

# Penalty Function for Identification of Regions with Similar Climatic Conditions

Daiga Cepīte-Frišfelde, Uldis Bethers,  
Juris Senņikovs, Andrejs Timuhins

Laboratory for Mathematical Modeling of Environmental and Technological Processes,  
Faculty of Physics and Mathematics University of Latvia, Zellu 8, LV-1002, Latvia  
E-mail: daiga.cepite@lu.lv

## Abstract

The method of defining the quantitative difference between the climates of any two points in the world is proposed. The defined quantitative distance is used to identify the regions with the present climate conditions the most similar to those expected in the territory of Latvia in the near (2021–2050) and far (2071–2100) future. The quantitative climate distance is obtained using 30-year long time series of gridded monthly average temperature and precipitation rates. As a result of using this method the regions of the globe have been identified representing the expected climate of Latvia in near and far future.

**Keywords:** Climate comparison, climate projections, climate models

## INTRODUCTION

Experimental measurements of the last century as well as the results of global and regional climate models with a set of emission scenarios show evidence of the relatively rapid climate change all around the world. Therefore many sectors of the Latvia economy should have been interested in knowing which parts of the world are nowadays similar to the climate we expect in the future. To be able to determine that one should have reasonable future projections as well as the ability to measure the distance between two climates to determine the congruence.

The aim of the present analysis is to propose the methodology for measuring the distance between the climatic conditions of any two areas in the world and to use it for giving better impression about the future climate in Latvia.

Until now a lot of effort has been done in the number of international research projects for obtaining the climate projections of the future (ENSEMBLES

members 2009). As well as the wide range of the impact studies have been done that use available results of the future climate projections. What refers to measuring the distance between climates and comparing the climates, one might notice in the scientific literature that it is done mostly to compare the model projections of the reference period with an experimental observations of the reference period. Monthly averages as well as interannual variability are the criteria considered for that purpose. These parameters can be used to build the penalty function that identifies the best performing climate model results, see Bethers and Sennikovs, 2009. In this paper we develop a similar penalty function for measuring the distance between the two climates.

## METHODS

The method is applied for finding the regions around the globe with temperature and precipitation conditions nowadays similar to those Latvia is going to have in the near (2021–2050) and far (2071–2100) future. The ensemble of future climate projections of Latvia used in the study originate from the climate projections of the European Commission's 6th Framework Programs 5 year Integrated Project ENSEMBLES results (see Hewitt, 2004 for more detail of the project). The typical spatial scale of the model results analysed is around 25 km and temporal scale – 1 day. More details on the models and their performance regarding the present climate in Europe and their projections of future climate changes are analysed by (ENSEMBLES members 2009). Statistical bias correction method and data modification algorithm described by Bethers and Sennikovs 2009 are applied. Analysis performed in the presented study uses the ensemble approach for determining the future climate projections of Latvia what is preferable than using one model results only as admitted by authors of ENSEMBLES members 2009 as well as by Teutschbein and Seibert 2010. Monthly mean temperature and precipitation of the period used further in the study correspond to 50% percentile from the set of the model projections for the particular month. Contemporary climate around the globe is characterised according to ERA-40 Reanalysis data provided in ECMWF (European Centre for Medium Range Weather Forecasts) data portal.

Non-dimensional distance between the climates in any two points of the globe  $\Delta$  is defined in order to analyse the distribution of climate quantitatively. It equals zero in case of the same climate and owns the maximal value 1. Monthly averages of the temperature and precipitation data series are included in the analysis of the climates equality.

The bias  $\Delta T_{t_i}^k$  has been calculated to characterize the differences among the monthly average temperatures in a following way:

$$\Delta T_{t_i}^k = \frac{1}{12} \sum_{m=1}^{12} |T_{t_0, m}^k - T_{t_i, m}^{LV}| \quad (1)$$

where index  $k$  represents the point of calculation, index  $m$  – the month of the year and  $t_i$  is 30 year long period – 1961–1990 in case of  $t_0$ ; 2021–2050 in case of  $t_1$  and 2071–2100 in case of  $t_2$ . Its dimension is the same as for the average temperature – °C.

In a similar manner the bias  $\Delta p_{t_i}^k$  has been calculated to characterize the differences among the monthly average precipitations rates in the control period in the point  $k$  and the monthly average precipitation rates in Latvia in the period  $t_i$ :

$$\Delta p_{t_i}^k = \frac{1}{12} \sum_{m=1}^{12} |p_{t_0, m}^k - p_{t_i, m}^{LV}| \quad (2)$$

Dimensions of  $\Delta p_{t_i}^k$  equals dimension of precipitation intensity – mm day<sup>-1</sup>. It should be noticed that the values  $T_{t_i, m}^{LV}$  and  $p_{t_i, m}^{LV}$  in formulas (1) and (2) are not unique numbers the same in all territory of Latvia but the data sets including values from all meteorological stations in Latvia. In the present paper the difference  $|T_{t_0, m}^k - T_{t_i, m}^{LV}|$  has been calculated in a following way:

$$|T_{t_0, m}^k - T_{t_i, m}^{LV}| = \begin{cases} |T_{t_0, m}^k - \min(T_{t_i, m}^{LV})|, & \text{in case } T_{t_0, m}^k < \min(T_{t_i, m}^{LV}); \\ |T_{t_0, m}^k - \max(T_{t_i, m}^{LV})|, & \text{in case } T_{t_0, m}^k > \max(T_{t_i, m}^{LV}); \\ 0, & \text{in case } \min(T_{t_i, m}^{LV}) \leq T_{t_0, m}^k \leq \max(T_{t_i, m}^{LV}). \end{cases} \quad (3)$$

The same approach is used in calculation of  $|p_{t_0, m}^k - p_{t_i, m}^{LV}|$  in formula (2). It means that zero difference is gained in case the monthly average temperature (or precipitation) is in the range between the minimal and the maximal monthly average temperature (or precipitation) of the period in meteorological stations of Latvia. The monthly averages are considered according to the 50% percentile values of the projection ensemble. The values of  $\min(T_{t_i, m}^{LV})$ ,  $\max(T_{t_i, m}^{LV})$ ,  $\min(p_{t_i, m}^{LV})$  and  $\max(p_{t_i, m}^{LV})$  are included in Table 1 and Table 2.

Table 1 The minimal and maximal monthly average temperatures among the stations in Latvia in three analysed periods

$m$	$\min(T_{t_0,m}^{LV})$	$\max(T_{t_0,m}^{LV})$	$\min(T_{t_1,m}^{LV})$	$\max(T_{t_1,m}^{LV})$	$\min(T_{t_2,m}^{LV})$	$\max(T_{t_2,m}^{LV})$
1	-7.78	-3.29	-4.87	-0.35	-2.54	2.06
2	-6.78	-3.03	-4.95	-0.99	-2.19	1.79
3	-2.59	0.32	-0.37	2.35	2.21	4.64
4	2.90	5.56	5.00	7.29	7.19	8.74
5	8.21	12.10	10.32	13.21	12.48	14.67
6	13.09	15.71	15.03	17.37	16.79	18.48
7	15.70	17.19	16.77	18.49	18.23	19.97
8	14.72	16.34	16.24	18.23	17.64	19.66
9	10.04	12.61	11.61	14.52	13.42	16.16
10	5.17	8.40	7.34	10.54	9.06	12.19
11	-0.33	3.66	1.52	5.61	3.15	7.28
12	-4.85	-0.35	-3.00	1.75	-0.49	4.06

Table 2 The minimal and maximal monthly average precipitation rate among the stations in Latvia in three analysed periods

$m$	$\min(T_{t_0,m}^{LV})$	$\max(T_{t_0,m}^{LV})$	$\min(T_{t_1,m}^{LV})$	$\max(T_{t_1,m}^{LV})$	$\min(T_{t_2,m}^{LV})$	$\max(T_{t_2,m}^{LV})$
1	0.89	1.71	1.08	2.02	1.24	2.30
2	0.80	1.28	1.00	1.54	1.09	1.70
3	0.86	1.50	1.02	1.62	1.16	2.02
4	1.06	1.69	1.21	2.01	1.31	2.17
5	1.10	1.75	1.25	1.95	1.55	2.19
6	1.40	2.42	1.66	2.72	1.62	2.61
7	2.02	3.05	2.47	3.45	2.44	3.37
8	2.10	3.08	2.25	3.33	2.00	3.03
9	1.83	3.04	2.03	3.50	1.96	3.40
10	1.52	3.16	1.82	3.60	1.72	3.53
11	1.50	3.39	1.64	3.73	1.84	4.10
12	1.28	2.40	1.44	2.77	1.60	2.98

Table 3 Values of  $\max \Delta T_{t_i}^k$  and  $\max \Delta p_{t_i}^k$  used in computation of relation (3)

Period, $t_i$	$\max \Delta T_{t_i}^k$	$\max \Delta p_{t_i}^k$
$t_0$	55.5	23.7
$t_1$	57.4	23.3
$t_2$	59.5	23.2

After obtaining  $\Delta T_{t_i}^k$  and  $\Delta p_{t_i}^k$  for each of the calculation grid points the distance between the climates that measures the effect of both temperature and precipitation differences all together is calculated

$$\Delta_{t_i}^k = 0.5 \left( \frac{\Delta T_{t_i}^k}{\max(\Delta T_{t_i}^k)} + \frac{\Delta p_{t_i}^k}{\max(\Delta p_{t_i}^k)} \right). \quad (4)$$

$\Delta_{t_i}^k$  is a nondimensional number below 1 in all locations  $k$  in the calculation domain. To calculate the distance between the climate in Latvia and climates in the southern hemisphere six month phase shift has been used.

## RESULTS AND DISCUSSION

The main result of the present study is the distribution of the distance between the contemporary climate of the world and Latvia climate projections.

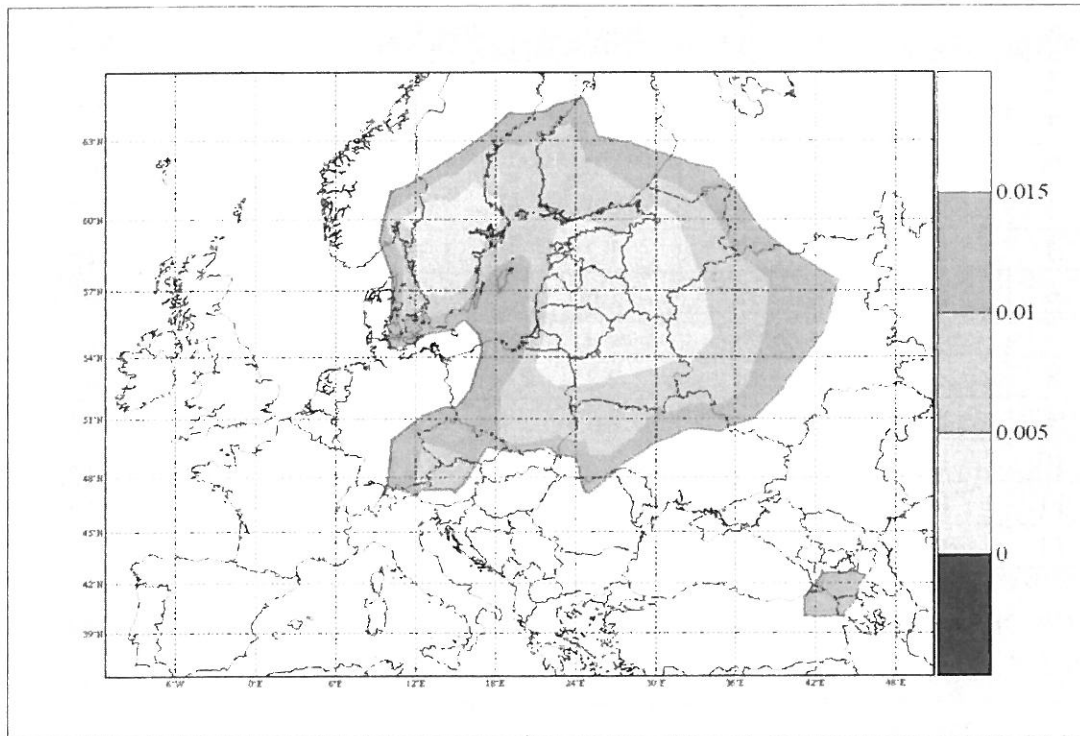


Figure 1 The distance between the contemporary climates of Europe and Latvia  $\Delta_{t_0}$ . Regions within the distance 0 to 0.015 (0 to 1.5 %) are shown

shows that the closest regions to the contemporary climate of Latvia are located in the territory of Lithuania, Estonia and parts of Russia, Belorussia, Poland and Sweden as well.

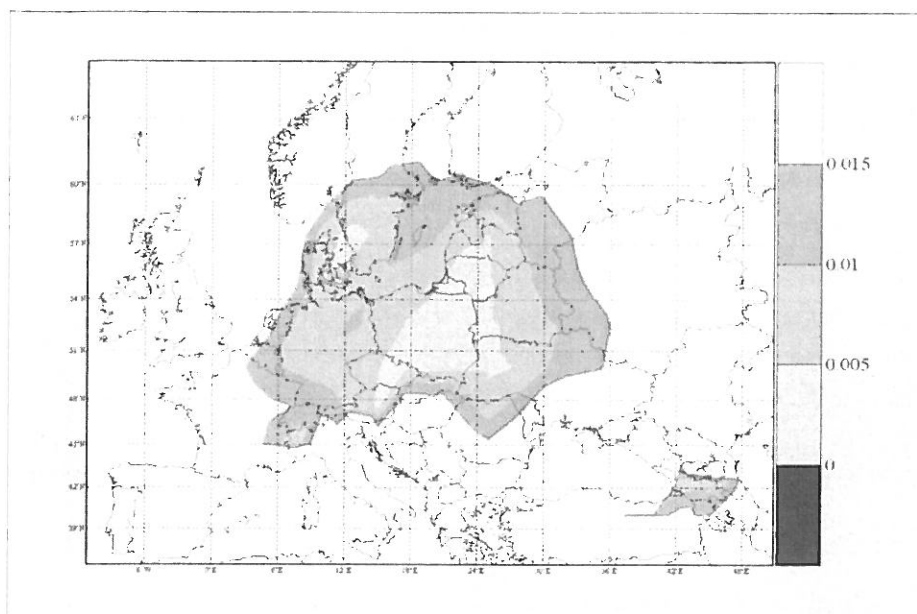


Figure 2 The distance between the contemporary climate of Europe and the near future climate projection of Latvia  $\Delta_{t_1}$ . Regions within the distance 0 to 0.015 (0 to 1.5 %) are shown

demonstrates that the region of the contemporary climate that is the closest to near future climate projection of Latvia is shifted in the SW direction in comparison with the closest region shown in Fig. 1.

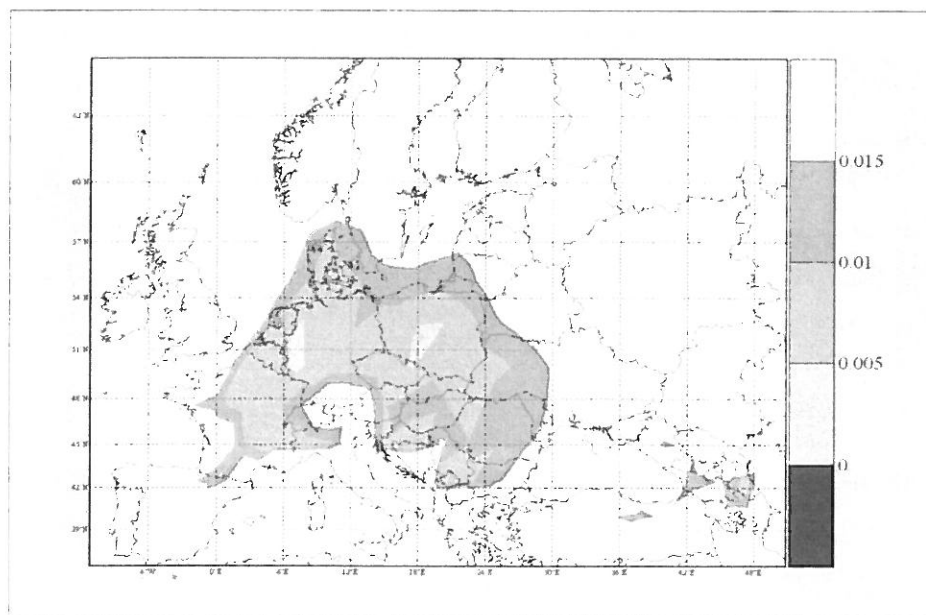


Figure 3 The distance between the contemporary climate of Europe and the far future climate projection of Latvia  $\Delta_{t_2}$ . Regions within the distance 0 to 0.015 (0 to 1.5 %) are shown

confirms that the shift of the closest region in SW direction continues in case of the Latvia climate projections in the far future as well.



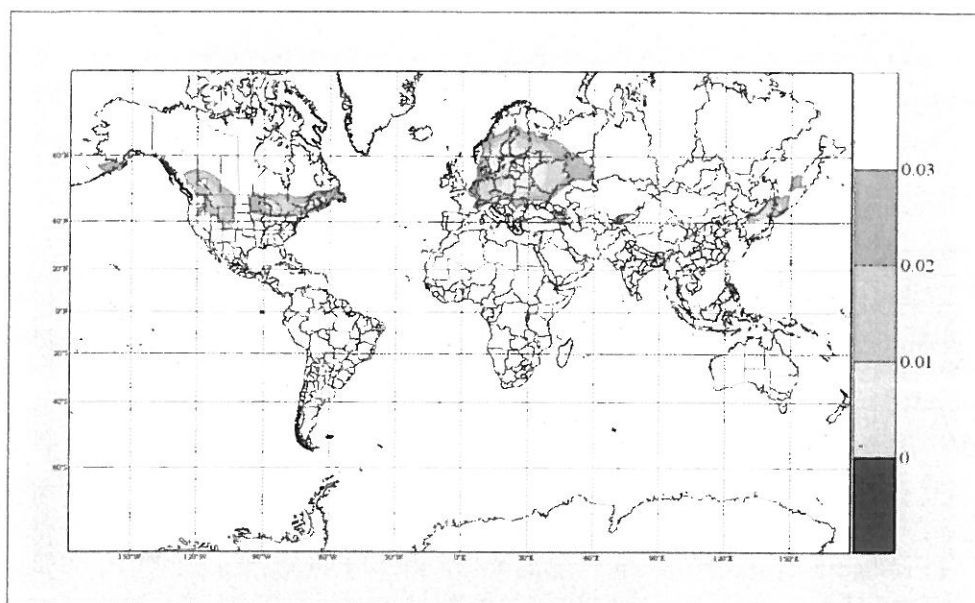


Figure 4 The distance between the contemporary climates of the world and Latvia  $\Delta_{t_0}$ . Regions within the distance 0 to 0.03 (0 to 3.0 %) are shown

shows that there are regions with a distance from contemporary climate of Latvia less than 0.03 in North America and Asia. There are the regions with a distance less than 0.01 in the USA that are located in the states of Michigan, Wisconsin and Colorado.

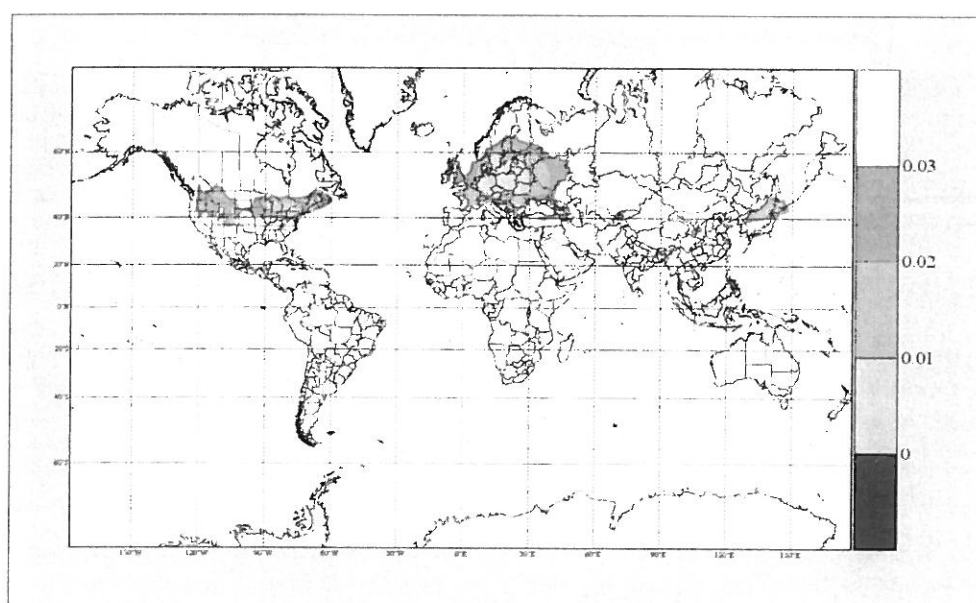


Figure 5 The distance between the contemporary climate of the world and the near future climate projection of Latvia  $\Delta_{t_1}$ . Regions within the distance 0 to 0.03 (0 to 3.0 %) are shown

shows that the regions with a distance less than 0.03 could be found outside Europe in case the comparison with the near future projections of the climate

of Latvia is done. There are the regions with a distance less than 0.01 in the USA and Canada that are located in the states of Michigan, Colorado and New-York, as well as the province of Ontario. It is even more surprising to detect the close regions in Georgia, Turkey and Dagestan.

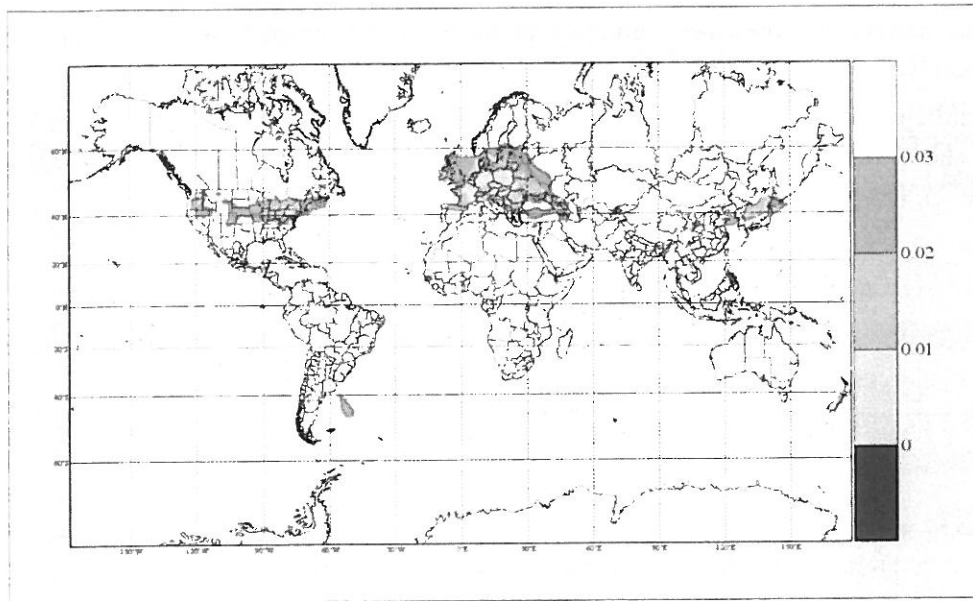


Figure 6 The distance between the contemporary climate of the world and the far future climate projection of Latvia  $\Delta_{t_2}$ . Regions within the distance 0 to 0.03 (0 to 3.0 %) are shown

shows that in case the comparison with the far future projections of the climate of Latvia is done the regions within the distance of 0.01 can be found in the states of Pennsylvania and New-York, West Virginia and Ohio in the USA and in the province of Ontario in Canada. There is another close region with a distance less than 0.01 found in Dagestan on the coast of Caspian Sea.

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Data series of the contemporary climate have been downloaded from ECMWF (European Centre for Medium Range Weather Forecasts) data portal [http://data-portal.ecmwf.int/data/d/era40\\_moda/](http://data-portal.ecmwf.int/data/d/era40_moda/)



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