# AIR TEMPERATURE AND PRECIPITATION CHANGES IN EUROPE IN THE 21$^{ST}$ CENTURY ACCORDING TO CANADIAN CLIMATE MODEL

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**Abstract**

Climate change owing to increasing greenhouse effect means serious problem at present. The most important sources of information about behaviour of climate system under changed conditions are climate models. In this paper Canadian climate models outputs (CCCM 2000) are utilized for preparation of climate change scenarios (air temperature, precipitation amount) for Europe in the 21$^{st}$ century. The results are based on outputs from "A2-SRES" forcing scenario, which represent a pessimistic variant. We can say that the increasing of air temperature is growing from ocean`s part (1.2 °C) to continental`s part (7.0 °C). Also optimistic "B2-SRES" forcing scenario for illustration and comparison with "A2-SRES" is used. Results demonstrated a more modest warming in the 21$^{st}$ century in Europe in case of the "B2-SRES" scenario.

Key words: climate change, climate scenarios, climate model, air temperature, precipitations amount

## Introduction

Combustion of fossil fuels, land-use changes, industry, agriculture, … cause growth of greenhouse gases concentration in the atmosphere. The result of this process is that the world is getting warmer. The global average surface temperature has increased by 0.6 ± 0.2°C since the late 19$^{th}$ century. It is very likely that the 1990s was the warmest decade and 1998 the warmest year in the instrumental record since 1861. It is likely that the rate and duration of the warming of the 20$^{th}$ century is larger than any other time during the last 1,000 years. Even the 1990s are likely to have been the warmest decade of the millennium in the Northern Hemisphere, and 1998 is likely to have been the warmest year (IPCC 2001).

According to Bartholy and Pongrácz (2006) global and European trends of the extreme temperature indices are consistent with the global warming. Regional temperature of Central/Eastern Europe became warmer during the second half of the 20$^{th}$ century.

The most advisable method for creating future climate scenarios is climate models outputs. At the present time the most highly developed climate models are atmospheric and oceanic general circulation models (GCMs). In many cases the GCMs of the atmosphere and oceans are developed as separate models. The coupled GCMs then arise by mutual combining. Climate change experiments based on different GCMs have been carried out by several groups (e.g. Boer et al. 1992, McFarlane et al. 1992, Murphy and Mitchell 1995, Russell and Rind 1999, Flato and Boer 2001, The GFDL Global Atmospheric Model Development Team 2004).

In this paper model data from the Canadian Centre for Climate Modelling and Analysis in Victoria, B.C. is utilized. This center has developed six global climate simulation models for climate prediction. A brief description of some these models and their results can be found e.g. in McFarlane et al. (1992), Boer et al. (1992). CCCM 1989 model, CCCM 1992 model and CCCM 2001 model are only global atmospheric GCMs. Next three models are the global coupled models (CCCM 1997 model, CCCM 2000 model, the third coupled CCCM model is at present in the final stage of development and testing; model outputs are not available at the present time). We utilize model data from the second version of the Canadian Global Coupled Model (CCCM 2000 or CGCM2). Oceanic part of the Canadian global coupled models is based on the GFDL MOM1.1 prepared in the Geophysical Fluid Dynamics Laboratory at Princeton University (New Yersey, USA). The second version of the Canadian Global Coupled Model (CCCM 2000) is based on the earlier CCCM 1997, but with some improvements (the ocean mixing parameterization, sea-ice dynamics, ocean spinup, flux adjustment procedure). Development of temperature scenarios for Slovakia on the basis of 4 Canadian model outputs is summarized in paper Melo, Lapin (2000).

Flato and Boer (2001) compare results obtained with two versions of the coupled global GCMs (CCCM 1997 and CCCM 2000 models). They outline annual mean surface air temperature change from 1971-1990 to 2041-2060, obtained with both models. In case of CCCM 2000 there are some technical differences in the ocean spin-up procedure and in the manner in which the monthly-mean heat and moisture flux adjustments are computed. Both model results show at the middle of the 21$^{st}$ century greater warming over land than over ocean and slight cooling in the northwest Atlantic (a result associated with changing ocean convection patterns). Climate change simulation made with CCCM 1997 show at the middle of the 21$^{st}$ century a marked hemispheric asymmetry with more warming in the northern high latitudes than in the south. New version of the Canadian climate model (CCCM 2000) exhibits in this period (2041-2060) a much more symmetric warming, compared to an earlier version, and agrees somewhat better with observed 20$^{th}$ century trends.

**Aim of work and methods**

The aim of this contribution is to outline air temperature change and precipitation change in Europe in the 21$^{st}$ century, especially at the end of this century according to Canadian climate model CCCM 2000. We utilize IPCC "A2-SRES" greenhouse gases and aerosol scenario. Also "B2-SRES" forcing scenario for illustration and comparison with "A2-SRES" are used. The Intergovernmental Panel on Climate Change (IPCC) for the Third Assessment Report (IPCC 2001) recommend these emission scenarios ("A2-SRES" and "B2-SRES") into attention for use in climate simulations (SRES-Special Report on Emission Scenarios).

A total of 153 grid points from the Europe region is available from this model. Upper left corner of selected region has coordinates 18.75W, 68.65N, lower left corner 18.75W, 38.97N, upper right corner 41.25E, 68.65N and lower right corner 41.25E, 38.97N.

Data (monthly/annual means of air temperature and monthly/annual values of precipitation amounts) from the time period 1990-2100 (111-year "A2-SRES" and "B2-SRES" simulations) are used. Also values for the time periods 1951-1980 (data for this period are obtained from the corresponding greenhouse gases and aerosol "IS92a" emission scenario simulation) and 2071-2100 ("A2-SRES" scenario) are used which are compared each other. The 1951-1980 period is selected as baseline scenario (control climate period).

The results in the figures (maps and graphs) are presented. Firstly it is result, which in case of air temperature as a difference between annual temperature means from the periods (2071-2100 and 1951-1980) and in case of precipitation in form of quotients between annual precipitation totals from the same periods is calculated. Maps (Fig. 1-2) were elaborated in Surfer8 Program.

In the second part of this paper we present the results in form of time series scenarios for annual air temperature means and annual precipitation totals for 15 selected grid points of the European territory in 1990-2100. In the figures (Fig. 3-4) linear trends are utilized.

Next the scenarios of both climatic elements (annual course of changes) for the climate of strengthened greenhouse effect (2071-2100) in comparison to the periods 1951-1980 in form of either differences (air temperature) or quotients (precipitation) between of these periods for 15 selected grid points of Europe are elaborated. Monthly means and monthly totals of studied climatic elements are used. The air temperature scenarios are prepared by the smoothing of annual course using simple weighting moving averages method (from three neighboring months): $x_i` = (x_{i-1}+2_{xi}+x_{i+1})/4$, where $x_i`$ are deviations from long-term means with smoothed annual course and $x_i$ are data with basic annual course. We do not expect abrupt jumps in annual air temperature course (from month to month).

Finally optimistic "B2-SRES" forcing scenario for illustration and comparison with "A2-SRES" only for selected grid points of Europe is used.

**Results**

According to Canadian climate model CCCM 2000 ("A2-SRES" forcing scenario) in the 21$^{st}$ century we will expect increase of air temperature in all over the Europe (Fig. 1). This increase of air temperature is growing from the ocean's parts to the continental' s parts. At the end of this century

(2071-2100) in the north part of Atlantic ocean the temperature will be increased about 1.2 °C and in the eastern part of this observed area (41.25E; 38.97N – continental part of Turkey) will be increased about 7.0 °C in comparison to 1951-1980. In the territorial boundaries of Europe the highest air temperature increase is on peninsula Kola (33.75E; 68.65N) – about 5.9 °C.

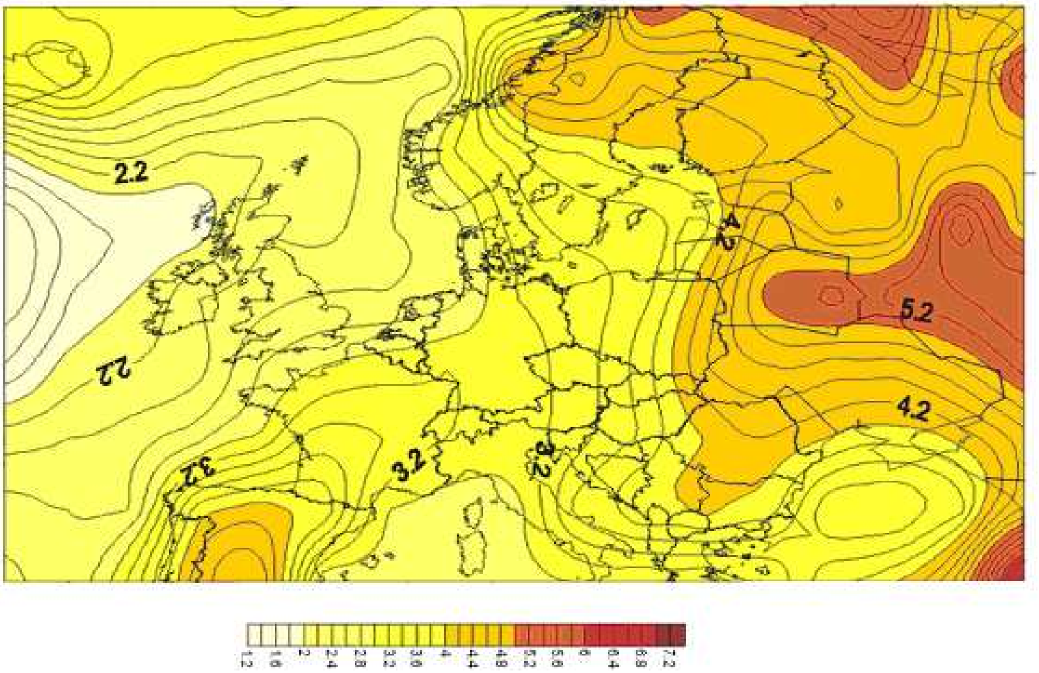


**Fig. 1 Change of annual air temperature mean [°C] in Europe in 2071-2100 compared to 1951-1980 according to climate model CCCM 2000.**

In contrast to the air temperature results (increase in all over the Europe) in case of precipitation amount we can state that some European regions (northern part of Europe) will attain higher values and some regions (southern part of Europe) will attain lower values of annual precipitation totals in 2071-2100 in comparison to 1951-1980 according to CCCM 2000 (Fig. 2). The most increase of annual precipitation totals will be in the region where the river Odra flows to the Baltic sea, in the central parts of Norway and Sweden and in the region of Atlantic ocean to the north of Iceland (increase about 24%). On the contrary the most decrease of annual precipitation totals will be in the central part of Portugal and Spain, in island parts of Aegean sea and in the continental part of Turkey (decrease about 30%).

Increases of annual air temperature means according to Canadian climate model CCCM 2000 will be relatively fluent in the period 1990-2100 in all studied model localities (differences are only in intensity of this growth). Likewise it is in case of annual precipitation totals. We can state relatively fluent increases or decreases of annual precipitation totals according to this model in Europe in 1990-2100. In the Fig. 3 and the Fig. 4 two European localities (southern part of Spain and north-eastern part of Ukrainian) as an illustration are chosen. Annual air temperature means will achieve increase about 4.6 °C in Spain and about 4.9 °C in Ukrainian both according to linear trends in 1990-2100 (Fig. 3). In case of annual precipitation totals will be decrease about 95 mm in Spain and increase about 60 mm in Ukrainian both according to linear trend in 1990-2100 (Fig. 4).

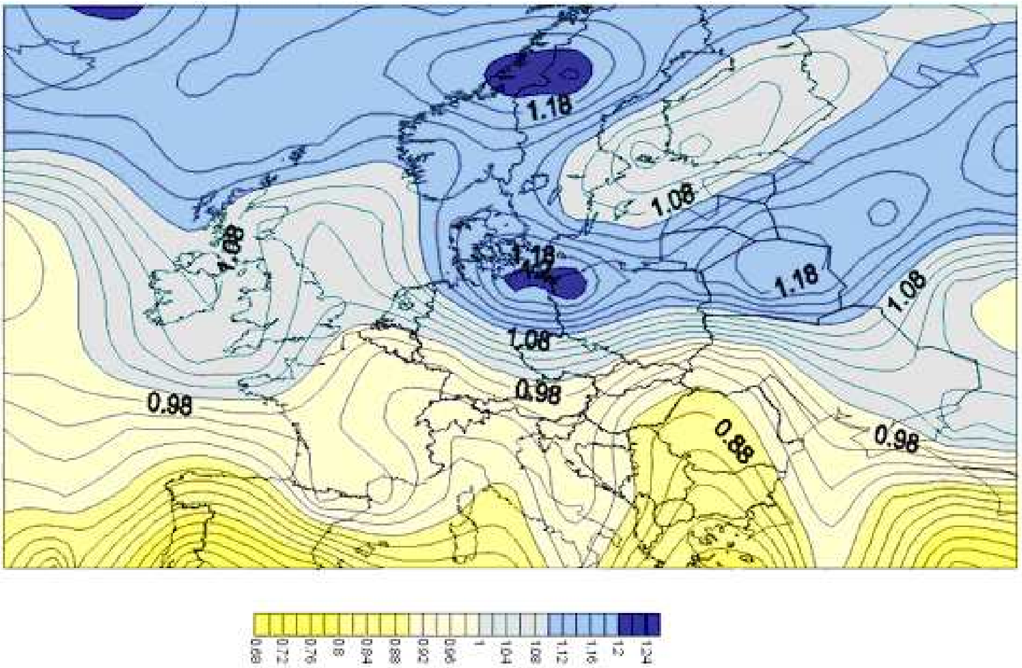


**Fig. 2 Change of annual precipitation totals [in form of quotients] in Europe in 2071-2100 compared to 1951-1980 according to climate model CCCM 2000.**

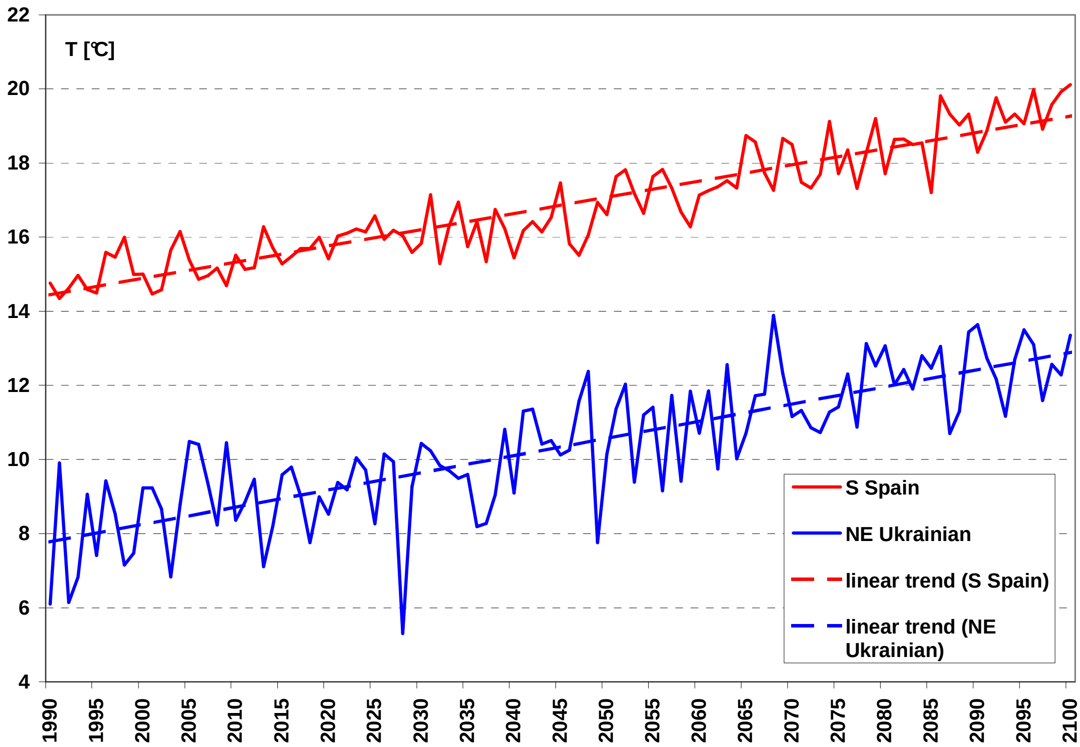


**Fig. 3 Annual air temperature means [°C] in the southern part of Spain (3.75W; 38.97N) and in the north-eastern part of Ukrainian (33.75E; 50.10N) in 1990-2100 according to CCCM 2000 (not modify model data).**

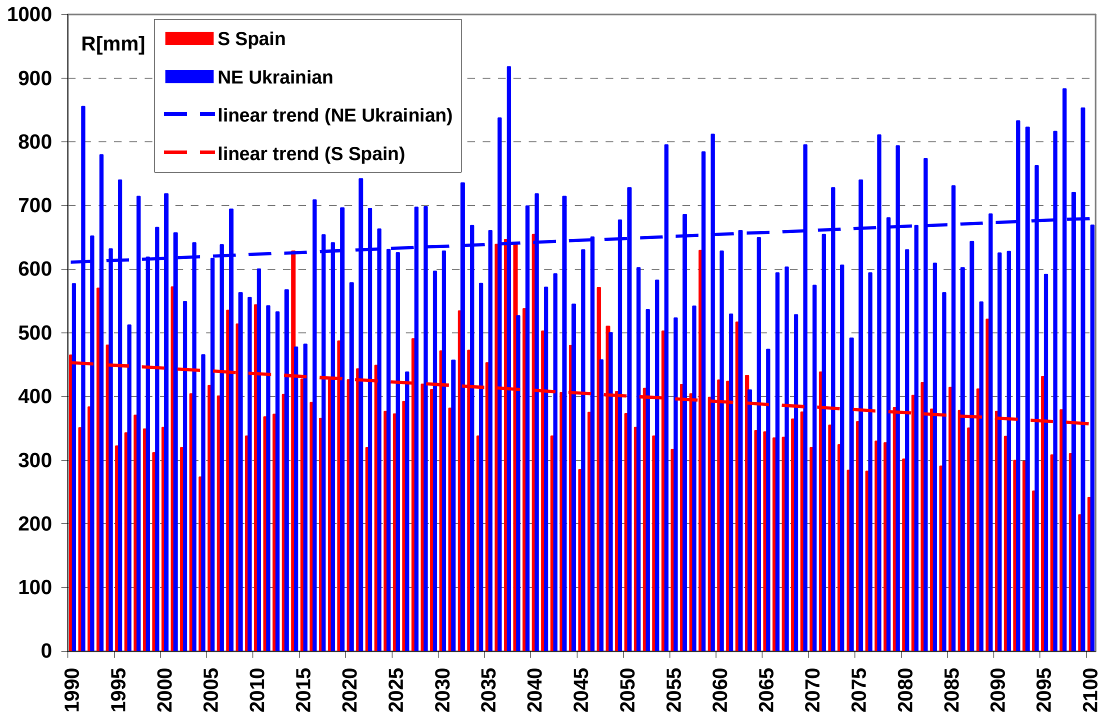


**Fig. 4 Annual precipitation totals [mm] in the southern part of Spain (3.75W; 38.97N) and in the north-eastern part of Ukrainian (33.75E; 50.10N) in 1990-2100 according to CCCM 2000 (not modify model data).**

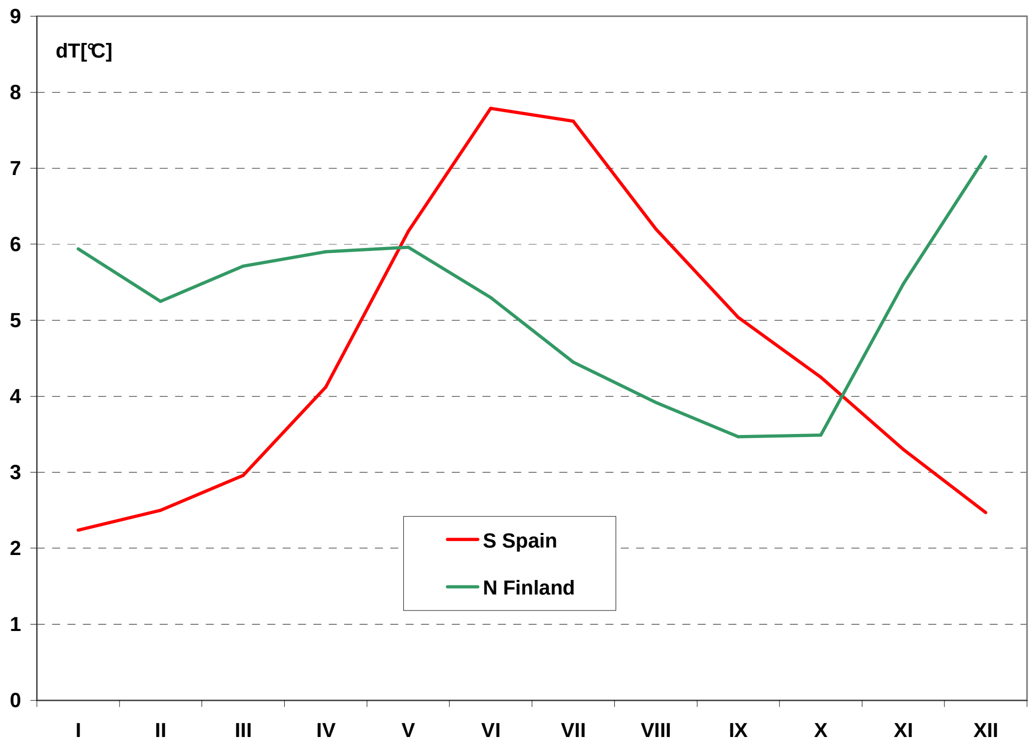


**Fig. 5 Annual course of air temperature changes [°C] in the southern part of Spain (3.75W; 38.97N) and in the northern part of Finland (26.25E; 68.65N) in periods (2071-2100) – (1951-1980) according to CCCM 2000.**

In annual course of air temperature changes higher values of this increase in the southern part of Europe in summer period (June, July and August) in 2071-2100 compared to 1951-1980 are calculated (Fig. 5). In the northern part of Europe higher values of the air temperature increase in winter (especially in February and March, somewhere else in January and December) are expected. On the contrary lower values of this increase in case of the southern Europe in winter and in case of northern Europe in autumn and summer are calculated. In annual course of precipitation totals changes high decrease in summer in the southern Europe (maximally for some grid points in one month up to 75%) and low decrease or even low increase in winter in 2071-2100 compared to 1951-1980 are calculated (Fig. 6). In the northern part of Europe it is increase of precipitation totals in summer (maximally for some grid points in one month up to 40%) and small increase or even decrease in winter. As an example from the southern part of Europe Spain and from the northern part of Europe Finland are chosen (Fig. 5 and 6).

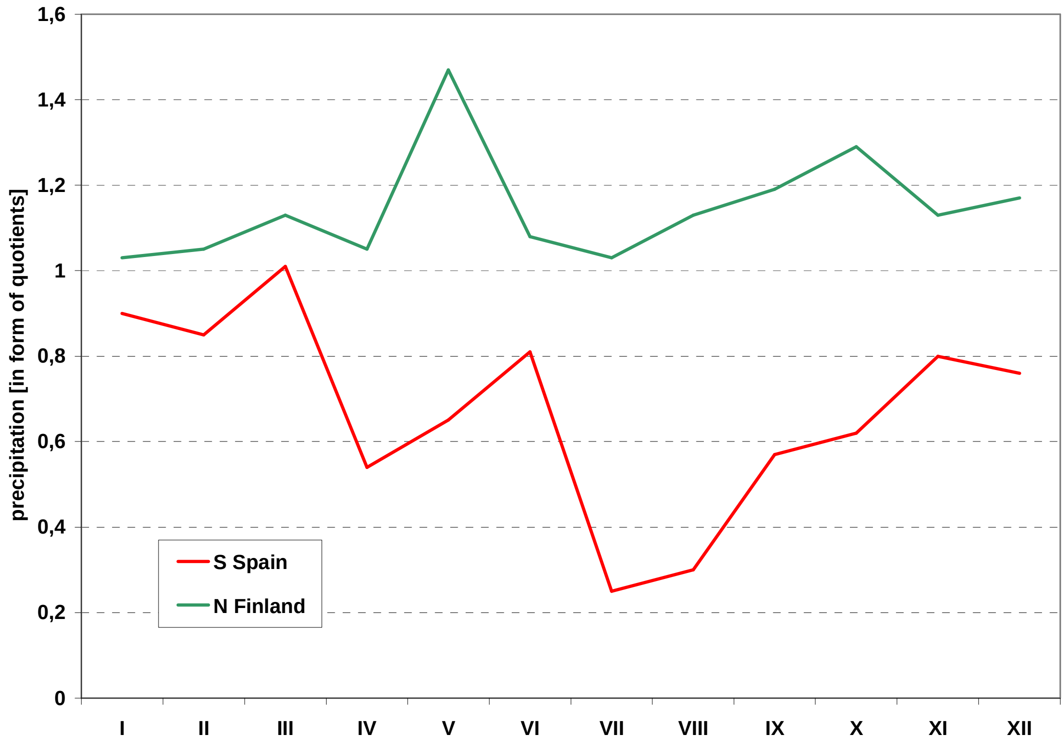


**Fig. 6 Annual course of precipitation totals changes [in form of quotients] in the southern part of Spain (3.75W; 38.97N) and in the northern part of Finland (26.25E; 68.65N) in periods (2071-2100) / (1951-1980) according to CCCM 2000.**

In case of “B2-SRES” scenario the results are slightly different. The “B2-SRES” scenario produces a more modest warming in comparison to the “A2-SRES” scenario. For example annual air temperature means increase in the southeastern part of Poland in 1990-2100 is about 3.0 °C according to “B2-SRES” forcing scenario (linear trend), while according to “A2-SRES” up to 4.6 °C in the same period (Fig. 7). Annual precipitation totals achieve increase about 50 mm in the southeastern part of Poland in 1990-2100 according to “B2-SRES” forcing scenario (linear trend), while according to “A2-SRES” it is decrease about 100 mm in the same period (Fig. 8).

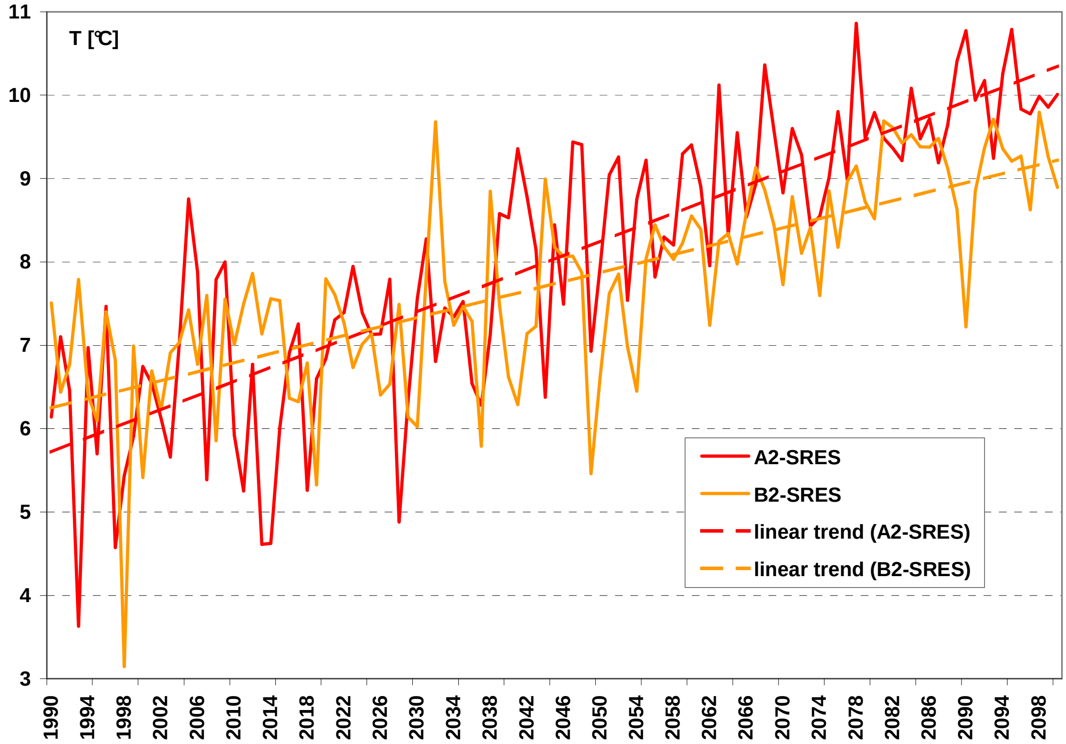


**Fig. 7 Annual air temperature means [°C] in the southeastern part of Poland (22.50E; 50.10N) in 1990-2100 according to “A2-SRES” and “B2-SRES” forcing scenario based on CCCM 2000 (not modify model data).**

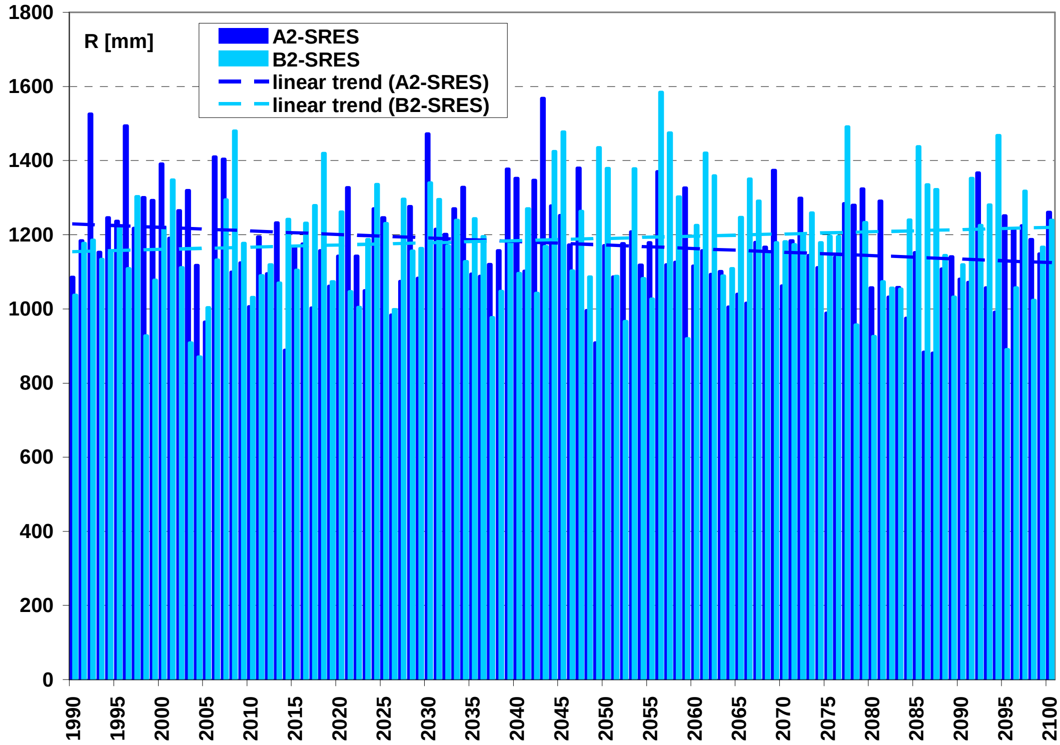


**Fig. 8 Annual precipitation totals [mm] in the southeastern part of Poland (22.50E; 50.10N) in 1990-2100 according to “A2-SRES” and “B2-SRES” forcing scenario based on CCCM 2000 (not modify model data).**

## Conclusion

Air temperature has increased in Europe in the last decades. Results from the Canadian model outputs (CCCM 2000) show at the end of the 21st century additional warming in this territory (with higher value in case of “A2-SRES” forcing scenario). Greater warming over the land than over the ocean is achieved. In the future is appropriate to prepare the similar scenarios of climate change for Europe in the 21st century according to some another climate model because of different structure climate models from another world’s climate centers. Results can be different from model to model in individual climate working groups. Obtained results can be used as inputs for the impacts and vulnerability assessments e.g. mainly in agriculture, forestry and hydrological applications.

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