

## Methodology of Lithuanian climate atlas mapping

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**Abstract:** Climate atlases summarize large sets of quantitative and qualitative data and are results of complex analytical cartographic work. These special geographical publications summarize long term meteorological observations, provide maps and figures which characterise different climate elements. Visual information is supplemented with explanatory texts. A lot of information on short and long term changes of climate elements were provided in published Lithuanian atlases (Atlas of Lithuanian SDR, 1981; Climate Atlas of Lithuania, 2013), as well as in prepared but unpublished Lithuanian Atlas (1989) and in upcoming new national atlas publications (National Atlas of Lithuania. 1<sup>st</sup> part, 2014). Climate atlases has to be constantly updated to be relevant and to describe current climate conditions. Comprehensive indicators of Lithuanian climate are provided in different cartographic publications. Different time periods, various data sets and diverse cartographic data analysis tools and visualisation methods were used in these different publications.

**Keywords:** Climate atlas, Climate normal, ArcGIS

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### 1. Introduction

Climate is a sum of various weather patterns over the given area and is described by a long term averages of meteorological variables. World Meteorological Organization (WMO) recommends to use 30-years periods to describe climate conditions. Averages of these periods are considered as a “climate normals”. A 30 year period is long enough to filter out the inter-annual weather variations and anomalies (WMO, 2011).

At the International Meteorological Conference in 1935 in Warsaw (Poland) scientists and experts proposed to use 30 year periods for the climate analysis. For most climate elements it was proposed to use a period from 1901 to 1930 as a baseline for “climate normals”, longer period was determined for precipitation values (1891–1930). This agreement between scientist and experts provided the reference point to compare climate elements globally and established the unified methodology for generation of climate data sets in different countries.

In 1957 during the International Meteorological Conference in Washington (USA) it was decided to keep this methodology and new baseline periods for climate normals were established (1931–1960, 1961–1990). These baseline periods had to be consecutive, but not overlapping 30-years periods.

At the moment WMO recommends to use 1961–1990 climate normals to describe the climate conditions. Average values of meteorological elements from this period is considered as a “normal climate” and is used as a point of reference to evaluated climate conditions and trends in different countries. WMO recommends to recalculate climate normals every 30 years. Next period for climate normals will be considered 1991–2020 (Climate Atlas of Lithuania, 2013).

In climatology different 30-year period averages may be calculated to track more recent climate fluctuations. These climate averages are recalculated every 10 years. The recent period is 1981–2010, before it was 1971–2000 and etc.

Although WMO recommends to recalculate climate normals every 30 years, scientist from different countries emphasize, that this interval is too long. Due to the climate change standard climate normals can not describe the real state of climate any more. The most rapid changes were detected in the case of the air temperature. Average air temperature in Lithuania in 1981–2010 has increased by  $0.7^{\circ}\text{C}$  if compared to average of 1961–1990 (Fig. 1). These changes are even more obvious on particular months, e. g., in January standard climate normal temperature in Lithuania is  $-5.1^{\circ}\text{C}$ , but in period 1981–2010 it was  $-3.2^{\circ}\text{C}$  ( $1.9^{\circ}\text{C}$  higher).

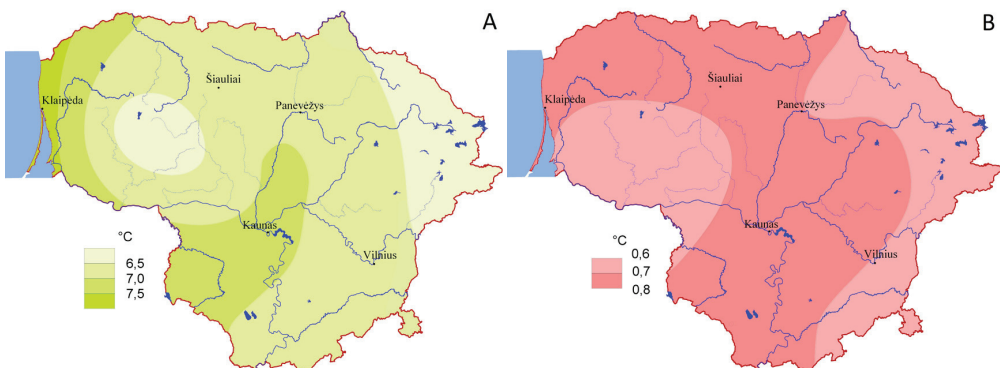


Fig. 1. Average air temperature in 1981–2010 (A) and its deviation from 1961–1990 standard climate normal (B)

On 9<sup>th</sup> of July 2014 in Heidelberg, Germany, the WMO Commission for Climatology has proposed to change the existing methodology and update climate normals every 10 years. Scientist and specialists recommended to start employing the data of 1981–2010 period as climate baseline and update this period every 10 years. The 1961–1990 period still will be used as reference point to assess the long-term climate variability and change (WMO, 2014).

The new methodology proposed by WMO Commission for Climatology will be submitted for consideration and adoption by the World Meteorological Congress, which will take a place in Geneva from 25 May to 12 June 2015. It is anticipated that WMO Congress will adopt this technical regulation on “Calculating Climatological Standard normals Every 10 Years” (WMO, 2014).

## 2. Methodology of map generation for Climate Atlas of Lithuania

There are two key aspects when producing climate atlas:

1. Long time series of climate data.
2. Quality of data.

Time period of available meteorological observations is very important for assessment of climate conditions. Time series of climate observations can vary by length, there can be data gaps, which aggravate the analysis. In addition, location of meteorological stations can change, and, last but not least, the surrounding environment can change too (e.g., urban sprawl in neighbourhood). All these different factors may overlap and change the precipitation and temperature patterns, because these climate characteristics depend on the location and landscape of station area. Besides, precipitation during warm season can be very local, and all these factors may aggravate the analysis of long term precipitation changes.

In the Climate Atlas of Lithuania the latest climate normals were used to characterize climate conditions in the country (Climate Atlas of Lithuania, 2013) (fig. 1). The assessment and visualisation of meteorological elements is based on 30 years of consecutive observations, with no data gaps.

All data used in climate atlas concern the same time period. During compilation of atlas data homogenisation was an important issue, because it is very important to have standardized data when mapping climate elements. Another important aspect was to have the same climate normals, because usage of different time periods could distort the spatial distribution of climate elements and could lead to inaccurate assessment of current climate conditions.

Development of new climate atlas showed apparent need to recalculate climate normals every 10 years, in order to produce objective and qualitative maps of climate elements. This is another argument why WMO Congress in 2015 should adopt new technical regulation on calculation of standard climate normals.

The latest 30 years climate normals, however, is not suitable for evaluation of absolute climate records. Mapping and assessment of climate records should be

based on the longest available observations and not restricted to a particular time period.

Comparison of maps in different atlases of Lithuania showed that there are some essential differences. E.g. the latest Climate Atlas of Lithuania (2013) was compiled using the newest climate normal period (1981–2010), while in Atlas of Lithuania (1981) the length and period of time series is not shown. Missing metadata and methodology raises the question about the cartographic quality and reliability of provided spatial distributions of climate elements. The same methodological error was made in unpublished Atlas of Lithuania (1989), which again raised the uncertainty about the quality of mapping. In new (yet unpublished) National Atlas of Lithuania (2014) all time series of climate data cover 30 years period from 1981 to 2010.

All climate data used in different atlases of Lithuania were obtained from the observations at meteorological stations. These observations are made following the recommendations of WMO (WMO, 2008). Keeping of WMO recommendations standard ensures the homogeneity and quality of observations. For atlases of Lithuania, climate data was obtain from the archives and databases of Lithuanian Hydrometeorological Service. This institution is responsible for keeping data records of all existing and closed stations in Lithuania. Climate Atlas of Lithuania (2013) was prepared and published by the Climatology Division of the Lithuanian Hydrometeorological Service, using the latest climate normal period (1981–2010) (Galvonaitė et al., 2007, Galvonaitė, Valiukas, 2005).

Data from 18 meteorological stations were used for mapping of meteorological elements. Statistical graphs are based on data from 8 meteorological stations, which are more representative for the different regions of Lithuania. For assessment of particular climate elements (e. g. precipitation, snow cover) additional data from water gauging stations and climatological posts (which make observations of some meteorological elements) was used as well.

Meteorological stations are located in areas which best represent the local climate conditions. However, some stations may work in areas which have specific micro-climatic conditions. When mapping distribution of climate elements, it is important to omit the data from these stations or use this data with caution, especially if observation network is scarce.

At the moment in Lithuania there are 18 meteorological stations (MS), 9 automatic meteorological stations (AMS), 43 ago-meteorological stations (AGMS) which have comprehensive observation programs. Additionally there are 35 water gauging stations which make the observations of air temperature, precipitation and snow cover.

During compilation of Climate Atlas of Lithuania only data from stations which had continuous meteorological measurements during 1981–2010 period was used. Data from stations which had a shorter observations periods was not included, for example, network of ago-meteorological stations was re-established in 2009, so data from these stations could not be included in climate assessments (Fig. 2).

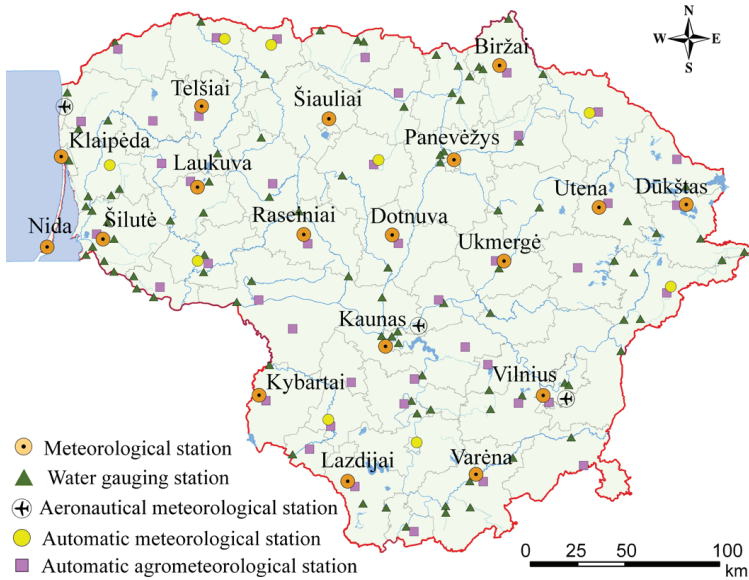


Fig. 2. Meteorological observation network in Lithuania

Number of stations in Lithuania varied throughout the history. Varying network of observations was an issue in the assessment and mapping of climate elements in the Atlas of Lithuania published in 1981. The observations of air temperature in Lithuania started in 1770 in the observatory of Vilnius University. However, data from the first 7 years of observations was lost and time series of air temperature in Vilnius is available only from 1777 (Fig. 3). It is one of the longest time series of air temperature in Eastern and Central Europe, but it does not represent the variety of climate in the whole country.

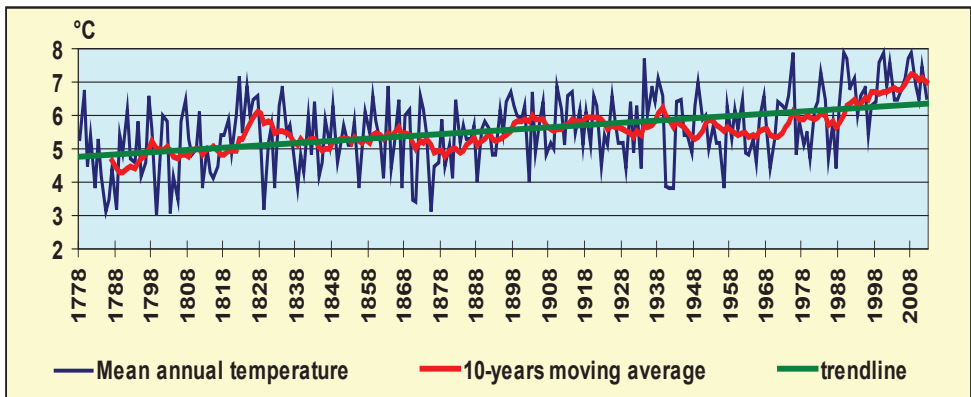


Fig. 3. Annual air temperature in Vilnius during 1778–2013

There are 5 meteorological stations in Lithuania which have the continuous observations for more than 100 years. The extensive network of meteorological observations with consistent and qualitative measurements was developed in the second half of XX century.

As was mention earlier, for mapping of climate elements it is important to have at least 30 years of consecutive observations. During certain periods (e.g. between I and II world wars and in 60's) observation network was denser when it is in current decades. However, it should be stressed that observations in many of those stations and posts were performed only for a short time periods and this data is applicable only for the assessments of short term climate variations, but not for a long climate trends.

Measurements of main meteorological elements at meteorological stations are performed every 3 hours. After the modernization of observation network automatic stations measure meteorological parameters every hour. Number of observations can have an influence on the values of daily means of meteorological elements. Of course the differences are not significant.

The monthly means air temperature from manual observations at Kaunas meteorological station (every 3 hours) and hourly automatic observations from Kaunas automatic meteorological station the same site are presented in Table 1. The analysis of temperature data from 2013 showed that in February and June there was 0.1 °C difference between manual and automatic air temperature observations (Table 1).

Table 1. Average monthly air temperature in Kaunas in 2013

Station/ Month	01	02	03	04	05	06	07	08	09	10	11	12
Kaunas AMS	-2.9	-9.2	1.9	7.7	13.8	15.2	19.4	17.1	13.3	7.4	4.8	-4.3
Kaunas MS	-2.9	-9.1	1.9	7.7	13.8	15.3	19.4	17.1	13.3	7.4	4.8	-4.3

AMS – automatic meteorological station

MS – meteorological station

The difference of 0.1°C might seem trivial, but in climate trend assessments it is important. In graphs produced for Climate Atlas of Lithuania this difference is insignificant and visually is not noticed. However when mapping, the temperature difference of 0.1°C or precipitation difference of 1.1 mm is very important, because it can determined in which interval it will fall and how spatial distribution will be assessed. Especially it is important when mapping temperature in very narrow intervals. Temperature in Climate Atlas of Lithuania was mapped using 0.5°C interval. In lower resolution maps, when isotherms are drawn in 2°C or 5°C intervals the 0.1°C difference maybe not so significant. These wider intervals are used when mapping temperature in Baltic Sea region, or Europe. When maps are created in high resolution and they cover small uniform regions, even small difference can be significant.

### 3. Methods to map climate elements

Cartographic methods of visualization of spatial distribution of different parameters are constantly improving. Improved methods also require more precise and homogenous spatial data. For example, climate maps in Lithuanian Altas of 1981 were made using traditional cartographical methods just by interpolating climate elements. In Climate Atlas of Lithuania (2013) maps were created using ArcGIS software. Another important, but subjective factor of mapping is a researcher, because accuracy of complex natural phenomena depends from his experience and knowledge. The main advantages of computer software is: 1) it is possible to create map faster and more accurately; 2) there is always a prompt possibility to correct mistakes.

When mapping climate elements it is crucial that meteorological observation network is sufficient to represent the different regions and landscapes inside the country. In 1898 the network of meteorological observations was scarce and it was not possible to make reasonable interpolation of climate elements. But data from this network was enough to make low resolution climate maps. In 1898 data from Lithuanian meteorological network was used to map the climate elements in Russian Empire (during that time Lithuania was part of Russian Empire).

Selection of appropriate interpolation method is one of the most important factors, which influence the accuracy and level of details in the final map of climate elements. Different interpolation methods can result in different spatial distribution of mapped elements. If climate elements are represented by graphs and histograms rather than isopleths maps this does not cause a problem. If all countries would use the same interpolation methods and same period of climate normals it would be easier to compare the climate maps from different countries.

Compiling maps for Climate Atlas of Lithuania (2013) the *Spline* interpolation method was used. It interpolates a surface from points using a minimum curvature technique. Isolines drawn by this method are similar to the isolines made by manual interpolation. Using this interpolation method it is possible to take into account other factors influencing the spatial distribution of climate elements (e.g. relief). In Lithuania there is no high diversity of relief, so during the interpolation of climate elements the relief and elevation model were not included. Corrections of maps were performed manually, taking into the consideration the effects of relief, forests and large water bodies.

Producing maps with ArcGIS software, corrections of spatial distribution of climate elements was done manually. Corrections allowed to represent the distribution and intensity of natural phenomena closer to the genuine distribution. As an example, we provide map of average cloudiness during spring season (Fig. 4a). In Šiauliai and Dūkštas meteorological stations average total cloudiness during the spring is 60 %. ArcGIS software Spline interpolation method automatically assumes, that around these stations there is a tendency of decreasing cloudiness. It results that in final map around Šiauliai and east of Dūkštas cloudiness is smaller, although there is no such observations. Assumption that cloudiness is smaller in this areas would be incorrect.

More correct would be to assume that cloudiness in this areas should be the same as observed at meteorological stations (60 %). To correct this mistake, two new polygons were created to mask the artificial tendency of decreasing cloudiness (Fig. 4b). After manual corrections, final cloudiness map of spring season was produced (Fig. 4c).

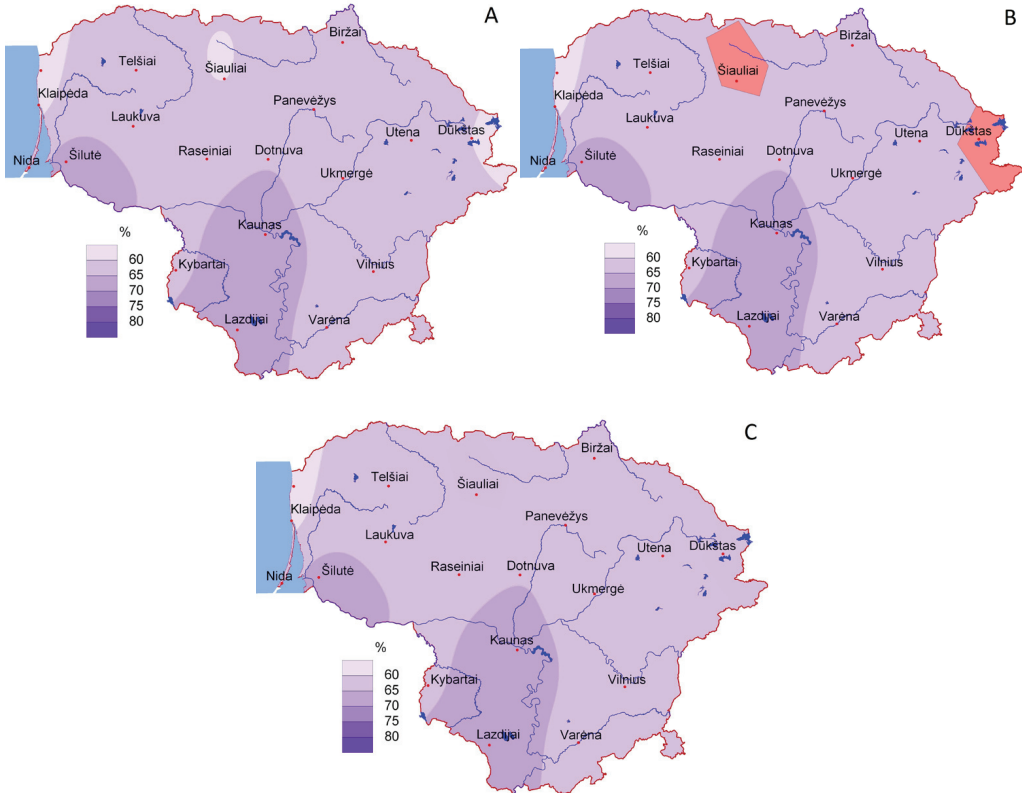


Fig. 4. Average total cloudiness during spring season in 1981–2010

During compilation of Climate Atlas of Lithuania these kind of manual corrections were done for most of the maps.

Some climate elements can not be mapped using isolines and interpolation, because it would cause biased results. In most cases these are very local climate phenomena, e. g., fog, hail. Interpolation also can not be applied for mapping wind direction and its recurrence (Climate Guide, 2000). These specific weather phenomena in Climate Atlas of Lithuania were visualized using localized graphs (Fig. 5).



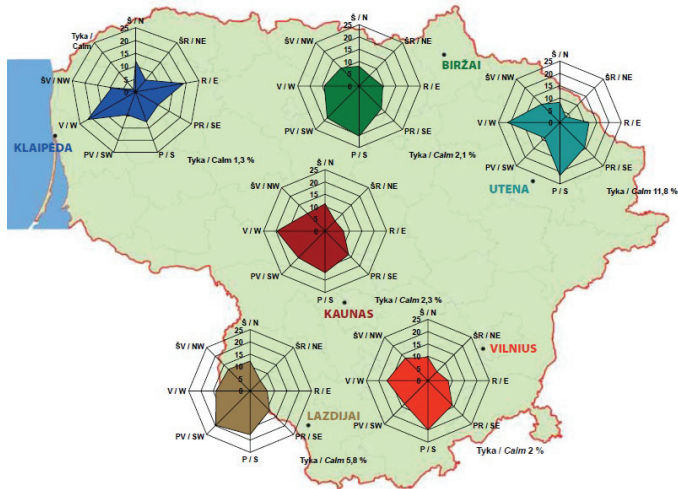


Fig. 5. Annual wind direction recurrence (%)

Localized graphs are suitable for climate elements which are registered in particular meteorological stations. Additional tables and graphs as additional elements in maps are appropriate for quantitative climate record values. This method is often applied for producing thematic maps. These maps help to visualise different types of information and provide a synthetic view of complex phenomena. Climate records might be visualized by providing quantitative and qualitative information on the map (same as wind roses). Using this approach climate record value and date can be marked on the concrete location. Additional information provided in graphs or unscaled markings requires more space on the map. This reduces the application possibilities of this method – you need to increase scale of the map or map only the most important (exclusive) climate records.

Most of the maps in Climate Atlas of Lithuania were created using quantitative background method. This type of mapping was determined by the ArcGIS software and its visualising options. This may be one of the shortcomings of the climate atlas. There are many additional text information, graphs and tables in the atlas (Fig. 6).

This thematic atlas is an important contribution to the understanding of Lithuanian climate and variation of its elements. Therefore this publication has very important informative and educational functions.

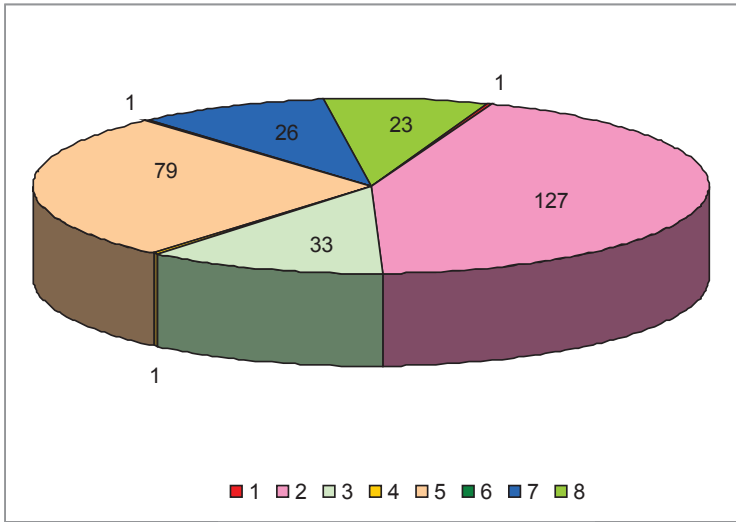


Fig. 6. Distribution of the data visualisation and information types in Climate Atlas of Lithuania: 1 – Maps created using signature method; 2 – maps created using quantitative background method (multi-tone one colour scale); 3 – maps created using quantitative background method (multicolour scale); 4 – maps with localised graphs; 5 – graphs and diagrams; 6 – maps created using signs of movement; 7 – tables, 8 – pictures

#### 4. Conclusions

Most appropriate solution for mapping climate elements is to use the 30 years period averages, which enables to standardise archived data and compare it between different countries. WMO Commission for Climatology has proposed to change the existing methodology and update climate normals every 10 years and to use 30 years period for climate trend assessments, which would allow to use the same standard climate elements and averages in unified way.

Accuracy of climate maps is determined by the quality of meteorological data and availability of long term climate data. In Climate Atlas of Lithuania present state of the climate was presented by visualising and describing newest climate normal. Data used for mapping was homogeneous and that ensured credible representation of spatial distribution of climate elements.

Comparison of different atlases and different climate maps showed that during its compilation the recommended standard climate normals and standard periods were not kept which hinder the possibility to compare the changes in climate elements during past 60 years.

ArcGIS software was employed to generate maps for Climate Atlas of Lithuania, and the same software was used to perform interpolation of quantitative elements. To generate maps, *Spline* minimum curvature technique interpolation method was

employed. Isotherms obtained by this method correspond to the isolines drawn manually, which helps to ensure quality of maps.

Most of the maps in Climate Atlas of Lithuania were made using quantitative background method. This type of mapping was accessible with the ArcGIS software and its visualising options. It should be acknowledged that this caused the monotony of maps in the Climate atlas, which is one of the main shortcomings of applied solution.

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**Metody opracowania atlasu klimatycznego****Donatas Valiukas<sup>1,2</sup>, Audronė Galvonaite<sup>1</sup>, Algimantas Česnulevičius<sup>2,3</sup>**

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**Streszczenie**

Atlasy klimatyczne powstają w wyniku analiz wielu danych o charakterze ilościowym i jakościowym. Ten specjalny rodzaj publikacji geograficznej podsumowuje długoterminowe obserwacje meteorologiczne, dostarcza map i wykresów, które charakteryzują różne elementy klimatu. Zawiera też uzupełniające informacje opisowe. W atlasach litewskich (Atlas of Lithuanian SDR, 1981; Climate Atlas of Lithuania, 2013) opublikowano wiele ciekawych informacji na temat krótko i długookresowych zmian klimatu. Część z nich znajdzie się w przygotowywanym do druku Litewskim Atlasie Narodowym (National Atlas of Lithuania. 1<sup>st</sup> part, 2014). W artykule przedstawiono założenia metodyczne oraz przykłady map klimatycznych, które znajdują się w atlasie narodowym.