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Detecting changes in winter seasons in Latvia: the role of arctic air masses

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Empirical climate variability and change studies may be particularly beneficial when they combine a search for dynamic causes with the examination of trends in meteorological variables. By using an air-mass-based methodology, arctic air masses over Latvia were identified for the 1950–2005 period according to the classification used by Berliner Wetterkarte, which defines air mass types by their origin and the extent of continental or maritime influence. The frequencies of maritime, transformed and continental arctic air masses and the class of arctic air masses were examined to evaluate whether and to what extent these account for changes and variations in the surface temperature. Trends in the frequency of arctic air, monthly-average temperature and monthly lowest minimum temperature series at seven observation sites were determined by using the non-parametric Mann-Kendall test. The results indicate that the frequency of arctic air masses during winter seasons decreased significantly during this period, with the majority of the decrease being associated with maritime arctic air, and that the frequency of the bitterly cold continental arctic air has also demonstrated a decrease. This trend in the monthly frequency of arctic air was the greatest in February. The increase in the winter, near-surface air temperature was partially attributable to a decrease in maritime arctic air mass frequency and, at a seasonal scale, these changes tended to smooth the peaks in the monthly temperature time series.

Introduction

The nature of air masses makes them an essential index which represents the influence of a combination of several meteorological parameters and their numerical values. For that reason the study of air mass dynamics may be considered a particularly useful tool applicable for the analysis of a series of meteorological elements and for the geographical interpretation of climatic data. Air mass advection and processes taking place mostly within one pressure system, including the air mass transformation, input of solar radiation and several others, are the main climate-forming processes in the eastern part of the Baltic Sea region (Bukantis 2002). An air mass, by definition, is a large body of air in the troposphere that is approximately homogeneous over its horizontal extent. Hence the temperature and moisture gradients are small, but vertically the properties of the air mass vary according to the regularities inherent to it as a whole. An individual air mass may extend over thousands of square kilometers, and normally its area exceeds that of Latvia.

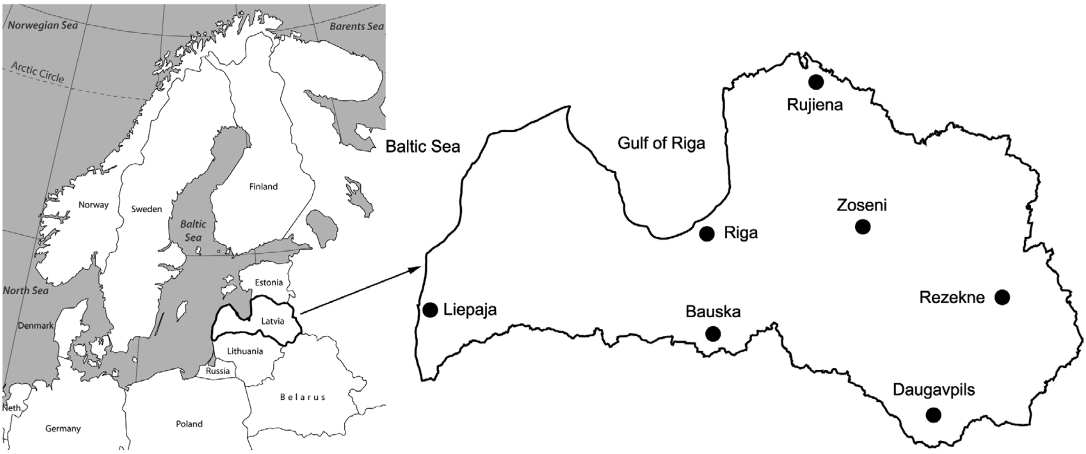

Fig. 1. Location of the meteorological stations of Latvia used in this study.

Because of Latvia's location at the northern rim of the mid-latitudes between 56°N and 58°N and in a transitional position between the oceanic and inner regions of Europe, it has a boreo-nemoral ecotone, the annual frequency (57%) of arctic and subpolar air masses being fairly high (Fig. 1). Since arctic air masses are the northern hemisphere's coldest air masses, they often, though not always, bring the coldest days and are the most likely to produce minimum near-surface temperatures. Krauklis and Draveniece (2004) analyzed the frequency of air masses over Latvia in relation to the twelve landscape seasons and showed that, at a seasonal level, the period from full autumn (October) to early spring (mid-April) is characterized by arctic and subpolar air masses. Arctic air masses may appear in Latvia during any season with the exception of the summer seasons lasting from June to the end of August, but the period from October to mid-April is the time of the highest arctic air mass frequency.

Published papers that investigate the climate variability over the eastern part of the Baltic Sea (Jaagus and Ahas 2000, Jaagus *et al*. 2003, Laiviņš and Melecis 2003, Bukantis and Rimkus 2005, Draveniece *et al*. 2006) reveal that in recent years there has been a significant upward trend in the winter air temperature, decline in snow cover indices, decrease in the seasonal differences of air temperature and precipitation, and changes in continentality. However, evaluation of the form and extent of climate variability urge one to move beyond the empirical examination of records, since these provide only gross evidence of the variations and changes. However useful the trends of monthly or seasonal average temperature, these may provide only modest insight into structural causes (Schwartz 1995). As pointed out by Brinkmann (1993), a reduced equator-to-pole temperature contrast might lead to changes in circulation patterns and thus to changes in the frequency of different air masses reaching a midlatitude location. For example, the mean temperature increases in the western North American Arctic were found to correlate positively with an increased frequency of the warmest air masses at the expense of colder air masses (Kalkstein *et al*. 1990). My earlier study (Draveniece 2007) reported statistically significant trends in the time series of November and January temperature and pseudo-potential temperature for Latvia during the 1958–2000 period at the 850-hPa level, which is the most appropriate level to achieve scientifically sound results in identifying air mass types.

The objective of this paper is to evaluate changes in the frequency of winter season arctic air masses over Latvia for the period from 1950 to 2005 and to examine whether and to what extent these changes account for the variability of the temperature in the winter season.

Material and methods

Air mass classification and arctic air mass identification

The air masses were identified by the climatologically objective method and classification scheme originated and used by Berliner Wetterkarte (Geb 1981). The method is based on determining an air mass back trajectory and checking of typical thermodynamical properties of an air mass. The applied classification recognizes arctic, subpolar, warmed subpolar, mid-latitude, subtropical and tropical air masses, each defined also by the extent of continental or oceanic influence. Thus, arctic air may be defined as maritime arctic air, mixed or transformed arctic air and continental arctic air (*m*, *x* and *c*, respectively). Understanding of the air mass back trajectory and establishing of energy content, which was checked with regard to fitting in the statistically estimated range of mean temperature and pseudo-potential temperature at the 850-hPa level of European air masses, was normally sufficient to identify the air mass type. The origin of the air mass was the decisive criterion and overruled the temperature in cases of uncertainty that evolved from overlapping numerical ranges of temperature and pseudo-potential temperature, each representing a distinct air mass type. The air mass moisture content and, to this end, the relative humidity at the 850-hPa level were also considered. For instance, the origin or transformation of an air mass over the continent, together with a current relative humidity of less than 50%, were regarded as sufficient reasons to identify it as a continental air mass. Transformed maritime arctic air, on the other hand, generally showed intermediate properties concerning the meteorological parameters, namely temperature, pseudo-potential temperature and relative humidity at the 850-hPa level.

Maritime arctic air (*m*) brings snowfall, and thus the inflow of *m* air is combined with a persistent cloud cover resulting from both frequent frontal passages and the establishing of air mass cloudiness that cuts off direct solar radiation and creates conditions favorable for the establishment of a continuous snow cover over Latvia (on the average 8–29 December, except in the coastal territories adjacent to the Baltic Sea where it is established during the first decade of January). In cases when the air mass has moved farther out and over the ocean and, through contact with the ocean surface, has become more warm and moist, it is identified as maritime polar air, which brings moderate (> 0 °C) air temperatures and greatly changeable weather. Continental arctic air (*c*), an infrequent air mass in Latvia, comes with north-easterly or easterly airstreams and occurs only in winter (end of November to March). It originates over the Arctic basin and Siberia, where snow and ice cover chills the lower layers, and forms a marked temperature inversion up to 850 hPa. In winter, the source region is limited by the –15 °C isotherm. In *c* air, near-surface temperatures may drop to –40 °C. Transformed arctic air (*x*) brings slightly milder weather than *c* air and usually comes with northerly and north-easterly airstreams. After a series of cyclones, a migratory high pressure cell may develop in the maritime arctic air over Scandinavia, and this air is transformed into *x* air, a drier and colder air. In winter the daily temperature under clear or partly cloudy skies may decrease to –25 °C and even below –30 °C at night.

The analysis was restricted to the cold landscape seasons from pre-winter to pre-spring that encompass the months of November, December, January, February and March, because all three types of arctic air masses generally occur in Latvia within a period of only five months. During the analysis period, the extremely cold *c* air, although rarely identified in Latvia as early as December, was occasionally identified in the second half of November and as late as the third decade of March. In the context of air masses, November is considered a winter season in Latvia, because the cold air masses, namely arctic and subpolar air, gain the upper hand over warmer air masses. Moreover, occasionally the yearly minimum temperatures over the entire country are confined to November, as it occurred in 1993 and 1998.

Radiosounding data, weather maps and surface weather observations

The data from upper-air soundings carried out in

Riga (56°58´N, 24°02´E and Liepaja (56°31´N, 21°01´E) were used for generating the time series of the 850-hPa temperature, relative humidity and pseudo-potential temperature, which was calculated using observation data obtained at 00:00 and 12:00 UTC, and for identification of arctic air masses for the 1950–2005 period. In Latvia, the upper air soundings were done only at these two sites. The weather maps of the Latvian Environment, Geology and Hydrometeorology Agency for the years before 1992 and the European Meteorological Bulletin issued by the Deutscher Wetterdienst for the years 1993–2005 were utilized to determine air mass trajectories arriving at Riga during cold air advection. For specific details, the daily weather bulletins, meteorological monthlies and monthly weather summaries for the territory of Latvia were consulted. However, the upper-air soundings at the Liepaja station were carried out only in the years from 1961 to 1992 and some data were missing for the Riga station, too. For instance, starting from the year 1999, the radiosondes are launched in Riga once a day, and due to technical problems the upper air soundings have not been done for several days in January 1981 and in some other months. A shorter 850-hPa data series for Liepaja can not be regarded as a serious drawback because generally the upper air sounding data for Riga may be considered sufficient for identifying the air masses over Latvia. Since in this paper we consider the days dominated by arctic air masses, the daily weather bulletins and monthly weather reviews for the territory of Latvia, as well as the 850-hPa isotherm maps for the Atlantic-European sector of the National Center for Environmental Prediction-National Center for Atmospheric Research (NCEP-NCAR) reanalysis, which are available on the Internet, were sufficient to detect the inflow of arctic air. The 850-hPa isotherm maps were used to fill in the missing information for days without upper air soundings.

While the surface temperature appears to be a problematic descriptor for air mass identification, it is well applicable for describing the effect of a known air mass on the weather pattern and surface conditions perceived by humans. To investigate the interrelation between variations in monthly frequency of arctic air masses and near-surface temperatures, time series of monthly average temperature and monthly lowest minimum temperature were created, and the latter series were supplemented with the dates of minimum recorded temperature. Thus, the coldest day of each month was established. A set of seven meteorological stations in Latvia was considered sufficient to investigate whether and to what extent the lowest values of winter surface temperatures and their variations are related to arctic air advection over Latvia. On the one hand, the selected stations cover the territory of the country sufficiently evenly, and, on the other hand, they are located in various geographical conditions. The stations involved in this study are Liepaja (56°31´N, 21°01´E) located on the coast of the Baltic Sea, Bauska (56°24´N, 24°13´E) located in the central part, Riga (56°58´N 24°02´E) located at the southern coast of the Riga Gulf, Rujiena (57°56´N, 25°13´E) located in northern Latvia near the Estonian border, Zoseni (57°09´N, 25°54´E) which is largerly representative of the Vidzeme Upland, and Daugavpils (55°52´N, 26°37´E) and Rezekne (56°31´N, 27°20´E) located both in the southeastern part of Latvia (Fig. 1).

In an earlier study, Krauklis and Draveniece (2004) showed that from November to March the average number of arctic air mass days in Latvia was from 8 to 9.5 days per month (Fig. 2). Because of the considerable share of arctic air masses and their substantial role in bringing winter weather to Latvia, the latter may, to a large extent, influence both the near-surface monthly average temperature and the monthly lowest minimum temperature. Besides, examination of daily near-surface temperature series was a helpful tool in observing the range of temperatures within the particular air mass type and in establishing whether arctic air might arrive over Latvia in non-sounding days.

Statistical analyses

In this study the statistical analyses were applied as follows. First, an exploratory analysis was undertaken to show and evaluate the link of the winter near-surface temperatures in Latvia to larger-scale atmospheric dynamics. The relationships between the frequency of arctic air masses and surface temperature, more specifically the monthly average temperature and monthly lowest minimum temperature, at the seven observation sites from November to March for the 1950–2005 period were examined. The respective data sets, which consisted of 56 pairs, were subjected to Spearman's rank correlation test. The relationship between the number of arctic air masses and near-surface temperature was considered as being strong when the value of Spearman's correlation coefficient was greater than 0.67 and medium strong when the coefficient was between 0.34 and 0.66.

A simple linear regression analysis on the data of arctic air mass frequencies was done using the least-square method. The resultant regression lines were drawn to determine the slopes of the trends for the 1950–2005 period.

The major aim of the statistical analyses was to determine whether there was a trend in the frequency of all arctic air masses and separately of each arctic air mass type and, if so, to what extent these were attributable to variations in the mean and daily minimum temperatures of the winter months. In order to minimize the error from gaps in radio sounding data, it was considered reasonable to use either the number of days with arctic air or the frequency of arctic air masses expressed as a percentage, instead of examining exclusively the 850-hPa data.

As the first step, the arctic air mass days were summed to obtain the monthly values, and the monthly average values of near-surface temperatures were calculated. The trends in the time series of arctic air mass frequencies, monthly-average surface temperatures and monthly lowest minimum temperatures were analyzed using a linear regression analysis to detect temporal trends for the1950–2005 period. The time series were plotted on charts and simple linear regression trend lines were used to graphically display trends in data.

The non-parametric Mann-Kendal test (Hirsch *et al.* 1982, Hirsch and Slack 1984) for monotone trends in time series was chosen for detection of trends, as it is a relatively robust method concerning missing data and does not have strict requirements regarding data heteroscedasticity. Besides, this method is supposed to be relatively insensitive to outliers. The Mann-Kendal test was applied separately to each variable at each site, at a significance level of $p < 0.05$. A trend was considered as statistically significant if the test statistic extended beyond +2.0 or –2.0.

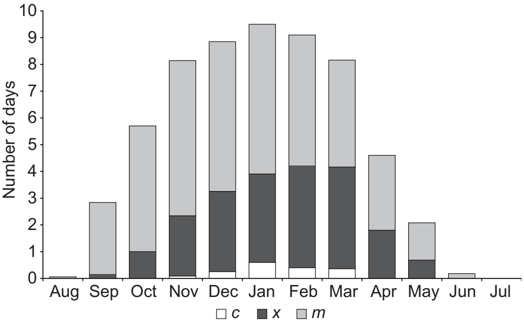

Fig. 2. Monthly-average frequency of arctic air masses over Latvia for the years 1950 to 2005. *m*, *x* and *c* are maritime, mixed or transformed and continental air masses, respectively.

Results and discussion

Arctic air mass frequency from November to March and link to surface air temperature

The mean frequency of arctic air masses arriving in Latvia in winter months (November to March) was 29%, ranging between 13% (1972/73) and 51% (1962/63). The long-term frequencies of each arctic air mass type were found to exhibit a pronounced seasonality and clearly revealed the small number of continental arctic air in comparison to two other arctic air mass types of maritime character (Fig. 2). Earlier, Krauklis and Draveniece (2004) described the annual cycle of air masses arriving in Latvia during the1990–2000 period and sorted all air mass types into three groups: all-season, seasonal and irregular. Thus, maritime arctic (*m*) and transformed maritime arctic (*x*) air masses were grouped as seasonal, and continental arctic (*c*), although strongly seasonal but not common each winter, as an irregular air mass.

Arctic air masses originate in snow and ice covered regions and reach Latvia along different trajectories whose origin ranges from the south-west to the north and northeast. Maritime arctic (*m*) air forms during the winter from continental arctic (*c*) air that has evolved over the ice in the Arctic between Greenland and Spitsbergen, via *x* air, when moving across the open water of North Atlantic, and is most often carried across the Baltic region by northwesterly air currents behind low pressure systems passing over northern Scandinavia. In contrast, the *x* and *c* air masses are associated with advection from the north to northeast and largely meridional airflow that is deflected by wintertime blocking situations (high-pressure areas) over Scandinavia. As can be noted, however, in winter the Arctic is ice-free in the Barents Sea and in regions of the Arctic rim that are conducive to a slight warming and moistening of the cold arctic air. Thus, transformed arctic (*x*) air masses evolve, traversing over a heterogeneous (water, ice floes, ice fields) underlying surface. The bitterly cold *c* air, which is the coldest air mass in the northern hemisphere, arrives in Latvia with northeasterly and easterly airstreams, and commonly a marked temperature inversion of up to 850 hPa is observed.

Moreover, in terms of seasonality, the lag effect of the annual cycle of air mass properties in relation to the culmination height of the annual cycle of the sun and to day-length is a noteworthy factor. The typical properties of an air mass with respect to temperature and water content are at their minimum about 1.5 months after the winter solstice, and thus arctic air masses possess the lowest heat content and brought the coldest weather in the last decade of January and first decade of February.

In Latvia, the *m* and *x* air masses remain common throughout all winter seasons from pre-winter to pre-spring. Thus, during the 56-year period, the *m* air was identified each season, more specifically each month from November to March with the exception of two non-arctic air mass months in November (2000, 2003), December (1960, 1972) and February (1972, 1990). The mean frequency of the *m* air masses over the investigated period was from 14% (March) to 19% (November), and that of *x* air masses from 7% (November) to 13% (February, March), whereas the *c* air reached its highest frequency (1.9%) in January, gradually decreasing in February and March.

Not the three types of arctic air masses alone, but continental subpolar (or subarctic) and transformed maritime subpolar air that arrives in Latvia generates and maintains typical winter weather, namely frozen precipitation, snow cover, and below zero air temperature. However, the winter in Latvia includes also days with the air temperature above zero, drizzle, rain or overcast sky without precipitation, brought by maritime subpolar air or warmer air masses that have originated or transformed over middle latitudes or subtropical latitudes.

Spearman's rank correlation test was used to discover the strength of a link between two pairs of the sets of data for the winter months in the period from 1950 to 2005 at seven observation sites: first, between the number of arctic air masses and the monthly-average near-surface temperatures and second, between the number of arctic air masses and the monthly lowest minimum temperatures.

A strikingly good correlation was found between the number of arctic air masses and monthly-average temperature for January, February and March, and a medium strong correlation in December and November. The strongest correlation coefficients over the territory of Latvia were found in February (from 0.81 to 0.85), slightly lower values of the coefficients were found in March (from 0.71 to 0.77) and January (from 0.68 to 0.73). The range of the values of Spearman's rank correlation coefficients (ρ) at the seven observation sites in December was from 0.61 to 0.69 and in November from 0.59 to 0.68. Indeed, the higher number of arctic air masses was associated with higher correlation coefficient values.

Spearman's ρ coefficients between the number of arctic air masses and the monthly lowest minimum temperatures in the analyzed months at the seven observation sites were slightly smaller than those for monthly average temperature. The highest ρ values (from 0.68 to 0.85) were in February, but the values of coefficients in other winter months between sites mostly fell into the category of medium strong correlation, namely in January they varied from 0.64 to 0.76, in March from 0.54 to 0.7, in December from 0.59 to 0.68 and in November from 0.36 to 0.47. It is understandable because the lowest minimum temperature is associated with a single day of the month, and in many cases the temperature may drop to the lowest value under anti-cyclonic circulation over the Baltic Sea region that brings to Latvia continental sub-polar or transformed maritime sub-polar air. The latter are identified in winter as frequently as arctic air masses. This finding about the values of Spearman's rank correlation coefficients was considered of sufficient importance to justify the utilization of the chosen near-surface temperatures.

Trends in arctic air mass frequency

Monthly frequencies of each arctic air mass type and the arctic air masses in total were examined by ordinary linear regression and the Mann-Kendall non-parametric test. The examined time series did not display significant linear trends, but there was an indication of changes in the characteristic features of the cold season (November through March).

The linear regression of the arctic air mass frequencies in November yielded an upward trend both for the transformed arctic air and maritime arctic air masses (Fig. 3a), and Mann-Kendall test showed a statistically significant increase in arctic air mass frequency (Table 1). Examination of the 56-year frequency series showed, however, that November is still a pre-winter month, occasionally bearing more resemblance to early autumn, as in 2000 and 2003, when inflow of arctic air was not observed at all. We noted, however, that over the 50-year period from 1950 to 1999, arctic air masses were present each November. The chilly *c* air masses were present only during five episodes of cold air outbreak and trend analysis was omitted for them. The *x* and *m* air mass frequencies showed fairly significant upward trends. This was in agreement with the downward trend in the November 850-hPa pseudo-potential temperature over the 43-year period of 1958–2000, which was found earlier and was considered to be indicative of more frequent advection of cooler and less humid air.

The frequency of *m* air in December showed a fairly significant downward trend. The trend that was detected with the Mann-Kendall test was matching with the one calculated using a linear regression analysis (Fig. 3b). The *c* air masses reached Latvia on the average once every five years for 1–2 days with the exception of the second decade of December 1962, when they stayed for three days. An insignificant trend was found in the *x* air frequency. Thus, the total frequency of arctic air masses showed an insignificant downward trend. In general, the coming of December heralds the start of a continuous snow cover over Latvia (on the average, 8–29 December), except in the coastal territories adjacent to the Baltic Sea, where it becomes established during the first decade of January. Since the inflow of *m* air masses is commonly associated with snowfall and formation of a snow cover, a downward trend in the *m* air frequency might partly explain the decreasing duration of snow cover found earlier by Draveniece *et al.* (2006).

Application of the Mann-Kendall trend test to frequency series for January showed a clear evidence of decrease of *c* air masses, as well as a fairly significant decrease of *m* air and the total frequency of arctic air masses that were perfectly matching with the trends calculated using a linear regression analysis (Fig. 3c). We explained the significant downward trend in *c* air mass frequency as the result of its absence

Table 1. Test statistics for Mann-Kendall test for trends in time series of frequencies of continental arctic *c*, transformed maritime arctic *x*, maritime arctic *m* air masses and the sum of all arctic air masses over Latvia (monthly and seasonal values) for the period 1950–2005. The following values and symbols are given: statistically significant values at $p < 0.05$ are set in boldface, at $0.05 < p < 0.1$ are set in regular face, and * denotes no significant trend.

	Nov	Dec	Jan	Feb	Mar	Nov–Mar
c	*	*	**–2.13**	*	*	*
x	1.36	*	*	*	*	*
m	1.34	–1.61	–1.37	**–2.72**	*	**–2.13**
Sum	**1.66**	*	–1.54	**–1.98**	*	**–1.85**

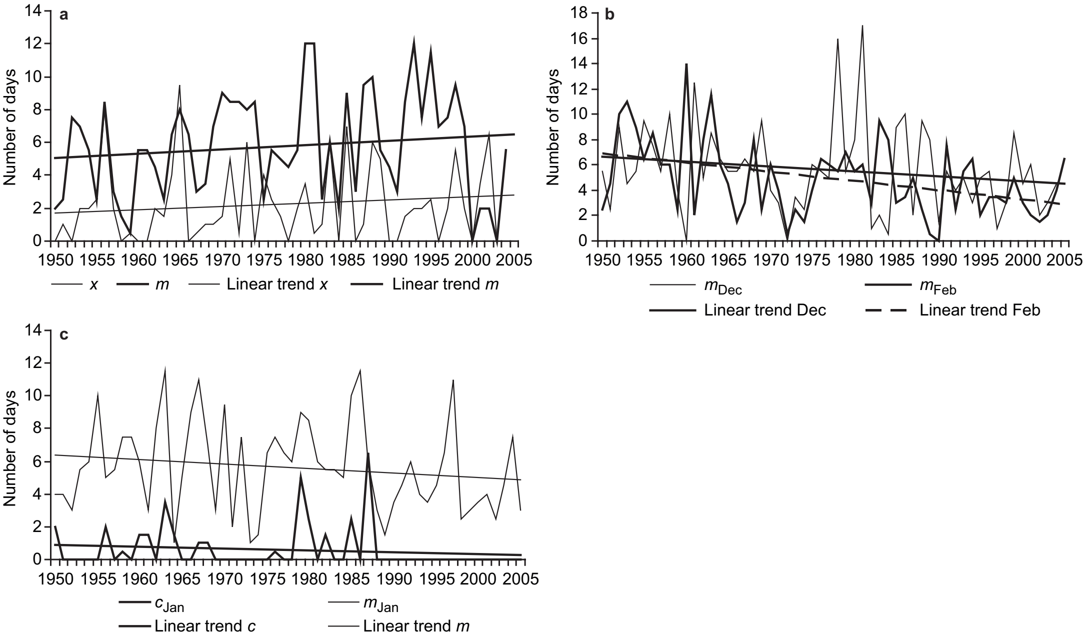

Fig. 3. (**a**) Monthly frequencies of maritime arctic (*m*) air masses and transformed arctic (*x*) air masses over Latvia in November (1950–2005), and the linear trends (slope for *m* air 0.0259 and slope for *x* air 0.0194). (**b**) Monthly frequencies of maritime arctic (*m*) air masses over Latvia in December and February (1950–2005), and the linear trends (slope in December –0.0376 and slope in February –0.072). (**c**) Monthly frequencies of continental arctic air (*c*) masses and maritime arctic (*m*) air masses over Latvia in January (1950–2005), and the linear trends (slope for *c* air –0.0102 and slope for *m* air –0.0274).

over the past 18 years, the 1987/1988 season marking the beginning of a period of relatively mild winters. January 1987, when an unusually cold outbreak of *c* air from the northeast brought near record low January temperatures and a record long period of very low (–25 to –30 °C) daily near-surface temperatures, is known to be the coldest on the 100-year record. In general, advection of bitterly cold air from the northeast is associated with persistent anticyclones over northern Europe and northwestern Russia. Such synoptic situations were found to be less common during the last two decades.

Noteworthy was the dramatic decrease in *m* air mass frequency (Fig. 3b) and thus in total air mass frequency in February (Table 1). However, the *c* air and *x* air frequency changes were insignificant. The February time series and the rest of the available information showed that during the 56-year period arctic air masses were missing for an entire month in 1990. It was the warmest February on the 100-year record, with precipitation only in the form of rainfall. The unusually mild weather “woke up” the dormant plants, and birch sap started rising during the last week of the month. The month’s warmth was due to several spells of mid-latitude and even subtropical air.

The frequencies of *c*, *x* and *m* air masses in March showed insignificant decreases during the 1952–2005 period. Noteworthy, however, was the observation that during the studied period, the last dates of occurrence of the frigid *c* air in Latvia shifted towards the first decade of March. Only in 1952 and 1963, the *c* air masses were identified in the third decade of the month.

Trends in arctic air frequency associated with trends in surface air temperature

The trends in arctic air mass frequencies and surface weather conditions were analyzed in combination with the monthly average daily temperature and monthly lowest minimum temperature time series at seven stations in Latvia. Application of the method of linear regression and Mann-Kendall test to examine the surface temperature series showed significant downward trends in the January, February and March records (Table 2). No statistically significant differences were found in monthly average and lowest minimum temperatures for November and December. The significant increase in both the monthly average and lowest monthly minimum temperature in February may be partly attributed to the significant downward trend in *m* air frequency. Besides, a slight decrease, although not significant, was found in the frequencies of *x* air and arctic air masses in general.

The situation was more complex in January and March. The statistically significant downward trend in *c* air frequency and the trends (with 90% significance) for both *m* air and all arctic air masses in January gave evidence that these played a role in the upward trend of the monthly-average temperature. However, the lowest minimum temperatures did not exhibit significant increasing trends with the exception of Riga, which may be explained by the city's heat-island effect. It was suspected that the absolute minimum temperatures over the territory of Latvia may have occurred exclusively within arctic air as a result of advection of the coldest, namely arctic air masses. Yet, examination of the time series of monthly lowest minimum temperatures showed that fairly often temperatures dropped to the lowest values in air masses other than arctic. To determine the reason, the types of air masses on days with monthly minimum temperature in January were determined for the period from 1950 to 2005. Most often the minimum temperatures were recorded in *x* sub-polar air and many times in continental sub-polar air. This seemed quite understandable since both were largely associated with anti-cyclonic weather and thus with only partial cloud cover or clear skies and light wind. Occasionally the minimum temperatures were recorded in *c* air, which is an infrequent air mass in Latvia. In March, the trends in arctic air mass frequencies were of less than 90% significance. Thus, the highly significant increases in surface temperatures are possibly attributable to a slightly changed frequency of arctic air.

Pre-winter and the first part of mid-winter in Latvia, namely November and December, exhibited opposite trends in *m* air frequency at 90% significance. Of greater importance is, perhaps, the fairly significant upward trend in the frequency of arctic air masses in November although the surface temperatures did not change significantly.

In general, during the 30-year period from 1975 to 2004, and still more explicitly in the past 15 years, the curves of arctic air mass frequencies from November to March were comparatively flat and did not exhibit a distinct maximum. Not disregarding the evidence of a seasonal cycle of the properties of each arctic air mass type, according to the analysis presented herein it is likely that a non-unequivocal change in the frequencies of arctic air masses has played an important role not only in warmer winter seasons but also in reducing differences within a particu-

Table 2. Mann-Kendall test statistics for trends in time series of monthly average temperature (AVG) and monthly lowest minimum temperature (Min) at seven Latvia's meteorological stations for the period 1950–2005. The following values and symbols are given: statistically significant values at $p < 0.05$ are set in boldface, at $0.05 < p < 0.1$ are set in regular face, and * denotes no significant trend.

Station	November		December		January		February		March	
	Avg	Min	Avg	Min	Avg	Min	Avg	Min	Avg	Min
Liepaja	*	*	*	*	**1.66**	*	**2.21**	*	**2.44**	1.46
Bauska	*	1.38	*	*	**2.11**	*	**2.19**	**1.85**	**2.85**	**2.65**
Riga	*	**2.16**	*	*	**2.28**	**1.92**	**2.32**	**2.11**	**2.75**	**3.35**
Rujiena	*	*	*	*	**2.00**	*	**1.96**	1.34	**2.74**	**3.00**
Zoseni	*	*	*	*	**2.21**	1.30	**2.75**	**2.29**	**2.85**	**2.75**
Daugavpils	*	*	*	*	**1.96**	1.32	**1.94**	**1.97**	**2.78**	**3.84**
Rezekne	*	*	*	*	**2.37**	1.29	**2.05**	1.44	**3.12**	**3.42**

lar winter season. While the current changes tend to have smoothed the peaks of monthly series, it is uncertain whether the documented trends will be reversed in the future or whether they are associated with changes on a larger scale.

Summary and conclusions

The purpose of this paper was to use an air mass-based methodology in order to reveal much more about winter season climate than does a trend analysis of various meteorological variables. It is hoped to expand this analysis to sub-polar air and to the entire period of arctic and sub-polar air masses from full autumn to full spring, that lasts from the beginning of October to late April.

The frequency of arctic air masses in Latvia during winter seasons decreased significantly during the period from 1950 to 2005, with the majority of the decrease being associated with maritime arctic air, while the decrease in transformed arctic and continental arctic air frequency was insignificant with the exception of January. The trend in the monthly frequency of arctic air is the greatest in February. However, a fairly significant upward trend exists in November arctic air frequency.

The majority of decrease in winter season maritime arctic air mass frequency may be, perhaps, related to changes in the number of cyclones and cyclone trajectories in central and northern Europe as discussed by Sepp *et al.* (2005). The decrease, although insignificant, of the frequencies of arctic air masses that originate or transform over the continent contribute in the end to the reduced impact of arctic air masses that initiate and maintain typical winter weather, including snow cover. Apart from affecting the state of landscapes in winter, the changes in artic air mass frequency, if sustained, will influence the process of stocking up or "conservation" of water caused by winter frost and, consequently, the runoff and evaporation at the start of the positive temperature period.

The increase in wintertime air temperature is partly attributable to a decrease in maritime arctic air mass frequency and, at a seasonal scale, the changes in arctic air frequencies tend toward greater uniformity of temperature within a season. A significant upward trend in the near-surface monthly average temperatures and monthly lowest minimum temperatures was the greatest in March, and that may be related to the cumulative effect of a decrease in arctic air mass frequency during the previous winter months and particularly during typical winter months: January and February.

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