

Time-Varying Parameter Analysis of the Baltic Sea Freshwater Runoffs

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Abstract The Baltic Sea runoff events during 1970–2000 were analysed with non-linear estimation in order to find potential stability and time-varying (non-constancy) properties of time series parameters. In the Baltic Sea area, the wintertime rainfall is expected to increase, especially in the northern parts of the watershed; furthermore, seasonality is expected to decrease, i.e. the runoffs will become more evenly distributed over seasons, mainly by decreasing springtime peaks. We found a general increase in runoffs over the time period studied that consisted of a level shift upwards during the early 1980s. The runoffs considerably resulted from inputs in the months of April to June (which points to the significance of winter precipitation) and are biased to northern parts of the catchment. Our results suggest that this is connected with snow and ice melting in the northern areas of the watershed, especially in the subarctic catchment area of the Neva River (the area includes, for example, three of the four biggest lakes in Europe, Lake Ladoga, Lake Onega and Lake Saimaa, which are annually covered by ice). The yearly variation in runoff is significantly stabilised by large N–S extension of the watersheds of these lakes. The results are generally in accordance with the presented climatic expectations; however, decreasing seasonality was not obvious in the series yet. However, we found potential implications of system change towards decreased seasonality. By better understanding of ongoing processes in the sea, the results can give us an opportunity to better evaluate the system control, predicted areal consequences and ecosystem effects of the climate change. The analysis proved to be

a sensitive tool for studying climatic variation in a relatively small area and over a short time span.

Keywords The Baltic Sea · Runoff · Non-linear estimation · Time-varying parameters · Climate change expectations

1 Introduction

The source of practically all incoming water into the Baltic Sea is the North Atlantic Ocean. Salinity is maintained at an intermediary level by seawater intrusions from the North Sea through the Danish Straits, which have a greater effect on the Southern Baltic and deeper water layers. Incoming freshwater is originally evaporated in the Atlantic (in the more or less constant high-pressure area between the Azores and the Bermudas), entering the catchment area via precipitation and finally reaching the Baltic Sea as freshwater runoffs that affect especially surface water hydrography in the northern parts of the Baltic Sea [22]. The largest river, the Neva, produces roughly 20% of the total freshwater runoff into the Baltic Sea [8].

According to scenarios of the Intergovernmental Panel of Climatic Change, Northern Europe will experience increased rainfall in the next decades due to global climate change [1]. Another expectation is that seasons will become more alike in terms of temperature, with milder winters. This is expected to produce the effect of decreasing seasonality, in which winters growing milder will affect the peak runoffs to be less pronounced in spring due to wintertime snow and ice melting. Moreover, peak runoffs are seen to spread over longer periods annually, thus decreasing the differences between high- and low-runoff cycles. A more regional and time-focussed expectation has been provided by the BACC Author Team [4], who expects the increase to happen predominantly in winter and in the northern part of the watershed. This might have fundamental implications for the

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ecology of the Baltic Sea and furthermore for areal economy. Increased runoff also means increased leaching of nutrients from soil into the sea (e.g. [10, 14]), which could possibly further accelerate the harmful processes of the Baltic Sea eutrophication (e.g. [4]). Because the sea supports the economy of some 85 million people in nine coastal nations, it is crucial to understand better the controlling factors behind the sea system, like for the runoff-driven eutrophication processes. When building up areal or regional scenarios with sophisticated predictive GCMs or RCMs, it is fundamental that the connections with original, existing baseline processes are attributed as appropriate as possible.

Using transfer function models, we have earlier presented a chain of events between changes in the North Atlantic weather patterns and subsequent changes in the Baltic Sea runoff and salinity [11] and finally in sea ecology (e.g. [12, 23]). In the present study, we aim to further define the Baltic Sea runoff processes on a seasonal level during 1970–2000 by using a non-linear statistical approach useful for providing information in time series analysis which may possess time-varying (i.e. time and value dependent) parameters. We were primarily interested in the behaviour of monthly runoffs during the study period to assess their oceanographical consequences and further ecosystem effects in the Baltic Sea system.

2 Materials and Methods

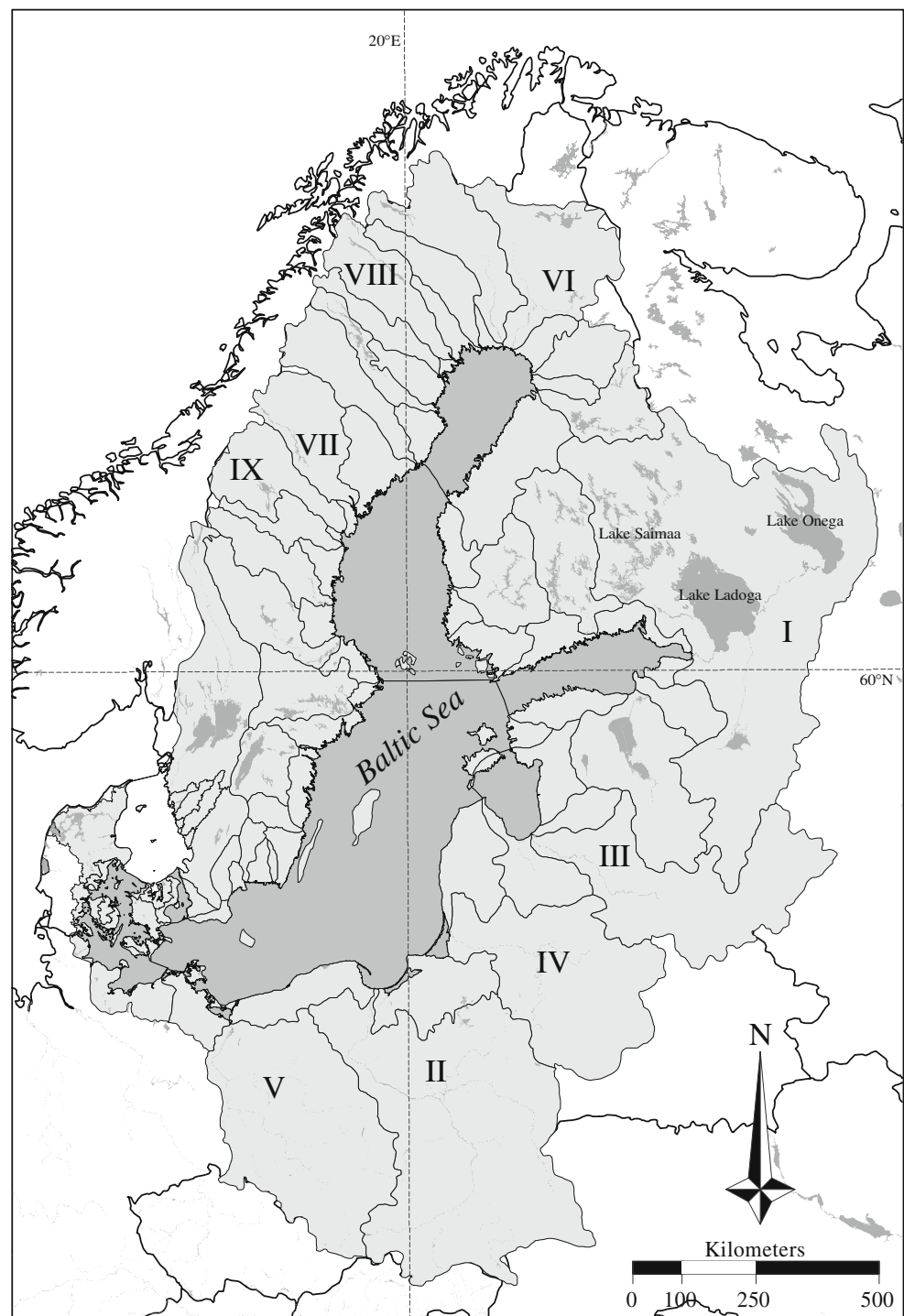
Study Area The semi-enclosed Baltic Sea is one of the major brackish water basins of the world with an area of 377,400 km², volume of 21,200 km³ and size of the drainage basin of 1,729,000 km² (Fig. 1). With a mean depth of only 56 m and a catchment area about four times as large as the sea itself, the Baltic Sea is profoundly influenced by freshwater runoff (e.g. [22]). Presently, rivers provide the majority of freshwater into the sea; evaporation about equals precipitation directly into the sea, and the water balance is positive. The 12 largest river basins account approximately for 60% of the total drainage area of the Baltic Sea (Table 1.). The recorded period of monitoring runoff into the Baltic Sea is about 100 years, with a substantial rise in runoff in the 1920s and another one in the 1980s (e.g. [4]). For the period 1950–1990, the mean annual river discharge into the Baltic Sea was about 500 km³ [6]. The restricted seawater inflow through the Danish Straits and freshwater runoffs into the Baltic Sea create a stratification of the water masses. Saltier water flowing in through the straits does not mix well with the less dense Baltic water, tending to sink down into deeper basins. At the same time, the less saline surface water flows above and out of the Baltic Sea. The horizontal variation of surface salinity is further complicated in the N–S dimension

of the sea due to the discharge effects of numerous streams and rivers. For a more detailed overview of the Baltic Sea oceanography, see, for example, [22].

Data The study was conducted for the period 1970–2000 by applying existing, already reviewed, institutional time series. The period was chosen in order to review the possible effects of increased runoff in late nineteenth century, pointed out by, for example, the BACC Author Team [4]. The runoff data, provided by the Swedish Meteorological and Hydrological Institute, were monthly values (km³) of total freshwater discharges from the catchment area into the Baltic Sea divided according to HELCOM Baltic sub-drainage basins (excluding Kattegat). The data comprised both monitored river runoffs and estimates of non-monitored runoff data. Monitored runoff consist altogether of some 200 river flow stations, representing 86% of the total area of drainage basin. Runoff areas not covered by measuring, mostly coastal areas located between major rivers, were estimated by the use of calculations of specific runoff from neighbouring stations considered as representative (according to Bergström et al. [5]). The runoff data were originally compiled for the 1970s and the 1980s by Stålnacke [21] and completed for later years by several organisations and projects operating in the Baltic Sea area (the compiling system and data are documented in more detail at http://nest.su.se/bed/river_inputs.shtml).

Statistical Analyses The statistical approach was to model statistically the time-varying parameters in observed Baltic Sea runoff time series. As time-varying components, we considered separate monthly runoffs into the sea (cubic kilometre, yearly from Jan to Dec). For modelling, we applied the Scientific Computing Associates Statistical System Software, release 8.0 [16]. Traditional time series models, such as ARIMA and Transfer Function models (e.g. [7]), typically assume that the model parameters and innovation variances are constant (i.e. invariant) regardless of the time and the values of the series. Whilst the behaviour (processes) for a vast variety of real-life time series can be approximated by such constancy models, there are situations where other types of time series models may be more useful for either understanding the behaviour/relationships of the time series or for improving the accuracy of models by better overcoming of assumptions for modelling. Collectively, this class of models is referred to as non-linear time series models [16]. Here, we apply a specific non-linear modelling method which can be used to examine the stability and potential non-constancy properties of the parameters in time series models. The method, time-varying parameters exploration or TVPEXPLORE analysis, provides a convenient method of studying the time-varying (time and value dependent) properties of

Fig. 1 The Baltic Sea and main water system with all the major river basins in the Baltic drainage area (*shaded area* inside *thick line*, Kattegat not included). *Roman alphabets* refer to major river basins presented in Table 1



Source: basemap - MapInfo, watershed - GRID-Arendal

estimated parameters, as provided information may help the analyst to find hidden characteristics in the time series that can be useful in the analysis or essential for improving forecasting performance as well [16].

Before the actual TVPEXPLORE analysis, we first specified a deterministic seasonal regression model for the runoff time series to define the monthly effects in series. The autoregressive component AR(1) (or ϕ_1) term was used

to accommodate month-to-month serial correlation in the model. The model was expressed as:

$$Y_t = C + \sum_{m=1}^{11} X_m + \frac{1}{\phi_1} \varepsilon_t \quad (1)$$

where Y_t = response (output) variable, i.e. runoff, X_m = monthly explanatory (input) variables ($m = \text{Jan, Feb, ...}$,

Table 1 The 12 largest rivers of the Baltic Sea system (in descending order of size of drainage area) with their approximate drainage areas, annual mean and specific runoff (modified from [5])

River	Drainage area (km ²)	Mean annual runoff (km ³)	Specific runoff [l/(s × km ²)]
I. Neva	281,000	77.6	8.8
II. Vistula	194,400	33.6	5.5
III. Odra	118,900	18.1	4.8
IV. Neman	98,200	19.9	6.4
V. Daugava	87,900	20.8	7.5
VI. Narva	56,200	12.6	7.1
VII. Kemijoki	51,400	17.7	11.0
VIII. Torniojoki	40,200	12.0	9.4
IX. Kymijoki	37,200	9.7	8.2
X. Ångersmanälven	31,900	15.4	15.0
XI. Dalälven	29,000	12.0	13.1
XII. Indalsälven	26,700	13.9	16.5

Nov), ε_t = residuals and C = constant term, a software-produced vector which also indicates a possible trend in the series when it exists with statistically significant t value (positive t value = increasing trend and vice versa).

Basically, the month-of-year effects are estimated as deviations from the overall mean of runoff, which is represented by constant term in the model. Since such a model uses the constraint Jan + Feb + ... + Dec = 0, the December effect is equal to

$$\text{Dec} = - \left(\sum_{m=1}^{11} X_m \right), m = \text{Jan, Feb, } \dots \text{Nov} \quad (2)$$

The use of the above deterministic seasonal model assumes that the month-of-year effects remain constant over time.

After this, the TVPEXPLORE analysis can be used to explore the validity of the assumption of invariant month-of-year effects for the runoff series. Together with TVPEXPLORE analysis, the WINDOWSIZE subcommand was used to specify the number of time periods in moving window estimation of the model parameters. The window size can be increased or decreased depending upon desired sensitivity in detecting the time-varying properties of the model parameters. This has to be balanced with the information “wasted” in the series forepart due to size of the window and applied degrees of freedom. However, compared, for example, with statistical moving average smoothing, the window sizing has no effect on serial structure of the original time series [16]. In our case, we found that the window size specified as 60 observations (5 years) was sensitive enough to reveal monthly differences in runoffs without losing anything essential in series forepart. Here, the first estimation will be from time span of 1 to 60, the second estimation will be from 2 to 61 and so on. Thus, the first produced estimate stand for Dec 1974 but comparably with the serial structure of the original series. The

parameter values and their t values are saved for each estimation window in designated variables. All model parameters that have been specified with labels (i.e. months Jan to Dec) in the model will accumulate in this manner during the TVPEXPLORE estimation.

In order to better visualise the time-varying properties of the constant and month-of-year effects, the overall monthly mean of the *Constant* vector (CMEAN_{*t*}) is computed and added to the month-of-year effects using the following analytic statements:

$$\left\{ \begin{array}{l} \text{CMEAN}_t = \text{MEAN}(C) \\ \text{Jan}_t = \text{CMEAN}_t + X_{\text{Jan}} \\ \text{Feb}_t = \text{CMEAN}_t + X_{\text{Feb}} \\ \text{Mar}_t = \text{CMEAN}_t + X_{\text{Mar}} \\ \text{Apr}_t = \text{CMEAN}_t + X_{\text{Apr}} \\ \text{May}_t = \text{CMEAN}_t + X_{\text{May}} \\ \text{Jun}_t = \text{CMEAN}_t + X_{\text{Jun}} \\ \text{Jul}_t = \text{CMEAN}_t + X_{\text{Jul}} \\ \text{Aug}_t = \text{CMEAN}_t + X_{\text{Aug}} \\ \text{Sep}_t = \text{CMEAN}_t + X_{\text{Sep}} \\ \text{Oct}_t = \text{CMEAN}_t + X_{\text{Oct}} \\ \text{Nov}_t = \text{CMEAN}_t + X_{\text{Nov}} \\ \text{Dec}_t = \text{CMEAN}_t + \text{Dec} \end{array} \right. \quad (3)$$

With saved values, the time-varying properties of the month-of-year effects can then be graphed by using any available graphing programme. As a post hoc analysis, we also applied additional trend analyses (linear functions) to derived *Constant* vector and month-of-year effects.

The test statistics of significance of the parameters is

$$t = \frac{(\text{estimate}) - (\text{hypothesized value})}{(\text{estimated STD of estimate})} \quad (4)$$

where the t value is the value associated with a one-sample t test with a test of ‘parameter = 0’. This statistic is then compared with a critical value of the t distribution with $n-p$ degrees of freedom (n = number of observations, p = number

of parameters estimated). As a rule of thumb, the parameter is significant when $|t| \geq 1.96$, when the number of observations is high ($n \geq 120$). For more comprehensive presentation of the TVPEXPLORE analysis, see, for example, [16].

3 Results

The month-of-year effects were estimated as deviations from the overall monthly mean of runoffs (Table 2). The analysis revealed an increasing trend in overall monthly mean of runoffs as the constant term got positive, statistically significant t value. The trend was verified also with separate analysis of observed series (Fig. 1), as well as with the trend analysis of estimated time-varying series (Table 3). We also found that spring and early summer runoffs (April, May, June) were substantially responsible for the yearly freshwater contribution into the sea as they were showing only positive, significant estimates and accounting altogether for 33% of the total runoffs (Table 2). About 13% of the freshwater were produced during May alone. Respectively, the quarter characterised by the lowest runoff proved to be late summer (July–September) with negative parameter values and with the share of 21.6% of total runoffs. However, when compared with the first and the last quarter runoffs, the deviation was insignificant. Generally, the model turned out fairly competent: it can explain about 73% of the total variation in runoff series (Table 2).

The TVPEXPLORE graph provided valuable information regarding monthly runoff series (Fig. 2). We found that the month-of-year effects were not stable over time; monthly processes were more or less stochastic independently. While the variation between the months was generally smaller during the quadrants of decreased runoffs, and although the series resembled more each other inside the same quadrants, we were not able to distinctly show the decreasing seasonality in the series yet. However, we revealed potential implications of system change towards decreased seasonality when trend analyses were applied to estimated series (Table 3). Since 1974, the general pattern with the summer runoffs has been the increase of the values. This has been comparable with the winter (Feb, Mar) runoffs as well. At the same time, the late autumn (Oct, Nov, Dec) and especially the months associated to delayed winter runoffs (April, May), due to ice and snow melting, have decreased their share in discharges. In general, periods normally dry are increasing their freshwater contributions, while previously high-discharged periods are reducing (Table 2). If this persists, this can be foreseen to decrease the gap between high/low-runoff periods and eventually result in decreased seasonality in

the system. Moreover, estimated constant revealed that in the early 1980s (1980–1982) there was a level shift upwards in average monthly runoffs, overlapping especially with the coincident increase of late autumn (October, November) and early winter (December) values. All the other months showed decreasing values at the same time.

4 Discussion

Our results are generally in accordance with the BACC expectations. Following the expectation of increased wintertime rainfall in the Baltic Sea area, especially in the northern parts of Europe (e.g. [2, 4]), we also found a general increase in runoffs over the time period studied that consisted of a level shift upwards during the early 1980s as well. However, decreasing seasonality was not obvious in the series yet. Instead, we found potential implications of system change towards decreased seasonality as periods normally dry increased and typically high-discharged periods decreased their freshwater contributions into the Baltic Sea. The latter occurred especially with the months associated to delayed winter runoffs (April, May), due to ice and snow melting in the northern parts of the watershed.

The finding that the majority of the Baltic Sea freshwater runoff will end into the sea during late spring (April–May) and early summer (June) can reliably be explained with conventional runoff events and snow/ice dynamics occurring in the northern areas of the sea, especially in the watershed area of the Neva River. The Neva is the largest river flowing into the Baltic Sea. Its catchment area covers 16% of the total drainage area of the Baltic, and it alone produces 18.2% of the total freshwater runoff into the Baltic Sea [8]. The mean annual discharge of the Neva River into the Gulf of Finland is around 80 km^3 , but it varies considerably from year to year (data exist from the year 1859, see [6]), ranging from $42 \text{ km}^3/\text{year}$ (observed in 1940) to $115 \text{ km}^3/\text{years}$ (in 1924). The high variation in Neva annual discharge is evidently connected with snow and ice melting in the northern watershed areas of the river. That area includes three of the four biggest lakes in Europe: Lake Ladoga and Lake Onega in Russia (connected by the Svir River) and Lake Saimaa in Finland (running to the Lake Ladoga by Vuoksi River), being annually covered by ice. According to Doganovsky and Mjakisheva [9], the characteristics of the ice cover on Lake Ladoga and Lake Onega show a rather complicated correlation with climatic parameters. The time of ice breakup depends on a multitude of factors, but it coincides rather well with the changes in air temperature. In spring, for example, ice melting in Lake Ladoga proceeds in south–north direction. The water in the shallower southern areas warms up faster; hence, ice breakup occurs earlier in these areas. The average duration of the ice-

Table 2 Proportions of monthly runoffs in 1970–2000 (in per cents) and initial estimates of monthly parameters with standard errors, *t* values and *p* values for identified time-varying runoff model

Month	$r^2 = 0.73, n = 372, SE (resid.) = 6.42$					
	%	Estimate	SE	<i>t</i> value	<i>p</i> value	
<i>C</i>	100.00	41.38	0.90	45.78	<0.001	
X_{Jan}	22.11	7.34	-4.96	1.20	-4.13	<0.001
X_{Feb}		6.64	-8.29	1.19	-6.96	<0.001
X_{Mar}		8.13	-1.40	1.19	-1.18	0.239
X_{Apr}	33.12	11.07	13.87	1.19	11.67	<0.001
X_{May}		13.02	23.27	1.19	19.58	<0.001
X_{Jun}		9.02	3.61	1.19	3.04	0.003
X_{Jul}	21.60	7.40	-4.11	1.19	-3.45	<0.001
X_{Aug}		7.21	-5.47	1.19	-4.60	<0.001
X_{Sep}		6.99	-7.20	1.19	-6.05	<0.001
X_{Oct}	23.17	7.77	-3.48	1.19	-2.92	0.004
X_{Nov}		7.86	-2.22	1.19	-1.86	0.063
<i>Dec</i>	7.54	-3.64	1.19	-3.06	0.002	
$I / (\phi_t) \varepsilon_t$		0.63	0.04	15.62	<0.001	












Coefficient of determination for the model is calculated with $r^2 = 1 - [(n - 1)/(n - p)][(\text{sum of squares}_{resid.})/(\text{sum of squares}_{total})]$, where *n* = number of observations and *p* = number of estimated parameters. The box around December estimates indicates that values are calculated separately. For a more detailed description, see text



free period for the Lake Ladoga area varies from 103 to 181 days. These variations are mainly due to the effect of latitude and local conditions. Normally, melting starts in early April and by May 15–20 Lake Ladoga is completely ice free. Lake Onega lies further north of Lake Ladoga, or Lake Saimaa, and therefore its annual ice cover persists for somewhat longer. Ice thickness in Lake Onega increases until mid-March, and depending on winter severity, the ice melts completely in the period from late April to early June [15]. Therefore, the large north–south coverage of the lake's

watersheds, together with Lake Saimaa, constitutes a long-lasting continuum not only regulating considerably freshwater discharges from the Neva watershed into the Baltic Sea but also stabilising substantially the annual variation in freshwater runoffs as well.

We believe that the same reasoning, i.e. snow and ice dynamics and following erratic runoff events in northern watershed areas, not only explains the higher annual variability in late spring and early summer time series (April through June) but also the given resemblance in their

Table 3 Linear trend functions for estimated time-varying monthly parameters with coefficient of determinations, *t* values and *p* values

Month	Linear function	r^2	<i>t</i> value	<i>p</i> value	Trend
<i>Const.</i>	$y = 0.011x + 39.63$	0.15	7.55	<0.001	
X_{Jan}	$y = 0.001x - 36.6$	0.00	-0.57	0.568	-
X_{Feb}	$y = 0.013x + 30.9$	0.17	8.10	<0.001	
X_{Mar}	$y = 0.013x + 38.3$	0.13	6.72	<0.001	
X_{Apr}	$y = 0.012x - 56.9$	0.11	-6.28	<0.001	
X_{May}	$y = 0.011x - 66.4$	0.12	-6.51	<0.001	
X_{Jun}	$y = 0.019x + 41.8$	0.25	10.05	<0.001	
X_{Jul}	$y = 0.008x + 35.5$	0.08	5.36	<0.001	
X_{Aug}	$y = 0.007x + 34.7$	0.13	6.92	<0.001	
X_{Sep}	$y = 0.002x + 34.4$	0.01	1.43	0.153	-
X_{Oct}	$y = 0.011x - 40.3$	0.17	-7.86	<0.001	
X_{Nov}	$y = 0.013x - 41.1$	0.36	-13.25	<0.001	
<i>Dec</i>	$y = 0.015x - 39.7$	0.41	-14.79	<0.001	

Trend column indicates the direction of observed trend:  = increasing,  = decreasing and - = no trend. Coefficient of determination for the models is calculated with $r^2 = 1 - [(n - 1)/(n - p)][(\text{sum of squares}_{resid.})/(\text{sum of squares}_{total})]$, where *n* = number of observations (314 in each functions) and *p* = number of estimated parameters (one in each functions)

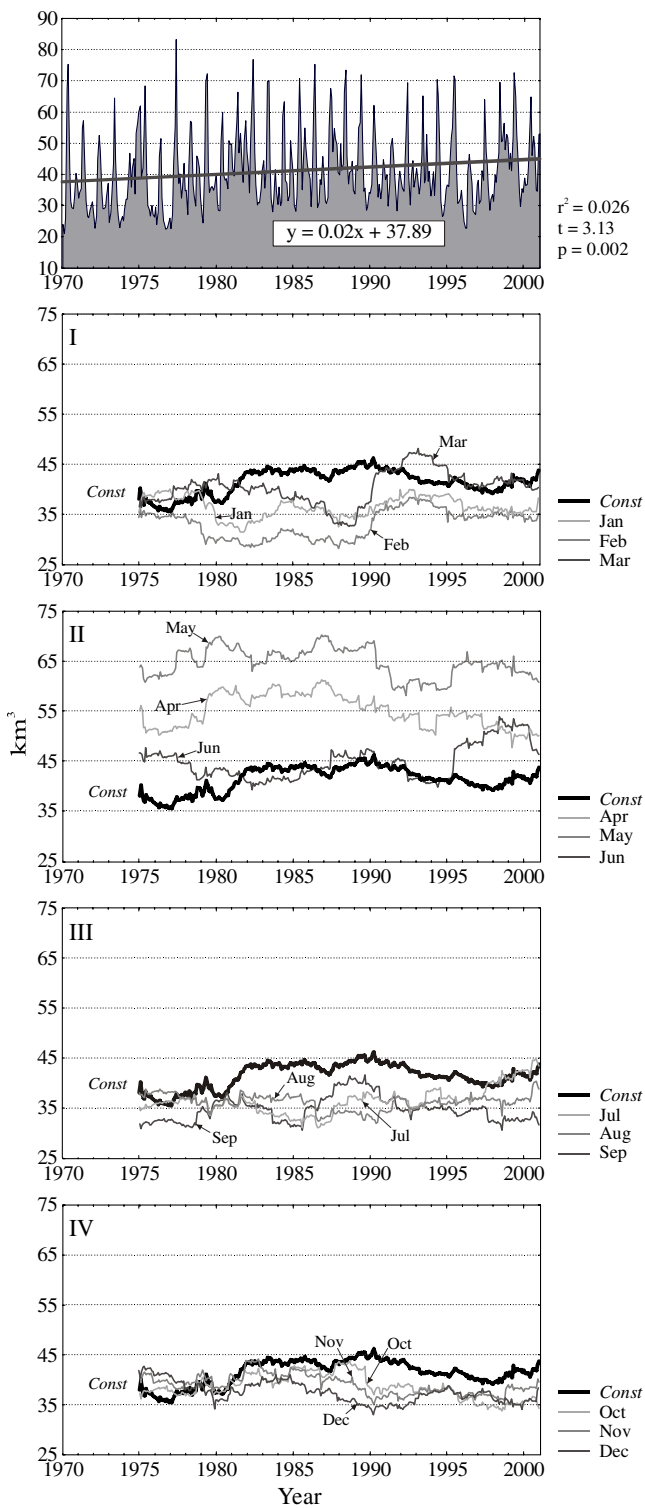


Fig. 2 Observed (*uppermost panel*) and modelled (*panels I to IV*) monthly runoffs as deviations from overall monthly mean into the Baltic Sea in 1970–2000. The *thick line* in observed series represents a linear function adjusted to the original runoffs for study period. The function matches exactly with the regression model $y=0.002x-394.7$ fitted to the same series ($r=0.1604$; $F(1, 320)=9.77$, $p=0.0019$). For simplicity, model *panels I to IV* are shown according to quarters. The *thick line* in model panels indicates the estimated constant (overall monthly mean) runoffs

April and May monthly values demonstrates that the Neva watershed is the basic source of freshwater within one winter, underlining the source's importance on the runoff processes of the Baltic water system in spring. On the other hand, during more stable periods in summer or fall, when the source of incoming water is more evenly shared between Baltic sub-drainage areas, only temporary random areal events, like rainy periods or drought, can fundamentally distort the processes between months, which until then can be detected in variation of time series.

The observation of a level shift upwards in the early 1980s agrees well with the previous findings of Baltic runoff events. For example, Meier and Kauker [18] showed that about half of the decadal variability of the average salinity of the Baltic is related to the accumulated freshwater inflow. They pointed out that two low-salinity phases during the 1920/1930 and during the 1980/1990 in the Baltic Sea salinities are explained by coincident stronger-than-normal freshwater discharges. This is supported by earlier analyses of runoff records (e.g. [17, 19, 20]). Long-term observations of changes in Baltic precipitation give more evidence of changed runoffs as well. According to the BACC Author Team [4], the latter half of the twentieth century was characterised by decadal scale fluctuations showing evidence of increased annual precipitation totals over most of Northern Europe. The increase concentrated mostly in the cold season from October to March. Moreover, Alexandersson [2] was able to define this and revealed (with anomaly time series between 1860 and 2004 in Sweden) that an increasing trend in precipitation was not only significant at the annual level but that the increase was particularly intensive after the 1980s. Seasonally, the largest increase took place in northern Sweden during winter. Somewhat contrary to this, later, the increase has proven not to be uniform and there are regions lacking the observed trends (e.g. in Finland and southeastern Norway) [4].

Our finding of increased runoff, resulting trendsetting events occurring in winter and summer, is in concert with some climate change modelling made regionally for the Baltic Sea (e.g. [4]). However, it is currently still impossible to distinguish between anthropogenic and natural contributions on variations in time series [4]. Whatever the causes are, the consequences enable us to ponder ecosystem changes that

monthly values. Basically, the high variation is simply a consequence of the fact that winters differ from each other annually. Snow and ice melting after cold and mild winters produce different amounts of discharges, and that can naturally also be seen in the annual variation of runoff series. However, we see that the mutual resemblance in

follow increased runoff. The North Atlantic Oscillation index (NAO) has repeatedly been demonstrated as one of the best indicators of climate conditions in Europe (e.g. [4, 13]). It has been shown by Alheit et al. [3] that a shift in the NAO general mode from negative to positive during 1980s caused a corresponding regime shift in both the North and Baltic Sea ecosystems. We have earlier modelled a cause-of-effect relationship between the NAO and Baltic Sea runoff and salinity [11] and finally with Baltic ecosystem and ecology [12, 23]. In addition, many excellent works associated with NAO issues have increased the understanding of the northern hemisphere ecosystem functioning, not only in the Baltic Sea area (e.g. [4]). It can turn out that the recent modelling will prove NAO a still more potential tool to evaluate anthropogenic and natural consequences of climatic change regionally in the future.

As shown, the use of traditional deterministic models with TVPEXPLORER reveals much about the series at hand that may lead to better understanding of processes in a relatively small area and over a short time span. The method can, for example, give us an opportunity to evaluate better the predicted areal consequences of climatic change. It can also be used to study seasonal effects, structural shifts and overall model performance as it relates to both parameter estimates and windows of time. However, with such high instability among the month-of-year effects over time, it would be unwise to rely on such deterministic models for forecasting applications only. Therefore, if forecasting is the primary application, adaptive models such as ARIMA are better suited. In addition, time-segmented or value-segmented (threshold) time series models may be useful in the analysis and forecasting of such series.

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