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ORIGINAL PAPER

Fog climatology in Latvia

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Abstract Fog has been recognised as a hazardous weather phenomenon that can cause accidents and affect urban air quality negatively. Therefore, assessing the characteristics of fog formation, as well as the changes in fog frequency and intensity as a result of climate change is of high importance. This study covers a 52-year period and contains an analysis of the frequency of fog occurring, long-term changes in fog frequency and atmospheric conditions that favour the occurrence of fog events in Latvia. During the analysis, two inter-annual maxima of fog frequency were identified in the spring and autumn; the seasonal differences in the formation of fog were also confirmed using satellite observations of low-level cloudiness. However, the long-term changes of fog frequency showed a decrease tendency of fog to form, which may be associated with improvements in air quality since industrialization and the observed increase of air temperature.

1 Introduction

Fog has been recognised as a hazardous weather phenomenon worldwide; it can cause accidents and negatively affect urban air quality, especially in combination with the impact of air pollutants (Lange et al. 2003; Singh and Dey 2012). The total economic loss associated with the impact of fog can be comparable to losses caused by tornadoes or, in some cases, winter storms and hurricanes (Niu et al. 2010). Problems with traffic flow such as flight delays, and automobile and marine accidents due to poor visibility can be considered as the most common negative effects of fog (Cermak and Bendix 2008; Heo et al. 2010). At the same time, fog can be associated with critical conditions in air pollution, resulting from air pollutants becoming trapped in the fog droplets and reaching high concentrations, causing the formation of smog or in some cases acid fog (Bendix 2002; Błas et al. 2002; Witiw and LaDochy 2008; Syed et al. 2012). However, fog, acting as a source of humidity, is also very important to the health of ecosystems and humans (Sachweh and Koepke 1997; Cereceda et al. 2002; Lange et al. 2003; O'Brien et al. 2012). In addition, fog has an important role in maintaining radiation balance and, as a result, long-term changes in the frequency of fog can play an important role in the accuracy of climate model predictions (Bendix 2002).

Fog is a very local phenomenon that can form as a result of advection, radiative cooling or a weather front moving over an area; its frequency and spatial distribution is closely related to orography and proximity to the sea (Błas et al. 2002; Witiw and LaDochy 2008; Syed et al. 2012; O'Brien et al. 2012). The high fog frequency at higher elevations is usually a product of orographic cooling (Lange et al. 2003), and the most frequent category of fog observed at these sites is slope fog, which forms as humid air ascents mountain slopes to an altitude of 1,000–1,600 m above sea level (Błas et al. 2002). However, over higher mountain ranges, such as the Alps, a reduced frequency of fog or a lack of fog coverage are observed, owing to a decrease in humidity (Bendix 2002). The occurrence of fog is also related to atmospheric circulation and the local geographical features of a site, so it differs in different parts of the world (Cereceda et al. 2002); for example, fog frequency in Taipei is the highest during March, which is the month when

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the minimum fog frequency can be observed in Mexico (Tsai et al. 2007; Garcia-Garcia and Zarraluqui 2008). Under the influence of diurnal changes in air temperature, the maximum occurrence of fog is characterised as being between 4–6 a.m. and the minimum during 1–3 p.m. To assess the intensity of fog, the measurements of horizontal visibility or the persistence of fog can be used (Sachweh and Koepke 1997; Błas et al. 2002).

In many sites in the industrialised world, the most intense fogs, in both persistence and density, were observed in the 1940s and 1950s, when some famous low-visibility episodes occurred in combination with heavy air pollution, such as the Great Smog of London in 1952 (Met Office 2005). During this event, visibility below 10 m lasted for nearly 48 h in Heathrow; such intense and persistent low visibility is almost unheard of today (Met Office 2005; Witiw and LaDochy 2008). Since this time, owing to the introduction of clean air legislation and a decrease in total suspended particulates, fog climatology has changed considerably and many sites have experienced a decrease in fog frequency (Bendix 2002; Witiw and LaDochy 2008; Shi et al. 2008). Owing to the anthropogenic factors influencing the climate in urban areas, studies have demonstrated a decrease in the annual number of fogs in big agglomerations, which could be connected with the growth of cities and the resulting decrease in natural surfaces (Sachweh and Koepke 1995; Shi et al. 2008). However, in developing countries such as India, with rapidly growing industry and rising anthropogenic emissions, the frequency of fog events has increased and visibility has rapidly decreased over the past 30 years (Singh and Dey 2012; Syed et al. 2012).

This study investigates the climatic characteristics of fog occurrence in Latvia. In general, the climate in Latvia is influenced by its location in the northwest of the Eurasian continent (continental climate impacts) and by the proximity of the Atlantic Ocean (maritime climate impacts). A highly variable weather pattern is a result of the strong cyclonic activity over Latvia. These variable conditions over the territory contribute to differences in the regimes of air temperature and humidity (Avotniece et al. 2010; Klavins and Rodinov 2010; Lizuma et al. 2010) and to the spatial heterogeneity in the occurrence of fog. Fog can be classified by its formation through the processes of advection, radiative cooling or a mix of both processes (Ahrens 2007), and throughout the year, each of these processes can trigger the formation of fog in Latvia. Radiation fog forms most frequently in the morning before sunrise, during conditions of high atmospheric pressure and clear skies, when small water droplets form a layer of fog near the Earth's surface due to radiative cooling and condensation processes. It is common for radiation fog to dissipate gradually as the sun rises above the horizon. Advection fog forms in conditions of warm advection over an area; in particular, in Latvia, dense and persistent advection fogs form in the cold half of the year, when the ground is covered with snow. Frequently, advection fogs form due to a warm front moving over a colder area, and these can be accompanied by light precipitation. However, in specific, much rarer conditions, fog can also form under the influence of cold air advection. Such conditions can be observed in Latvia during the summer, when the inflow of cold air triggers the cooling and condensation of the still warm air near the Earth's surface, which can sometimes result in very dense fogs forming that spread over large areas. A common feature of both warm and cold advection fogs is their persistence in comparison to the more temporary radiation fogs and their ability to form during any time of the day. However, in some cases, radiation fogs can gain advective features and spread over large areas for a prolonged period of time.

High-quality observational data of various parameters describing fog are not available in many countries owing to sparse observation networks and, consequently, it is practically impossible to carry out a reliable and spatially coherent analysis of fog distribution based only on the surface observation data (Bendix 2002). However, satellite data can provide important information on the spatial distribution, dynamics and properties of fog (Cermak and Bendix 2008). Despite the importance of fog both from an applied research perspective and in respect to a better understanding of extreme climate events, there have been no studies of fog climatology carried out in the Baltic region. Therefore, the aim of this article is to analyse fog climatology, the trends of changes of fog events and the impact of atmospheric conditions (especially large-scale atmospheric circulation processes) on the occurrence of fog in Latvia, as well as to study the possibility of using satellite data for the climatic characterisation of fog occurrence.

2 Data sources and methods

Daily observation data of fog events and precipitation amount were provided by 14 major meteorological observation stations in Latvia (Fig. 1). The data obtained from the Latvian Environment, Geology and Meteorology Centre covered a 52-year period from 1960 to 2012. Fog is commonly classified by its intensity; however, there are differences in the classifications applied between countries. The classification of fog in Latvia follows the criteria established by the Stare Fire and Rescue Service, which marks three classes of fog: fog with horizontal visibility of 500–1,000 m, fog that reduces the visibility to 100–500 m and fog reducing visibility below 100 m, which is classified as very poor visibility (Latvian Environment, Geology and Meteorology Centre 2011).

In addition to the surface observations, satellite data were also used in the analysis. For the climatological characterisation of the occurrence of fog, satellite observations of low clouds for the period 2008–2013, provided by the Satellite Application Facility on Climate Monitoring (CM SAF), were used as an indicator of the most favourable sites for the formation of fog (CM SAF 2009). Monthly and seasonal

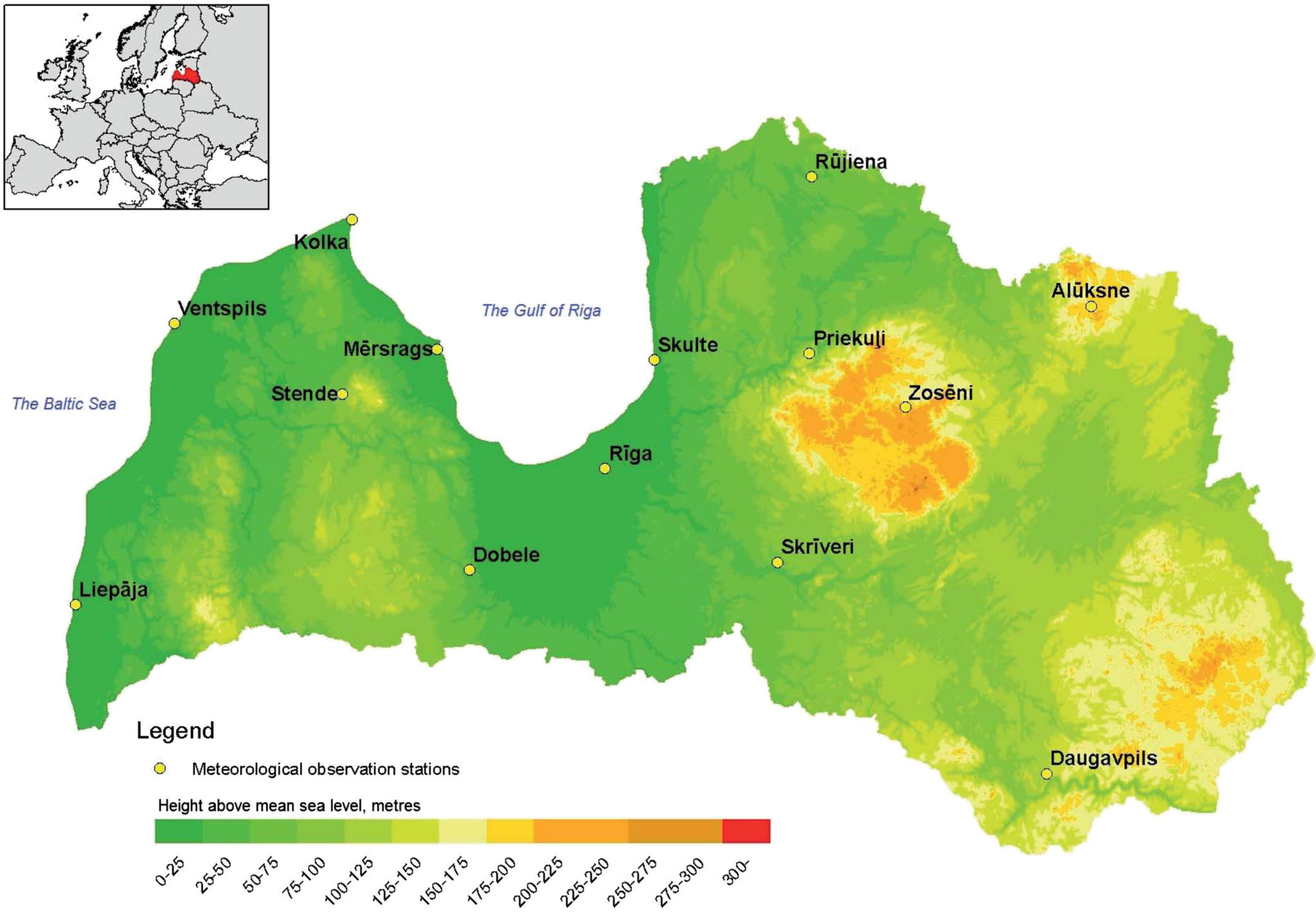


Fig. 1 Geographical locations of 14 major meteorological observation stations in Latvia. The *colours* of the map represent the height above mean sea level, with a maximum of 311.5 m in the eastern part of Latvia

mean amounts of low clouds were calculated from the satellite data with software tools CDO (*Climate Data Operators*) and R and were compared to the surface observation data.

For the characterisation of atmospheric conditions favourable for the occurrence of fog, 18 large-scale atmospheric circulation patterns for the Baltic Sea region, covering the period 1960–2002, were examined. The basis of this classification method of atmospheric circulation patterns was created by Baur, which formed the foundation for the 'Grosswetterlagen' of Hess and Brezowsky that was later reprocessed by Gerstengarbe and Werner (Gerstengarbe et al. 1999). The atmospheric circulation patterns used in this study were derived from modifications to the circulation classification of Gerstengarbe and Werner (Hoy et al. 2013) that have been made available for scientific research by the European Cooperation in Science and Technology Action 733. This classification approach is based on predefined circulation patterns determined according to the subjective classification of the so-called Central European Großwettertypes. It is assumed that these Großwettertypes are defined by the geographical position of major centres of action, and that the location and extent of frontal zones can be sufficiently characterised in terms of varying degrees of zonality, meridionality and vorticity of the large-scale sea level pressure field over Europe (COST733 2012). The abbreviations of circulation type names presented in this study consist of the first letters describing the direction from which the air flows, and the second part describes the synoptic system (cyclone or anticyclone), so, for example, the abbreviation SW-A stands for south-west anticyclonic flow.

Trends in the annual number of days with fog were determined by applying the nonparametric Mann–Kendall test (Libiseller and Grimvall 2002; Salmi et al. 2002). The Mann–Kendall test was applied separately to each variable at each site, at a significance level of $p \leq 0.05$. The trend was considered statistically significant if the test statistic was greater than 1.96 or less than −1.96.

3 Results and discussion

3.1 Climatic characteristics of fog occurrence in Latvia

Fog is a rather frequent weather phenomenon in Latvia, and it can be observed on 19–59 days a year on average (Fig. 2). The

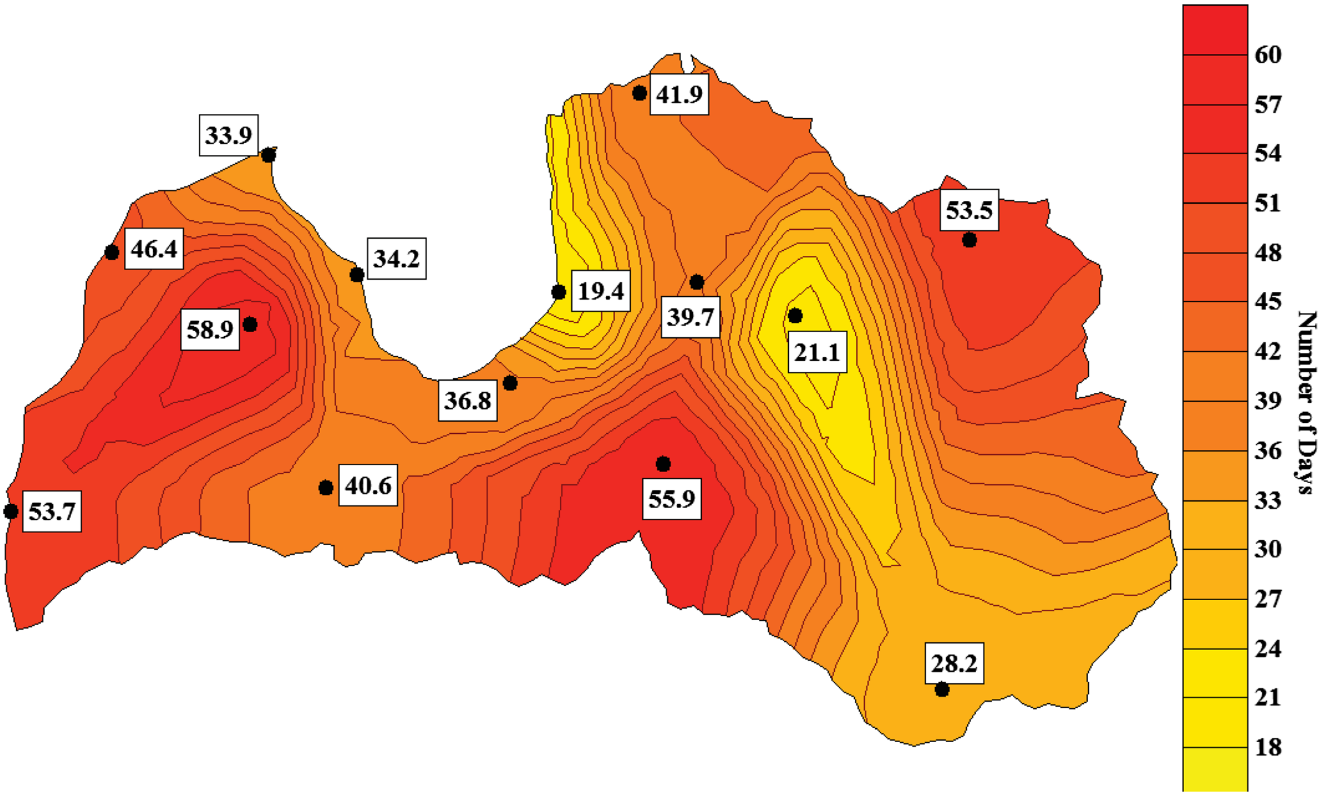


Fig. 2 Annual mean number of days with fog in Latvia during the period 1960–2012. The values over the country are represented by *interpolation on a triangular grid*

formation of fog is closely related to the local geographical features of a site, such as orography and slope exposure, proximity to the Baltic Sea and the Gulf of Riga and the different meteorological processes favourable to the development of fog; therefore, there are significant differences in the annual mean number of days with fog in different regions of Latvia. As a result, fog can be observed most commonly in the western areas of the upland regions of Latvia, while the fog is observed on the lowest number of days in the eastern areas of the uplands and in the coastal areas of the Gulf of Riga. Such a pattern of fog frequency represents the general mechanisms of humidity distribution in Latvia and also cloud formation and precipitation, due to prevailing westerly flows over the country. Overall, to the proximity to the Baltic Sea, fog frequency is greater in the western part of the country.

Figure 3 illustrates the long-term variation in fog frequency in Latvia. The range in the annual number of days with fog in Latvia varies from 0 days in Zoseni (1989) to 110 days in Aluksne (1960); additionally, the annual variations within each station are considerable. For 9 out of 14 observation stations, the data distribution is somewhat positively skewed. In general, the graph shows significant differences in the spatial and temporal distribution of the annual number of days with fog in Latvia.

The inter-annual variability of fog (Table 1) shows significant differences in the months with the maximum occurrence of fog between coastal and inland observation stations. In the inland stations, the maximum fog occurrence is during the second half of the year—between August and December. During the autumn months, radiation fogs form more frequently, while during winter and spring advection fogs gradually become more frequent. Therefore, in the coastal observation stations, the maximum frequency of fog occurs in spring—during March, April and May—when warm advection from the west triggers the formation of advective fogs.

Satellites are considered to be a powerful tool for the observation of fog, as satellite observations provide both wide spatial and temporal coverage, which is essential for the detection and characterisation of such a variable phenomenon. In essence, fog is very similar to low stratus clouds, and it differs from low clouds only by its base being located near the ground (World Meteorological Organization 1992); therefore, for the climatic characterisation of fog occurrence, it is possible to compare the surface observations of fog to the low cloud observations from satellites provided by the CM SAF. If the surface observations of fog and the satellite observations of low clouds in the autumn season (Fig. 4a) during a 6-year period are compared, one can see similar features. The greatest amount of low cloud (up to 47 %) can be observed in the south and west regions of Latvia, while in the coastal areas, the amount of low clouds is smaller. In the winter season, the low cloudiness in Latvia is smaller in general, and it does not

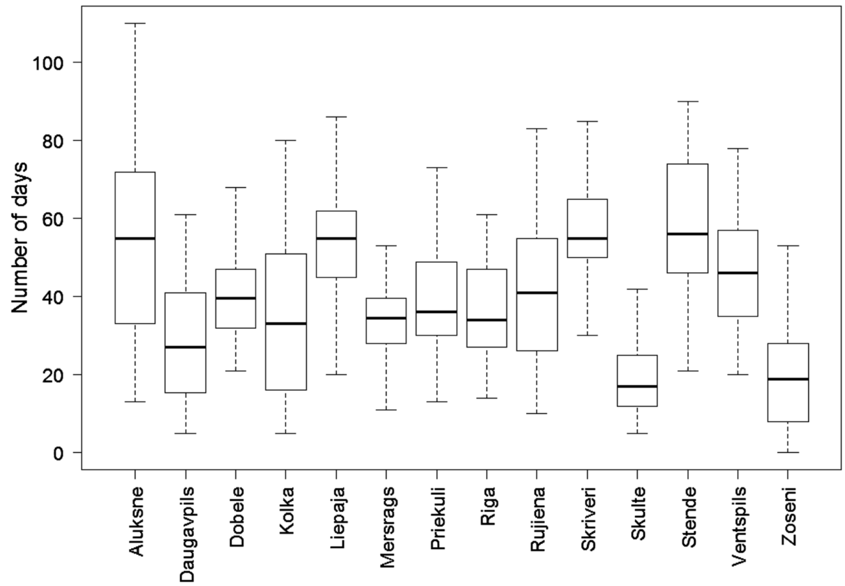


Fig. 3 Variations in the annual number of days with fog in Latvia during the period 1960–2012. The *bold lines* represent the median of the annual number of days with fog, the *upper* and *lower sides of the boxes* describe the upper and lower quartiles, the *whiskers* represent the greatest and smallest annual number of days with fog

exceed 42 % (Fig. 4b). During winter, a more expressed formation of fog is evident, in particular, over the west regions of Latvia, where it may be triggered by the influence of periodic thaws.

In spring, some differences in the low cloud and fog formation processes appear (Fig. 4c). In the western regions, where, under the influence of warm advection from the west, advection fogs form more frequently, the mean amount of low clouds is higher than in other parts of the country and reaches 40–42 %. However, at the same time, in the upland areas of Latvia, a gradual increase in the occurrence of radiation fog begins. In addition, during summer (Fig. 4d), the low cloudiness is greatest over the upland areas, where it reaches up to 40 % of the total cloudiness, owing to the dominance of radiation fogs.

The analysis of fog occurrence during the days with precipitation can also be an indicator of the formation process. As radiation fog commonly occurs in conditions of clear skies, there is usually no precipitation during days with radiation fog. However, in cases of very dense radiation fog, a very small amount of precipitation (up to 0.1–0.2 mm) can be caused by the fog itself. Advection fogs are usually associated with frontal systems, so such fogs are frequently accompanied by precipitation. Figure 5 illustrates the pattern of the

Table 1 Monthly mean number of days with fog during the period 1960–2012. The long-term monthly mean number of days with fog is presented, and for each observation station, the three months with the highest frequency of fog are highlighted in *pink*

	J	F	M	A	M	J	J	A	S	O	N	D
Aluksne	4.9	4.6	4.7	4.2	2.4	1.2	2.5	4.0	5.5	7.3	9.2	7.0
Daugavpils	1.5	2.0	2.4	1.8	2.0	1.3	1.9	3.3	4.3	4.5	3.1	2.6
Dobele	4.2	3.4	4.1	2.9	1.7	1.1	1.6	2.8	4.5	5.3	4.3	4.8
Kolka	2.7	3.3	5.4	5.9	4.6	2.1	1.7	1.9	1.9	2.3	2.6	2.0
Liepaja	3.9	4.6	6.5	7.3	7.1	5.2	3.7	3.7	2.8	4.1	3.7	4.4
Mersrags	2.3	2.4	3.6	4.5	3.4	1.8	2.8	3.6	3.2	3.2	3.2	2.3
Priekuli	3.9	3.9	3.8	3.2	2.7	1.3	2.2	3.8	4.2	4.5	4.8	4.8
Riga	3.3	3.3	3.8	3.0	2.3	1.4	2.3	3.0	3.5	4.2	5.0	4.4
Rujiena	3.6	3.7	3.7	3.1	2.2	1.7	3.0	4.8	5.0	5.2	4.8	4.5
Skriveri	5.2	4.5	4.5	3.1	2.4	2.2	3.5	6.2	4.8	7.3	7.1	6.8
Skulte	1.7	2.3	3.0	2.7	2.5	0.9	0.7	1.3	1.3	1.8	2.0	1.6
Stende	5.5	5.1	5.9	4.9	3.8	3.5	5.3	6.3	4.7	5.5	6.6	6.5
Ventspils	3.7	3.6	5.8	6.8	6.2	4.6	3.4	2.9	2.3	3.0	3.3	3.3
Zoseni	1.3	1.5	1.6	1.6	1.0	0.8	1.4	2.2	2.9	3.1	3.4	2.0

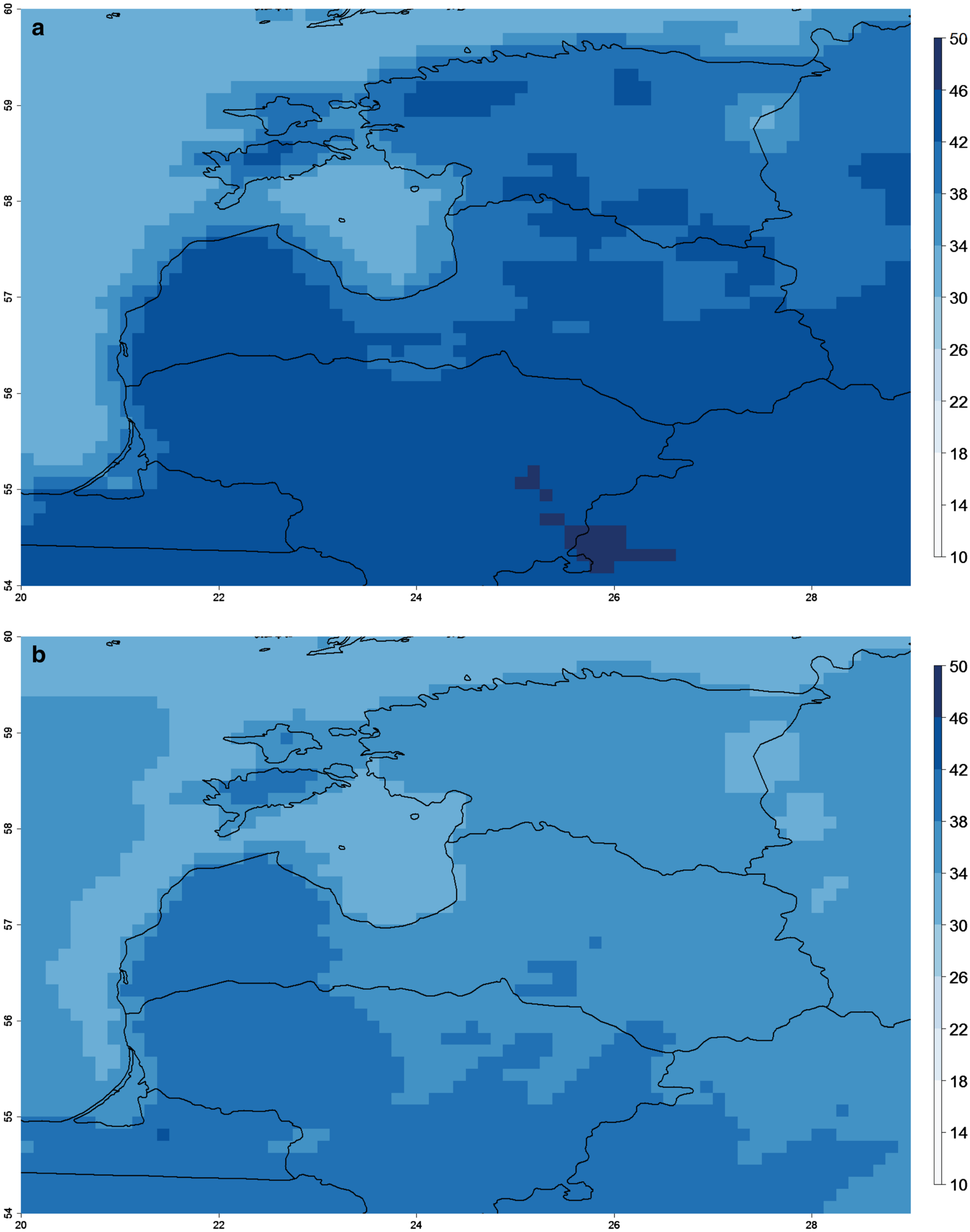
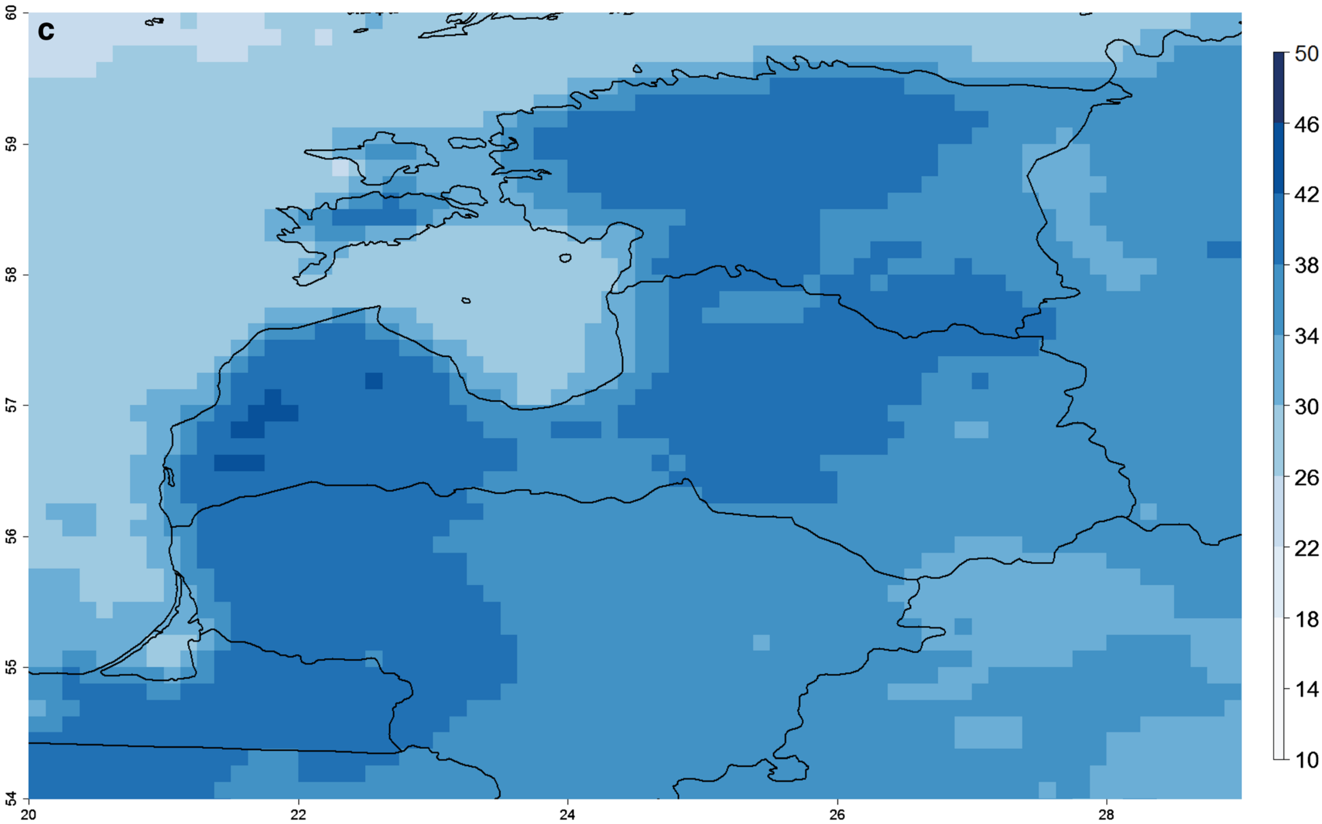


Fig. 4 Mean amount of low clouds (%) **a** in autumn (SON), **b** in winter (DJF), **c** in spring (MAM) and **d** in summer (JJA) during the period 2008–2013. Data obtained from the SEVIRI instrument onboard the MSG satellite with a spatial resolution of 15 × 15 km



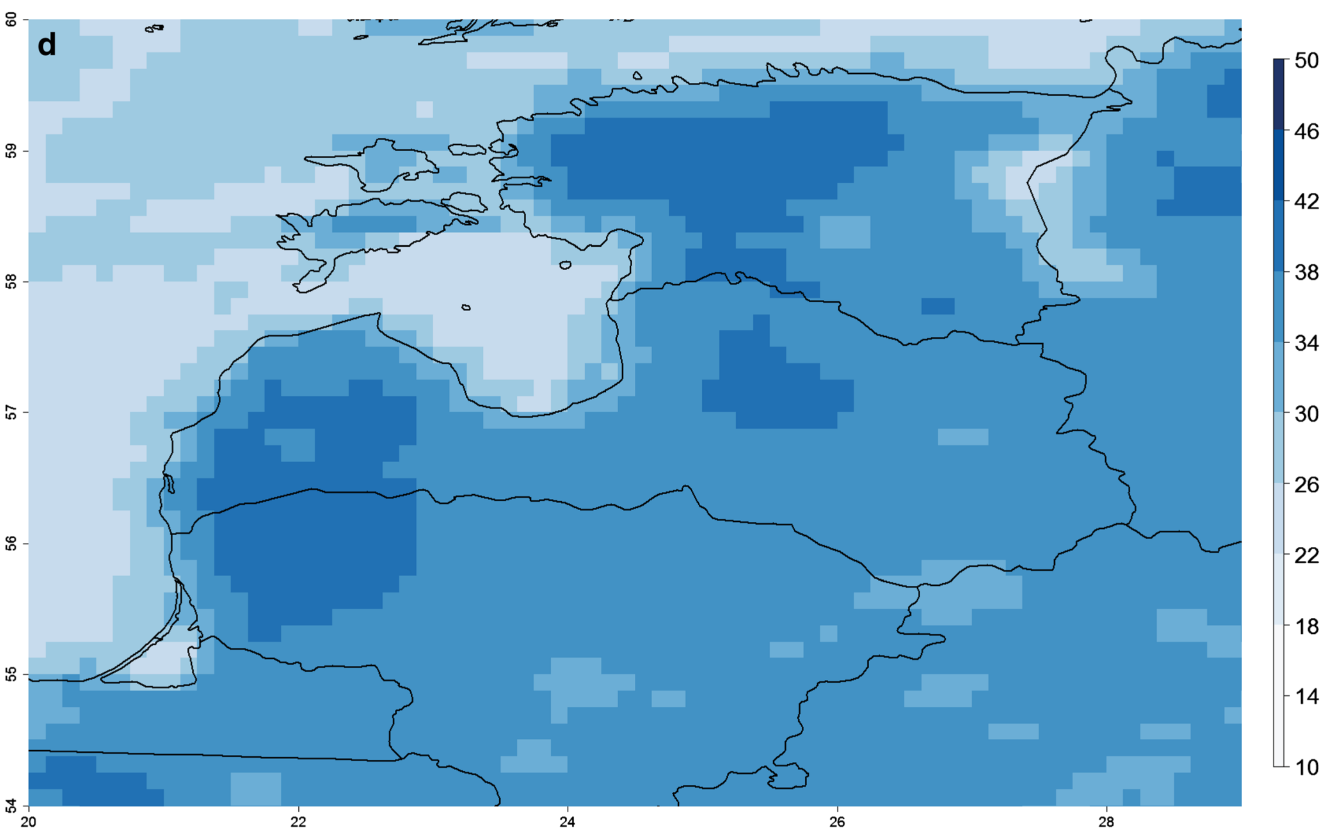


Fig. 4 (continued)

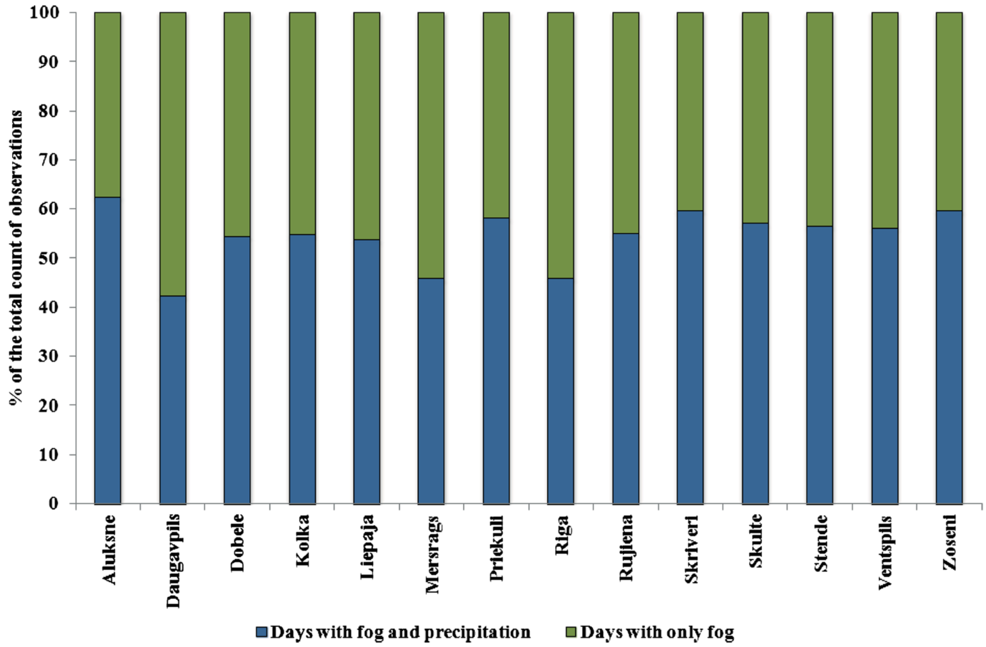


Fig. 5 The formation of fog on days with precipitation during the period 1960–2012. The number of fog on days with total precipitation of 0.1 mm or greater were counted and presented as a percentage of the total number of days with fog. The percentage of days with fog only is shown in *green* and the days when fog was accompanied by precipitation is shown in *blue*

formation of fog during days with precipitation. Overall, in Latvia, days with fog occurring together with precipitation predominate and consequently it is probable that advection fogs are, in general, more frequent. It is only in Mersrags, Riga and Daugavpils that most of the observed fogs occur during days with no precipitation, which could be associated with the specific local environmental factors of these observation stations. For example, at the Daugavpils observation station, which is located in the valley of the river Daugava, the formation of valley fogs could be a significant influence. In the capital city of Riga, air pollution with aerosols and particulate matter could be a reason for the higher frequency of radiation fog, while in the observation station of Mersrags, fog with no precipitation can be observed because of cold advection from the Gulf of Riga.

The annual number of days with fog in Latvia has decreased significantly during the past 53 years (Fig. 6). The stable decreasing tendency from 1960 to 1980 was followed by a more significant decrease during the beginning of the 1990s that could be associated with the rapid decrease in the industrial activities in the country. However, during the past decade, the frequency of fog has increased slightly.

Table 2 contains the results of the seasonal and annual trend analysis of fog frequency, performed by applying the Mann–Kendall test. The observed decrease in fog frequency is evident in all 14 meteorological observation stations, and there

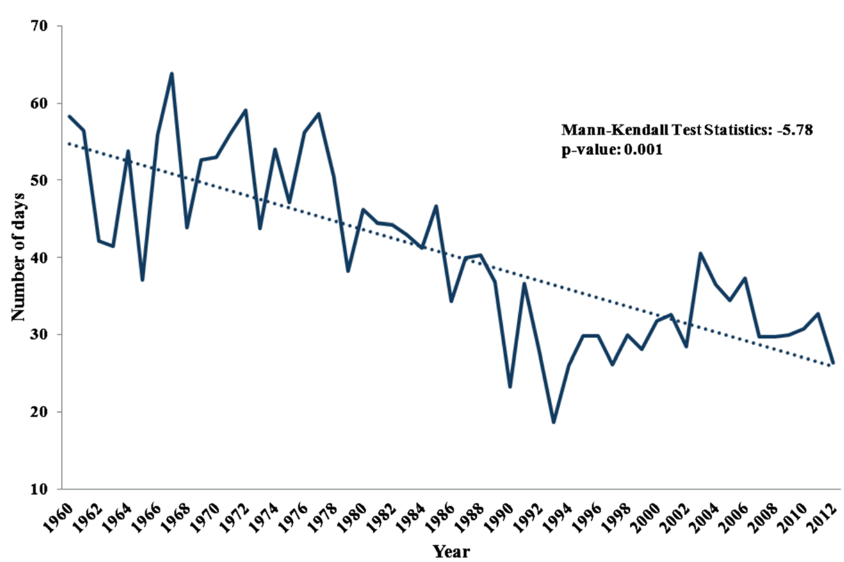


Fig. 6 Time series showing the annual number of days with fog in Latvia during the period 1960–2012. The annual mean number of days with fog over Latvia was calculated as the mean of data from 14 observation stations, and the Mann–Kendall test was applied at a significance level of 0.001 %

Table 2 The long-term trends of changes in the seasonal and annual number of days with fog in Latvia (Mann–Kendall test statistics) during the period 1960–2012. The statistically significant values are highlighted in bold

	Winter (DJF)	Spring (MAM)	Summer (JJA)	Autumn (SON)	Annual
Aluksne	**−5.09**	**−5.4**	**−3.87**	**−4.88**	**−6.59**
Daugavpils	**−5.3**	**−4.96**	**−4.41**	**−4.34**	**−6.42**
Dobele	**−2.81**	**−3.67**	**−2.26**	−1.93	**−3.71**
Kolka	**−4.73**	**−3.7**	**−3.45**	**−3.85**	**−4.15**
Liepaja	**−2.92**	−1.91	−0.86	−1.89	**−3.01**
Mersrags	**−2.84**	−0.67	−1.18	−1.24	**−2.44**
Priekuli	**−3.48**	**−2.85**	**−3.31**	**−2.15**	**−4.58**
Riga	**−1.99**	**−3.02**	**−4.22**	**−2.94**	**−4.28**
Rujiena	**−4.32**	**−4.86**	**−6.17**	**−4.18**	**−6.35**
Skriveri	**−2.47**	−1.71	**−3.06**	**−1.96**	**−4.01**
Skulte	**−2.82**	**−3.22**	**−4.3**	**−4.29**	**−5.08**
Stende	**−2.98**	**−3.46**	**−4.07**	**−3.13**	**−5.15**
Ventspils	**−3.33**	**−2.19**	**−2.21**	−1.49	**−4.48**
Zoseni	**−2.75**	**−2.54**	**−2.91**	**−2.66**	**−3.24**
Overall in Latvia	**−4.34**	**−3.41**	**−5.2**	**−4.08**	**−5.78**

has been a significant decrease in the number of days with fog across all seasons in most of the stations; however, the most significant changes have been observed in the winter. At the same time, in some stations in the western part of the country (Liepaja, Mersrags, Ventspils, Skriveri, Dobele) the decrease in fog frequency during spring, summer and, especially autumn, has not been significant.

Previous studies have shown that there has been a significant increase in the minimum and maximum temperatures in Latvia (Avotniece et al. 2013) that are especially pronounced

Table 3 Pearson correlation coefficients between the mean seasonal and annual minimum and maximum air temperatures and the number of days with fog over the period 1960–2012. The coloured cells show moderate correlation (0.3…0.5 for positive and −0.3…−0.5 for negative correlation), but strong correlation (0.5…0.8 for positive and −0.5…−0.8 for negative correlation) is highlighted in bold

Observation Station	Summer (JJA)		Autumn (SON)		Winter (DJF)		Spring (MAM)		Annual	
	T_{min}	T_{max}	T_{min}	T_{max}	T_{min}	T_{max}	T_{min}	T_{max}	T_{min}	T_{max}
Aluksne	-0.25	-0.33	0.02	0.00	-0.12	-0.11	-0.09	-0.27	-0.36	-0.37
Daugavpils	0.03	0.00	0.04	0.16	-0.13	-0.12	-0.07	-0.23	-0.34	-0.29
Dobele	0.32	0.19	0.40	0.47	0.06	0.01	0.35	0.31	0.32	0.32
Kolka	-0.37	-0.45	0.05	0.06	-0.26	-0.27	-0.29	-0.46	-0.47	**-0.50**
Liepaja	-0.33	-0.16	0.06	0.11	0.01	-0.03	-0.24	-0.39	-0.29	-0.34
Mersrags	-0.01	-0.01	0.19	0.37	-0.07	-0.08	0.06	-0.10	-0.21	-0.16
Priekuli	-0.11	-0.15	0.09	0.13	-0.08	-0.09	-0.04	-0.14	-0.29	-0.22
Riga	-0.18	-0.40	0.13	0.18	-0.12	-0.15	-0.07	-0.17	-0.24	-0.31
Rujiena	-0.20	-0.36	0.19	0.16	-0.05	-0.08	0.07	-0.26	-0.23	-0.33
Skriveri	-0.15	-0.48	0.13	0.24	-0.04	-0.01	0.08	-0.11	-0.09	-0.09
Skulte	-0.34	-0.27	-0.08	-0.04	0.00	-0.03	-0.37	**-0.50**	-0.42	-0.43
Stende	-0.13	-0.25	0.17	0.21	-0.08	-0.09	-0.09	-0.44	-0.27	-0.35
Ventspils	-0.47	-0.37	0.08	0.12	-0.24	-0.22	-0.30	-0.28	**-0.52**	-0.49
Zoseni	0.01	0.07	0.19	0.25	-0.17	-0.17	-0.25	-0.11	-0.23	-0.16
Overall in Latvia	-0.25	-0.36	0.18	0.24	-0.11	-0.12	-0.12	-0.32	-0.37	-0.39

in the winter and spring, while in the autumn, the changes of temperature have been the least significant. The trend analysis of fog and air temperature changes shows some similar signs when compared; the most significant change in fog frequency has also been observed in the winter, but the least significant change has been observed in the autumn (see Table 2). Therefore, it might be suggested that the long-term decreasing tendency in fog frequency in Latvia could be associated also with the increase in air temperature. However, the correlation coefficients between the seasonal and annual mean minimum and maximum temperatures and the number of days with fog do not show a consistent pattern over the country (Table 3). The lowest correlations between the frequency of fog and values of air temperature are found in autumn and winter, which are the seasons with the least (autumn) and most (winter) significant changes in fog frequency. Therefore, there might be other significant meteorological factors that favour the formation of fog during these seasons. The strongest correlations between air temperature and fog frequency can be found in spring and especially summer, when in most cases, there is a negative correlation—increasing temperatures are associated with fewer fog cases. This pattern is also evident for the correlations between the annual mean temperatures and number of days with fog. However, in some seasons (see autumn) and observation stations (see observation station Dobele), there has been a different relation—increasing temperatures correlate with the number of fog positively. Therefore, it can be concluded that the changes in air temperature are only one of the factors triggering the decrease in fog frequency, and changes in other factors, such as humidity, availability of condensation nuclei and atmospheric circulation, could have a stronger effect on the spatial and temporal distribution of fog.

3.2 Atmospheric circulation processes associated with the formation of fog in Latvia

The characteristics, transformation and trajectories of an air mass reaching a certain location, as well as its specific weather conditions, are mostly determined by large-scale circulation processes in the atmosphere (Jaagus 2006). The movement of an air mass is mainly dependent on the location of large-scale synoptic systems and the corresponding air flows in the atmosphere (Moberg et al. 2003). For these reasons, 18 large-scale atmospheric circulation patterns following the GWT (Großwettertypes) classification for the Baltic Sea region were examined in this study (COST733 2012). With the help of these circulation patterns, the character of large-scale atmospheric circulation and the types of synoptic systems determining the weather conditions over Latvia was derived for the days with fog during the period 1960–2002.

Fog is a frequent weather phenomenon in Latvia, and, as described above, its occurrence over the country is closely related to local geographical features; however, the conditions of air humidity and predominant pressure systems also play an important role. In addition, the long-term changes in atmospheric circulation conditions have a significant effect on climatic conditions (Cahynova and Huth 2010). As an example, the observed increase in the persistence of atmospheric circulation patterns since the 1980s could have led to changes in climatic conditions in the boundary layer, such as the increase in the persistence of both heat and cold waves (Kysely 2008)

Although meteorological conditions in Latvia are strongly influenced by cyclonic activity, the most favourable conditions for the formation of fog have been observed during the days when a high-pressure area determines the weather conditions across the country.

Table 4 The three most dominant atmospheric circulation types occurring on the days with fog during the period 1960–2002, presented as a percentage of the total number of days with fog

Observation station	Dominant atmospheric circulation types, frequency of their occurrence (% from the total number of observations)		
Aluksne	W-A	SW-C	SW-A
	12.40 %	11.27 %	10.97 %
Daugavpils	W-A	SW-A	S-A
	15.93 %	15.49 %	8.22 %
Dobele	SW-A	W-A	S-A
	15.42 %	11.53 %	11.53 %
Kolka	SW-A	W-A	S-C
	11.93 %	9.71 %	9.65 %
Liepaja	W-A	SW-C	SW-A
	13.64 %	11.58 %	10.62 %
Mersrags	SW-A	W-A	S-A
	14.07 %	11.80 %	9.80 %
Priekuli	W-A	SW-A	W-C
	14.71 %	10.83 %	8.57 %
Riga	W-A	SW-A	SW-C
	14.84 %	13.99 %	8.27 %
Rujiena	W-A	SW-A	W-C
	13.80 %	13.46 %	9.28 %
Skriveri	W-A	SW-A	W-C
	16.02 %	11.97 %	10.38 %
Skulte	W-A	SW-A	W-C
	14.50 %	12.79 %	9.87 %
Stende	W-A	SW-A	W-C
	13.62 %	10.51 %	8.97 %
Ventspils	W-A	SW-A	SW-C
	13.60 %	11.53 %	10.94 %
Zoseni	SW-A	W-A	SW-C
	13.39 %	10.98 %	7.85 %

Table 4 contains information on the most favourable atmospheric circulation patterns occurring on days with fog in Latvia during the period 1960–2002. The most common conditions for the formation of fog in Latvia are the days with westerly or south-westerly air flow and, less often, southerly air flow, with anticyclonic conditions prevailing over the area. In such conditions, with a warm and moist air advection in the western part of an anticyclone, both radiation and advection fogs can form. However, a significant proportion of fogs in Latvia also forms in cyclonic conditions—forming with southerly, south-westerly and westerly cyclonic flows. In these cases, the formation of fog is usually associated with frontal systems, and such fogs can be called frontal fogs. However, within southerly and south-westerly cyclonic flows, the formation of fog may also not be associated with frontal systems, but instead with the warm sector of a cyclone where, in conditions of increased moisture, warmth and light winds, dense and persistent advection fogs can form.

As one can see from Table 1, there are two maxima in fog frequency in Latvia; a maximum in spring is evident in the coastal stations while the maximum in autumn is characteristic for the inland stations. The most favourable conditions for the formation of fog (Table 5) in spring in the inland stations are south-westerly and westerly anticyclonic flows, but in the coastal stations, fogs can form in westerly and south-westerly flows during a predominance of both cyclonic and anticyclonic conditions. During springtime, all of these weather patterns are associated with an advection of warm air over cool and, in many cases, still snow-covered land, thus triggering the formation of persistent advective fogs. In autumn, in the whole territory of Latvia, westerly and south-westerly anticyclonic flows are the most favourable conditions for the

Table 5 The three most dominant atmospheric circulation types occurring on days with fog in spring (MAM) and autumn (SON) during the period 1960–2002, given as a percentage of the total number of days with fog during these seasons

Observation station	Dominant atmospheric circulation types and the frequency of their occurrence (% from the total number of observations)					
	Spring			Autumn		
Aluksne	SW-C	SW-A	W-A	W-A	SW-C	SW-A
	10.71 %	10.34 %	8.83 %	13.66 %	12.08 %	11.98 %
Daugavpils	SW-A	S-A	W-A	W-A	SW-A	S-A
	15.47 %	10.43 %	9.35 %	19.73 %	17.77 %	9.57 %
Dobele	SW-A	S-A	SE-A	SW-A	S-A	W-A
	12.75 %	11.88 %	8.12 %	16.25 %	13.75 %	12.97 %
Kolka	SW-A	SW-C	S-C	SW-A	W-A	S-C
	10.23 %	9.83 %	9.02 %	16.83 %	15.56 %	13.02 %
Liepaja	SW-C	W-C	W-A	W-A	SW-A	SW-C
	12.88 %	12.21 %	10.41 %	20.39 %	16.45 %	11.84 %
Mersrags	S-A	SW-A	E-C	SW-A	W-A	S-A
	10.52 %	9.69 %	9.28 %	20.20 %	15.66 %	11.11 %
Priekuli	SW-A	W-A	W-C	W-A	SW-A	S-A
	10.64 %	9.22 %	8.98 %	16.36 %	13.83 %	7.25 %
Riga	SW-A	W-A	A center	W-A	SW-A	SW-C
	13.16 %	10.63 %	8.35 %	18,79 %	15.43 %	9.93 %
Rujiena	SW-A	W-A	W-C	W-A	SW-A	SW-C
	12.77 %	9.88 %	9.16 %	16.37 %	15.77 %	9.76 %
Skriveri	W-A	SW-A	SW-C	W-A	SW-A	SW-C
	11.83 %	11.37 %	11.37 %	16.94 %	14.54 %	10.16 %
Skulte	W-A	W-C	SW-A	SW-A	W-A	SW-C
	10.54 %	10.26 %	9.69 %	18.55 %	18.15 %	10.08 %
Stende	W-A	SW-A	SW-C	W-A	SW-A	S-A
	11.06 %	10.59 %	9.19 %	16.42 %	13.51 %	8.48 %
Ventspils	W-C	SW-C	W-A	W-A	SW-A	SW-C
	11.78 %	11.41 %	10.55 %	21.60 %	18.40 %	10.93 %
Zoseni	SW-A	E-A	SW-C	SW-A	S-A	W-A
	11.67 %	9.44 %	8.33 %	17.13 %	11.59 %	10.33 %

formation of fog when, owing to radiative cooling, radiation fogs are more frequent. It is evident that the formation of fog in Latvia is mainly associated with the inflow of warm and moist air from the south-west and west, with anticyclonic conditions being the most favourable for fog formation.

4 Conclusions

Fog is a frequent weather phenomenon in Latvia and is characterised by a significant spatial and temporal variability in its occurrence. Fog most commonly forms owing to the inflow of warm and moist air from the south-west and west in conditions of anticyclonic circulation over the area. However, the general pattern of fog frequency over the country is mainly associated with the distribution of humidity; consequently, owing to the prevailing westerly flows, fog is more frequent in the western part of the upland areas, while in the eastern (leeward) part of the uplands, the frequency of fog is considerably lower. Fog has also been observed more frequently in the western part of the country, where the impact of the maritime climate of the Baltic Sea is the greatest. Although a significant majority of the observed fog cases have been associated with anticyclonic conditions, fog is commonly accompanied by light precipitation; this could be an indicator of the dominance of advective fog formation processes in the country.

Since the middle of the past century, the annual mean number of days with fog has decreased significantly; this could be associated with both the gradual decrease in industrial activities and the resultant improvements of air quality and the observed increase in air temperature. The warming has been the most significant in the winter and this might have triggered a decrease in the formation of advective fogs, which in this season usually form when warm and moist air flows over a cool or snow-covered surface. However, in spite of this observed decrease, fog is still one of the most dangerous and harmful meteorological phenomena affecting aviation in Latvia.

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