CURRENT CHANGES AND FUTURE PROJECTIONS OF SNOW COVER PARAMETERS IN LITHUANIA

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The objective of this research is to analyse the dynamic of snow cover parameters (number of days with snow cover and maximum snow depth) during observation period (1961–2015) in Lithuania and to create projections for 21st century according to different climate scenarios. For this purpose, data from the 18 Lithuanian meteorological stations were used. The magnitude of linear trends was determined and the statistical significance of the trend values evaluated using the non-parametric Mann-Kendall test. The relationships between snow cover and other meteorological parameters (mean air temperature, precipitation) were also investigated. Climate projections for 21st century are based on CMIP5 (Coupled Model Intercomparison Project Phase 5) models outputs according to four Representative Concentration Pathways (RCP). The multiple regression models were built to create snow cover projections for 21st century. The decrease in number of days with snow cover during the study period was determined throughout the entire territory of Lithuania. The changes were statistically significant in the large part of the country. Maximum snow depth also decreased in majority of country area, however changes were not statistically significant. It is very likely that current tendencies will remain in the future and the values of snow cover parameters will decrease in the 21st century according to all analysed climate scenarios.

Keywords: snow cover, Lithuania, climate projections

INTRODUCTION

The snow cover as a rapidly changing natural surface becomes a very important climate indicator in the middle and high latitudes of the Northern hemisphere. The most significant snow cover parameters (snow cover duration and maximum snow depth) depend on air temperature as well as on other important meteorological indicators (precipitation, wind speed, etc.). On the other hand, snow cover is not only the result of winter conditions but also one of the climate-forming factors (Cohen and Entekhabi, 2001). Analysis of snow cover changes during the observation period reveals major features of the climate trends (Lemke et al., 2007) and also is a very important issue in modelling of the climate variability in the 21st century (Frei and Gong 2005; Jylhä et al., 2008; Alexander et al., 2010).

Climate change has a major impact on snow cover parameters and, as a rule, results in its shorter duration, lower thickness, the later date of snow cover formation and earlier snow melting (Brown et al., 2009; Groisman et al. 2006). Due to the global warming, snow cover has significantly decreased in the Northern hemisphere over the last several decades (Kim, 2013). Especially large changes were observed at the second half of cold season. It is likely that similar tendencies will remain in the Northern Hemisphere up to the end of the 21st century. Snow covered areas will decline by 7% according to RCP2.6 scenario and by 25% according to RCP8.5 scenario in spring (Collins et al., 2013). In 1970-2004 snow cover has declined in large parts of Northern and Eastern Europe (Lemke et al., 2007), and it is predicted that snow cover will decrease in the future (Jylhä et al., 2008).

Snow cover parameters are highly dependent on atmospheric circulation. The strength and location of large-scale pressure centres have a great influence on European weather, especially during the winter season. During the positive phase of the NAO/AO the duration and thickness of the snow cover in the Baltic Sea region is smaller (Bednorz, 2002; Draveniece, 2009; Falarz, 2007; Jaagus, 2006; Klavins and Rodinov, 2010). The dynamic of snow cover parameters and its relation with atmospheric circulation in Lithuania were analysed in several works (Rimkus and Stankunavichius. 2002; Rimkus et al., 2014).

Snow cover is a key indicator of Lithuanian climatic conditions as well. On average in the east and in the north of country the first snow cover forms in the middle of November while in the coastal area at the end of this month. However, the permanent snow cover due to frequent thaws forms much later, after 3-4 weeks. When permanent snow cover forms its thickness gradually increases. The most intensively snow cover grows in the late December and January, when the most intense cyclonic activity occurs. The snow cover depth maximum values usually reaches in the second-third decade of February. In extremely snowy winters, the maximum thickness of the snow cover in highlands reaches 70-90 cm. After that snow cover usually start to melt and permanent snow cover disappear until the last decade of March. However, in some years snow cover can stay up until the middle of April, while short-term snow events can occur even in the beginning of May. On the other hand, over the last decades permanent snow cover has become increasingly uncommon.

The aim of this work is to analyse the dynamics of snow cover parameters in Lithuanian as well as to create projection for 21st century based on different climate scenarios.

MATERIALS AND METHODS

This study analyses the number of days with snow cover, the number of days with snow cover depth above 10 and 20 cm and the maximum snow depth (cm) in 18 Lithuanian meteorological stations during the winters of 1961-2015. A day with snow cover is considered when snow covers more than 50 percent of the surrounding area. The maximum snow depth is the highest daily value during the winter season. Relationships between the snow cover parameters and the average winter season's air temperature were investigated.

Analysis of long-term changes of snow cover parameters was performed. The magnitude of linear trends was determined and the statistical significance of the trend values evaluated using the non-parametric Mann-Kendall test. The changes were considered as statistically significant when $p<0,05$.

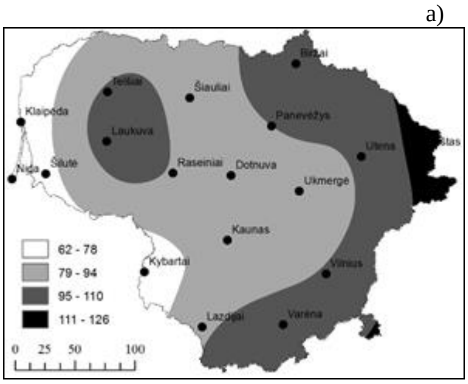
The projections of snow cover parameters changes in 21st century were created. Climate projections are based on CMIP5 (Coupled Model Intercomparison Project Phase 5) models outputs according to four Representative Concentration Pathways (RCP). The multiple regression models were built to create snow cover projections for 21st century. Monthly air temperature and precipitation amount values were used as independent variables during observation period. In most of multiple regression models the values of the multiple correlation *R* were above 0,8 for day with snow cover and above 0,6 for maximum snow depth.

Air temperature and precipitation projections for 21st century were derived from KNMI (Royal Netherlands Meteorological Institute) Climate Explorer database. Projections of snow cover parameters according to RCP2.6, RCP4.5, RCP6.0 and RCP8.5 were created for three different periods: 2016 – 2035, 2046 – 2065 and 2081 – 2100.

RESULTS

The average number of days with snow cover in the period of 1981-2010 in Lithuania varies from less than 70 days in the western and southwestern part to more than 110 days in the eastern part of the country (Fig. 1a). The average maximum snow cover thickness in Lithuania ranges from 10-20 cm in the west to > 30 cm in the southeast (Fig. 1b). The main factors that define distribution of snow cover parameters are distance from the Baltic Sea and absolute height of the location. The snow cover duration increases with distance from the sea, while the maximum snow thickness is recorded in highlands, where higher precipitation amount falls in the winter.

a)



b)

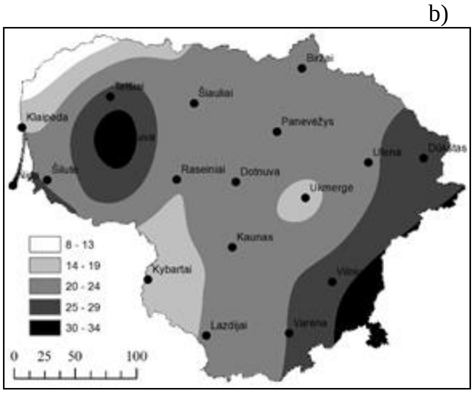


Figure 1. Mean number of days with snow cover (a) and maximum snow depth (b) in Lithuania in 1981-2010.

The decrease in number of days with snow cover was recorded in all Lithuanian meteorological stations during the period from 1961 to 2015. In average annual snow cover duration decreased by 4 days per decade (Fig 2). In 14 (from 18) meteorological stations changes were statistically significant. Territorial differences of changes are quite small, however, slightly higher negative changes were determined in the eastern part of the country.

The largest decrease in snow cover duration was recorded in the second half of the cold season (Fig. 2). In February and March negative changes were statistically significant in almost all meteorological stations while in January such changes were statistically significant in half of investigated areas. In other months changes were insignificant. Small increase in snow cover duration was observed in October.

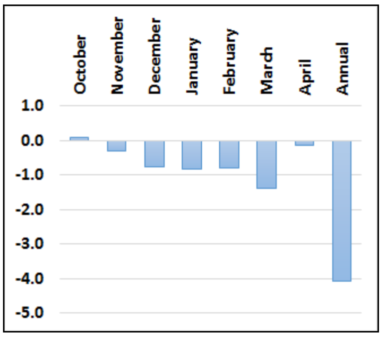


Figure 2. Changes of snow cover duration (days/ per decade) in Lithuania in 1961-2015

It has been determined that on average the number of days with snow cover thickness above 10 cm decreased by 3 days per decade, while a number of days with a snow depth above 20 cm reduced by 2 days (Fig. 3). Due to a very high interannual variability of this indicator such changes are statistically insignificant.

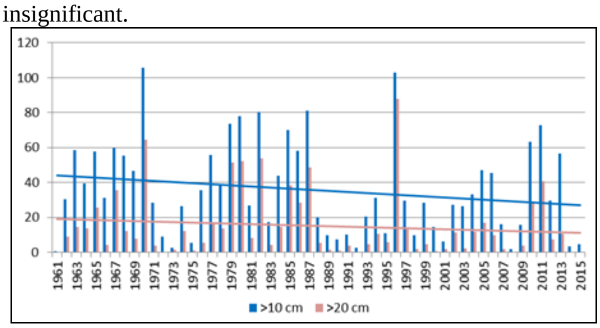


Figure 3. Dynamic of the average number of day with snow cover depth above 10 and 20 cm in Lithuania in 1961-2015.

Although the snow cover duration decreased significantly, the annual maximum snow thickness in Lithuania has not changed a lot. In average, an insignificant 0,2 cm decrease per decade was recorded (Fig. 4). Only in two meteorological stations statistically significant negative changes were determined. The largest decrease in snow depth was observed in February and March.

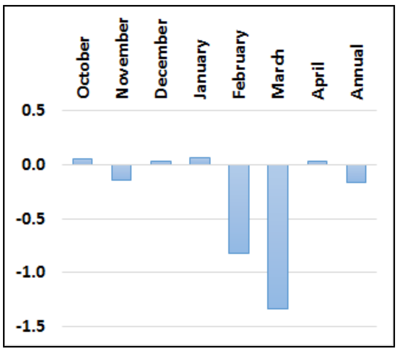


Figure 4. Changes of snow cover depth (cm/ per decade) in Lithuania in 1961-2015

The snow cover characteristics are mostly predetermined by the average winter temperature. There is a strong inverse relationship between the average air temperature and number of days with snow cover (in all meteorological stations the linear correlation coefficients between mentioned characteristics was below -0.85) and to a lesser extent with snow thickness. The maximum snow depth can form during one heavy snowfall and therefore this parameter is less dependent on general winter conditions. Thus, the changes in snow parameters are determined by air temperature rise in Lithuania in recent decades (Mickiewicz and Rimkus 2013).

It was discovered that the number of days with snow cover during the winter mostly depends on the temperature of December and February. In 88% of cases, the mean average or maximum temperature of both months was included in the multiple regression equation as independent variables. The temperature of December determines the beginning of permanent snow cover formation, while air temperature in February determines how long the snow cover will last in the spring. At the same time, the effect of precipitation amount on snow cover duration is negligible. According to all climate change scenarios, the number of days with snow cover in Lithuania will decrease. According to the predictions that until 2035 the number of days with snow cover will decrease by 14-15 (depending on the RCP scenario), until 2065 – by 18-34, and until 2100 – by 17-56 days to compare with reference period of 1986-2005 (Fig. 5).

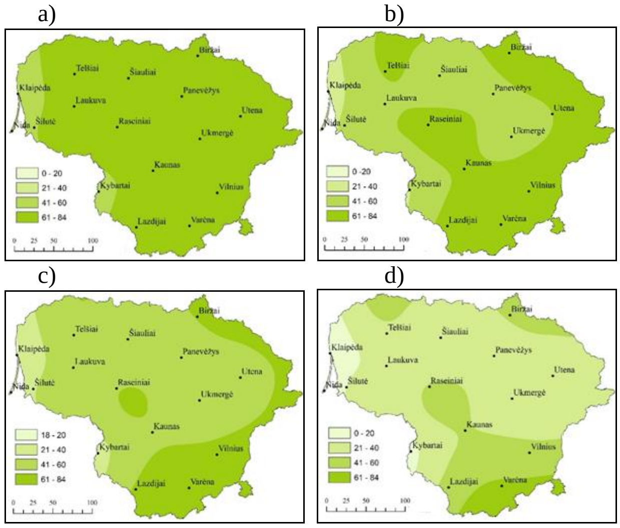


Figure 5. Projected changes of snow cover duration in 1986-2005 in Lithuanian according to RCP2.6 (a), RCP4.5 (b), RCP6.0 (c) and RCP8.5 (d) climate scenarios.

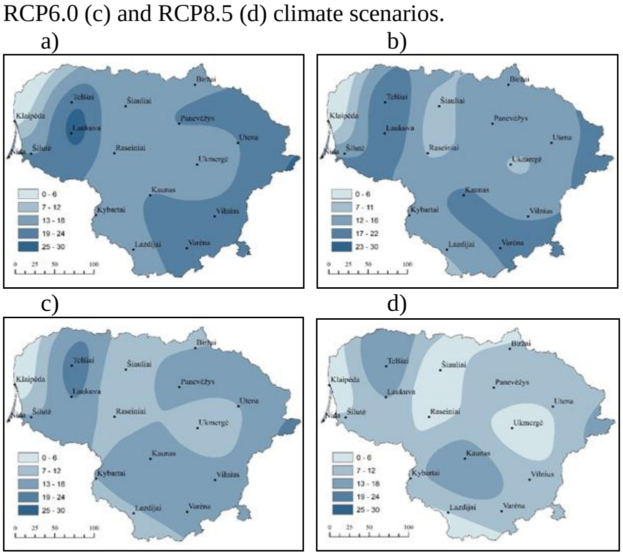


Figure 6. Projected changes of snow cover depth in 1986-2005 in Lithuanian according to RCP2.6 (a), RCP4.5 (b), RCP6.0 (c) and RCP8.5 (d) climate scenarios.

The annual maximum snow cover thickness in Lithuania was also mostly influenced by air temperature in December (in 88% of cases the mean average, maximum or minimum temperature of this month was included in multiple regression equations) and February (81%). Unlike days with snow cover, the amount of precipitation influence the maximum snow cover. The precipitation values in different months were independent variables in multiple regression equations in 38% of cases. It was estimated that the maximum snow cover thickness in Lithuania in 21st century will decrease. It is predicted that until 2035 the maximum snow cover thickness will decrease by 4-5 cm (depending on RCP scenario); until 2065 – by 5-9 cm, and until 2100 – by 5-14 cm (Fig. 6).

The smallest changes in snow cover indices are predicted according to RCP2.6, while the largest ones are predicted according to RCP8.5 scenario. The largest negative changes in number of days with snow cover are expected in the western part of the country, and the smallest in the East. On the coastal area the largest decrease of snow cover depth is also very likely.

CONCLUSION

The decrease of snow cover parameters' values was observed in the majority of the territory of Lithuania in 1961-2015. On average, the number of days with snow cover decreased by 4 days per decade. The largest statistically significant negative changes were observed in February and March. The number of days with snow cover thickness above 10 and 20 cm decreased by three and two days per decade respectively. A statistically insignificant decrease in maximum snow cover depth (-0.2 cm per decade) was determined.

The decrease in the number of days with snow cover and maximum snow depth during the 21st century is very likely throughout the whole territory of Lithuania. The largest changes at the end of the 21st century can be expected by the RCP8.5 climate scenario while the lowest changes predicted by RCP2.6. The most significant negative changes are foreseen in the western part of Lithuania.

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