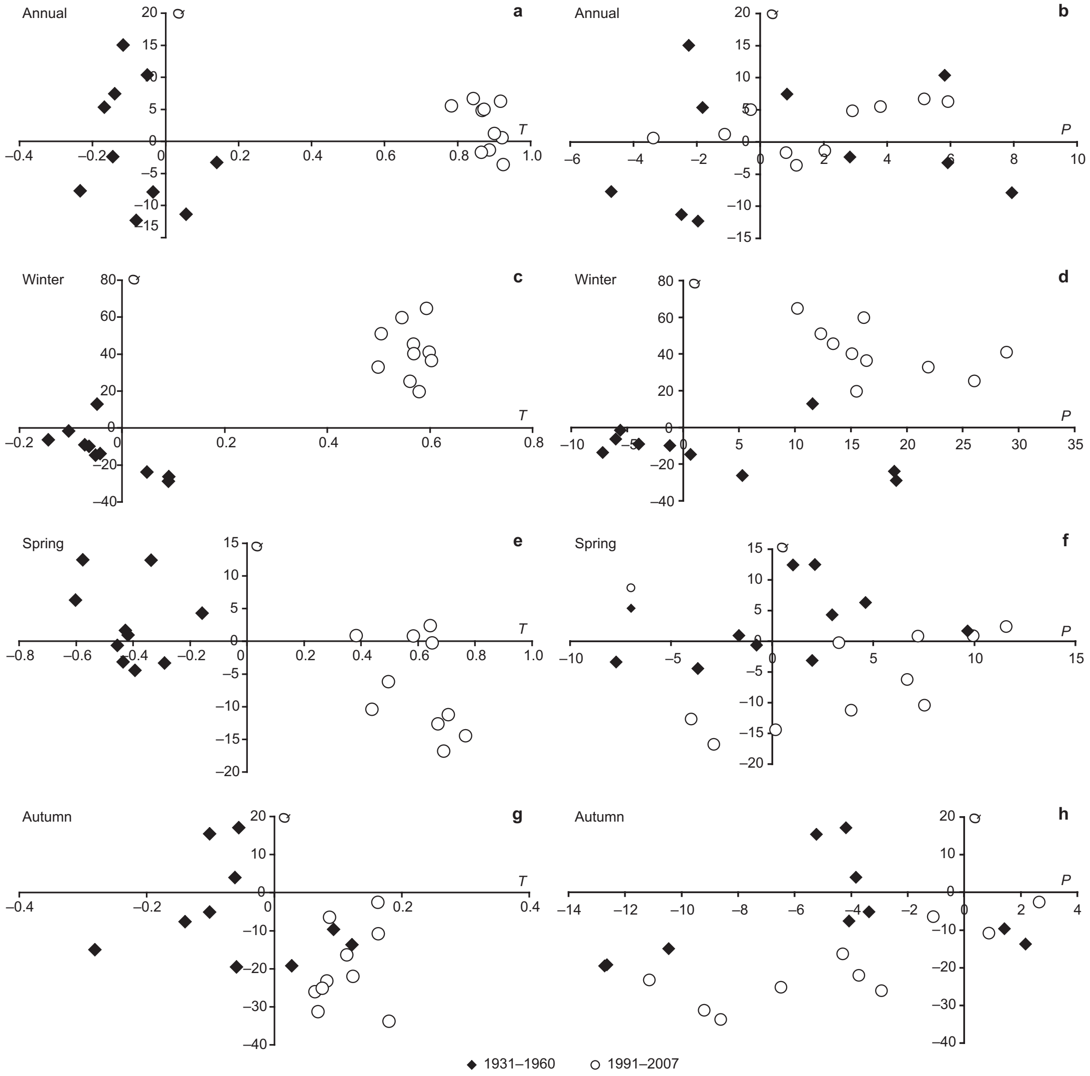

Fig. 7. Relations between annual and seasonal anomalies in temperature (dimensionless standard score) and discharge (*Q*, %) (left-hand-side column), and precipitaion (*P*, %) and discharge (*Q*, %) (right-hand-side column) relative to the mean of 1961–1990 for the 10 regions during 1991–2007 and 1931–1960.

discharge increased everywhere by 20%–60%. A 10%–20% decrease in the spring discharge occurred in the western regions of all the Baltic States (marine climate zone), but there were no significant changes in the spring discharge in the continental part of the countries (southeastern Lithuania and Latvia, eastern Estonia).

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