CLIMATE CHANGE SCENARIOS FOR MACEDONIA

SUMMARY

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Several economic branches, like agriculture, construction, energetic, tourism, etc., strongly depend on weather and climate. Knowing the present and foreseeing the future climate conditions enables an optimal use of natural resources taking into consideration not only economic but also environmental-friendly solutions in an aspiration for a better standard of living.

PRESENT CLIMATE CONDITIONS IN MACEDONIA

Although the entire region of Macedonia is small and comparable to a single grid-cell of current GCMs that are used to simulate the future climate change in a large scale, the heterogeneity of climate conditions on this area is very high. This is also evident from the observations of air temperature and precipitation[1] on selected fifteen meteorological stations (Figure 1, Table 1). The locations represent different climatic types and subtypes in the region of Macedonia, which are a combination of three major climate drivers: Mediterranean, Continental and Alpine climate impacts. According to the climate types proposed by Ristevski (Filipovski et al. 1996; Ristevski, 2006) defined mainly with regards to altitude, and according to the typical annual cycle of mean daily air temperature and precipitation amount (Figure 2) **six** geographical regions of Macedonia were treated separately in our analysis:

1. *south-eastern* part with *sub-Mediterranean* climate;
2. *central* part with combined *sub-Mediterranean / continental* climate;
3. *southern* part with *continental* climate;
4. *south-western* part with *continental* climate;
5. *eastern* part with *continental* climate;
6. *north-western* part with prevailing *mountain / Alpine* climate.
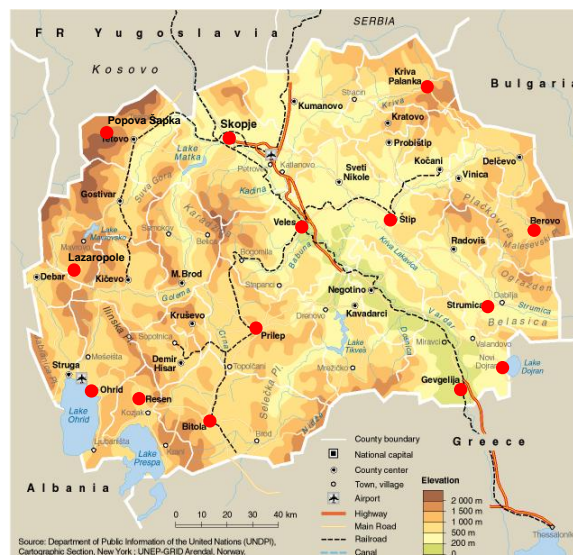

Figure 1: *Approximate locations of selected fifteen meteorological stations in Macedonia.*

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[1] Data were provided by Hydro-meteorological office of Macedonia.

Table 1: *Selected meteorological stations together with their geographical data: λ - longitude, φ - latitude and z - altitude), prevailing climate impacts and geographical region.*

Meteorological station	Geographical data			Prevailing climate impacts	Geographical region
	λ [°V]	ϕ [°S]	z [m]		
Gevgelija	22.50	41.15	57	Sub-Mediterranean	South / East
Nov Dorjan	22.72	41.22	180	Sub-Mediterranean	South / East
Veles	21.77	41.72	175	Sub-Mediterranean / Continental	Central
Strumica	22.65	41.43	224	Sub-Mediterranean / Continental	Central
Skopje Petrovac	21.63	41.95	234	Sub-Mediterranean / Continental	Central
Štip	22.18	42.02	326	Sub-Mediterranean / Continental	Central
Bitola	21.33	41.05	586	Continental	South
Prilep	21.57	41.33	673	Continental	South
Ohrid	20.80	41.12	760	Continental	South / West
Resen	21.02	41.08	881	Continental	South / West
Berovo	22.85	41.72	824	Continental	East
Kriva Palanka	22.33	42.20	691	Continental	East
Lazaropole	20.70	41.53	1332	Mountain / Continental	North / West
Popova Šapka	20.88	42.02	1750	Sub-Alpine	North / West
Solunska Glava	21.42	41.70	2540	Alpine	North / West

CLIMATE CHANGE PROJECTIONS FOR MACEDONIA

General circulation models (GCMs) are commonly used to assess the large-scale response of climate system to different forcings, such as changes in greenhouse gas concentrations. Different emission/concentration scenarios, based on socio-economic storylines that might be accomplished in the 21st century (Houghton et al., 2001), are used as an input to GCMs. Unfortunately, the GCM results are not representative on a regional or even a local-scale, mostly due to the low horizontal resolution and limited description of sub-grid processes. The entire area of Macedonia corresponds to the size of approximately one grid-cell in current GCMs, making it obvious that the GCMs can not explain the spatial variability of Macedonian climate. There is an evident need for methods for regional projections of GCM results to the scale, where the regional details of Macedonian climate are to be captured. There is a gap between large scale, where the GCMs are able to describe the most important climate features, and the local scale, where the climate change scenarios are needed for impact studies.

METHODOLOGY

Empirical downscaling was used to bridge the gap between the large-scale climate variability across the south-eastern Europe and the local-scale climate variability in Macedonia. The basic idea behind empirical downscaling is to use the observed relationships between large-scale climate variables (predictors) and local-scale climate or climate-dependent variable (predictand) for a projection of GCM results on a local level. The empirical model describing the link between the predictand and predictors, together with the credibility of GCM future climate simulations, plays a crucial role in the quality of such projections and resulting regional climate change scenarios.
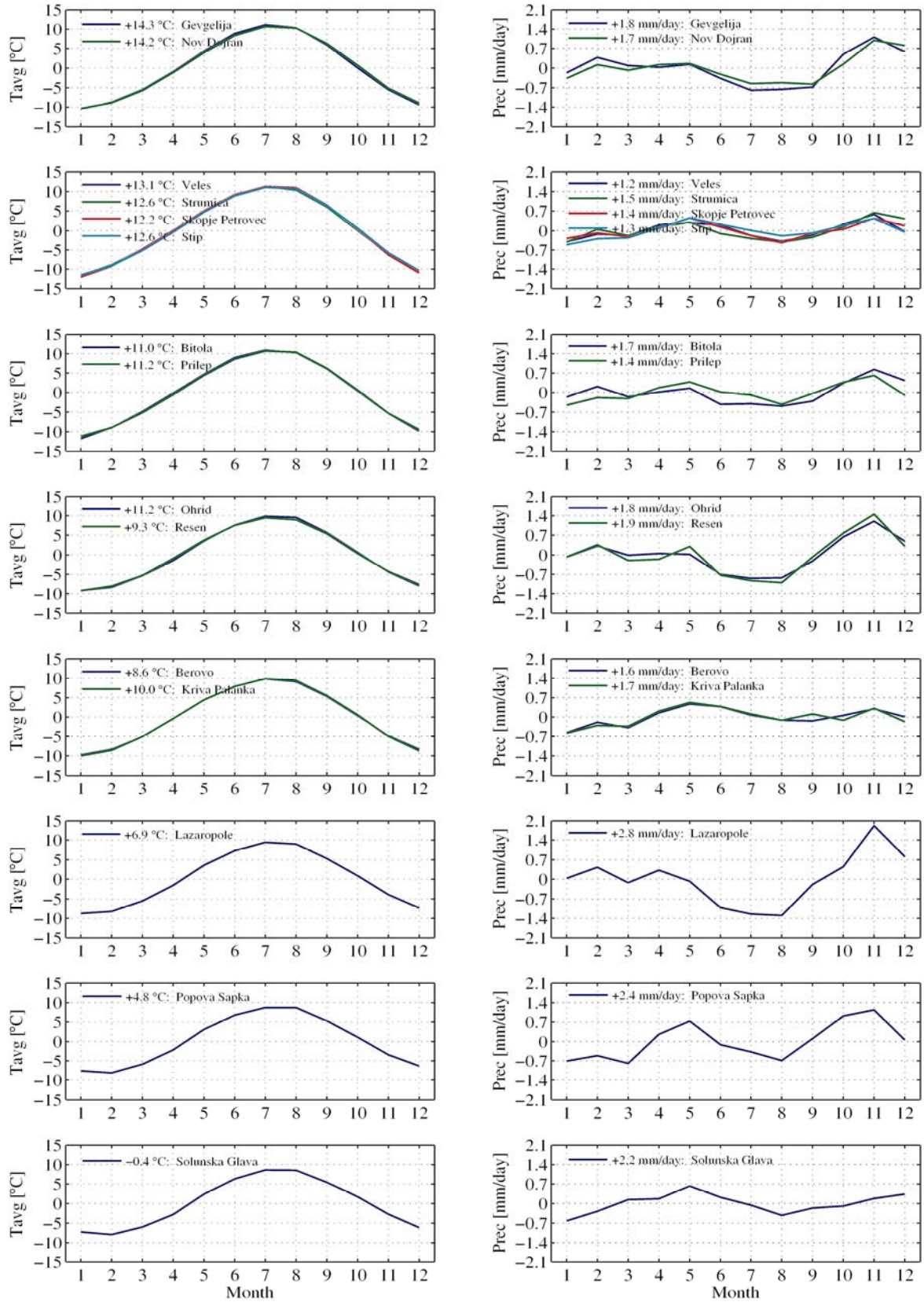
Figure 2: *Annual cycle of air temperature and precipitation amount deviations from average annual values (in figure legends) observed in the period 1961-1990 at different meteorological stations in Macedonia, grouped according to the similarity of annual cycles and average annual values.*

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Local observations of daily air temperature (Tavg) and daily precipitation amount (Prec) from the fifteen meteorological stations were used together with the NCEP/NCAR large-scale reanalysis (Kalnay et al., 1996; Kistler et al., 2001) to describe relationship between large-scale climate variability across south-eastern Europe and local-climate variability in Macedonia. Empirical Orthogonal Functions Analysis (e.g., Preisendorfer, 1988; Storch & Zwiers, 1999) was used to extract important features from large-scale climate variables. These features were related to the local climate variables using Partial Least Squares Regression (e.g., Bro, 1998; Helland, 2001; Martens, 2001). Developed empirical models were used for local climate change projections (Bergant et al, 2005, 2006) of future climate simulation results performed by four GCMs. The GCMs are: Australian CSIRO/Mk2 developed by the Commonwealth Scientific and Industrial Research Organization (Gordon & O'Farrel, 1997), the UKMO/HadCM3 developed by the Hadley Centre of United Kingdom Meteorological Office (Pope et al., 2000; Gordon et al., 2000), the USA DOE-NCAR/PCM developed as a common project of the National Center for Atmospheric Research and Department of Energy (Washington et al., 2000), and the German MPI-DMI/ECHAM4-OPYC3 developed as a common project of the Max Planck Institut für Meteorologie and the Deutsches Klimarechenzentrum (Roeckner et al., 1996; Stendell et al., 2000) (Table 2). For the air temperature a predictor domain extending from 12.5°E to 30.0°E and from 35.0°N to 50.0°N was selected as most suitable, and for precipitation extending from 15.0°E to 27.5°E and from 37.5°N to 47.5°N. Average annual cycle for the reference period 1961-1990 was removed from all monthly values of local and large-scale climate variables and remaining anomalies were used for the development of empirical models. Empirical models were developed separately for the four seasons (winter – DJF, spring – MAM, summer – JJA, and autumn – SON). As the simulations of future climate with GCMs are based on a limited number of emission scenarios, usually SRES A2 and B2, the local climate change projection were additionally scaled to other marker SRES emission scenarios (A1T, A1b, A1Fl, B1) using pattern scaling method (Mitchell, 2003).

Table 2: *General circulation models, the results of which were used in this study: model label, country of development, period for which the data were used, and the approximate horizontal resolution of data.*

Model	Country	Period	Resolution
NCEP/NCAR reanalysis	USA	1961-2005	1,9×1,9°[2]
CSIRO/Mk2 model	Australia	1961-2100	5,6×3,2°
UKMO/HadCM3 model	United kingdom	1961-2099	3,8×2,5°
DOE-NCAR/PCM model	USA	1961-2099	2,8×2,8°
ECHAM4-OPYC3[3] model	Germany	1961-2100	2,8×2,8°

When reporting the climate change estimates we need to define the period that the changes refer to. In our case 1961-1990 (labeled *1990*) was used for a reference period, as

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[2] In case of sea-level pressure data the horizotal resolution of NCEP-NCAR reanalysis is 2.5°×2.5°.

[3] The entire name of the model includes the label of development centers (MPI-DMI/ECHAM4-OPYC3). Data for monthly averages of maximum and minimum daily tempertures were not available for this model.

for this period the available[4] GCM simulations are based on observed concentrations of greenhouse gasses and sulfate aerosols, and after 1990 on SRES emission scenarios. Estimated changes for the periods 1996-2025 (labeled *2025*), 2021-2050 (labeled *2050*), 1946-2075 (labeled *2075*) and 2071-2100 (labeled *2100*) in comparison to 1961-1990 (labeled *1990***)** are presented in the Tables 3 to 6, separately for different geographical sub-regions of Macedonia, as well as for entire country on the base of direct GCM output. As none of the SRES emission scenarios is supposed to be more probable than the others, the values in Tables are presented as the mean values across all six marker scenarios (*mean*), as well as their range across the six emission scenarios using averages across the GCMs (*low/high*).

RESULTS
DIRECT GCM OUTPUT TO THE LEVEL OF ENTIRE COUNTRY – FIRST ESTIMATE

As a first estimate of expected climate change on the level of the entire country, the results of selected GCMs were interpolated to the geographic location 21.5°E and 41.5°N - approximately to the middle of the country – using simple bilinear method (Press et al., 2001). The results of such approach, called direct GCM output, show the highest increase in air temperature till the end of this century and on the level of entire country in summer season together with the most intensive decrease in precipitation. In case of precipitation, practically no change is expected in winter, but a decrease in all other seasons. An increase in average daily temperature range is expected for summer and a small decrease in winter. Details on direct GCM output projections can be found in Table 3.

Although some projected changes for Macedonia might seem very dramatic, especially precipitation and temperature changes for summer period (Table 3), the projected values are in correspondence with the results obtained by MAGICC/SCENGEN[5] software using the same models and all six marker scenarios (not shown here). Generally, if the results of GCMs in a large-scale are realistic also their direct interpolations to location representing Macedonian region should be realistic. A stronger increase of air temperature in summer in comparison to other periods of the year could be related to the expected decrease in precipitation as precipitation has a cooling effect on near ground temperature conditions in summer months. Not only the average temperature should increase in case of decrease in precipitation, but also the temperature range would enlarge if there would be less precipitation and more sunny days. We also have to be aware, that providing precipitation change in percentage, which is common in climate change studies, also has some caveats. The changes for summer period might seem more dramatic in comparison to autumn and spring also due to the fact that there is a minimum of precipitation in most regions of Macedonia in summer months. Consequently, the same absolute change presented as absolute value for summer and autumn can result in a much different relative value presented in %.

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[4] This is true for GCM simulations performed for the third IPCC assessment report - TOR (Houghton et al., 2001), and which were used in our study. Newer results of GCM simulations made recently available at IPCC data distribution centre are based on observed concentrations of greenhouse gasses and sulfate aerosols up to 2000. Due to the limited time for analyses, the newer GCM results performed for the upcoming fourth IPCC assessment report – AR4 were not used in this analysis.

[5] MAGICC-SCENGEN software is freely available at web pages
http://www.cgd.ucar.edu/cas/wigley/magicc/installation.html

Results of direct GCM output are also in correspondence with the results of a PRUDENCE project for Macedonia (PRUDENCE, 2004). Our estimates for temperature and precipitation change in 21st century are more dramatic as estimates based on IS92a and IS92d emission scenarios used in previous study (UNDP Macedonia, 2003). The direction of expected changes (e.g., strongest increase in air temperature in summer, precipitation decrease in summer, etc.) is anyway the same, but the intensity is different. The difference is probably related to the fact that IS92 emission scenarios, proposed by IPCC in 1995, were more optimistic that SRES scenarios proposed in 2001. This can be seen also in global temperature change projections based on IS92 emission scenarios which were lower than those based on SRES scenarios (Houghton et al., 2001). The other reason could be in different GCM models used in both studies.

In case of direct GCM output, additional projections of changes in scalar wind speed (Wind in m/s) and incident solar radiation (Srad in W/m^2) were performed. For both variables relative expected changes are very small, practically not exceeding 10% in either direction when considering the expected range. A minor increase in Srad is expected in all seasons, the highest in summer. The general small increase in incident solar radiation in all seasons, the strongest in summer, is in the correspondence with projected precipitation changes showing the also highest decrease in summer (Table 3). Less precipitation means more clear days and so more solar radiation received at the ground. Practically no change is expected in wind speed over Macedonia when considering direct GCM output of the four GCMs.

*Table 3: Projected changes of average daily air temperature (°C), precipitation (%), incident solar radiation (%) and scalar wind speed (%) for Macedonia based on direct GCM output interpolated to geographic location 21.5°E and 41.5°N with regard to the period 1990. Values are presented separately for different seasons and are based on projections of results from four GCMs (CSIRO/Mk2, HadCM3, ECHAM4/OPYC3, NCAR-PCM) scaled to six emission scenarios (SRES A1T, A1Fl, A1B, A2, B1, and B2). **Mean:** average across different emission scenarios and different GCMs, Low/High: minimum/maximum across different scenarios averaged across different GCMs.*

	AVERAGE TEMPERATURE [°C]																			
	DJF				MAM				JJA				SON				ANNUAL			
	2025	2050	2075	2100	2025	2050	2075	2100	2025	2050	2075	2100	2025	2050	2075	2100	2025	2050	2075	2100
Low	0.7	1.4	1.8	2.2	0.7	1.3	1.8	2.2	1.2	2.2	3.2	3.7	0.8	1.5	2.2	2.6	0.9	1.6	2.2	2.7
Mean	0.8	1.7	2.3	3.0	0.8	1.5	2.2	3.2	1.4	2.5	4.1	5.4	0.9	1.7	2.8	3.7	1.0	1.9	2.9	3.8
High	0.9	1.9	2.9	4.2	0.9	1.8	2.9	4.6	1.7	2.9	5.1	7.6	1.1	2.0	3.6	5.3	1.1	2.1	3.6	5.4

	PRECIPITATION [%]																			
	DJF				MAM				JJA				SON				ANNUAL			
	2025	2050	2075	2100	2025	2050	2075	2100	2025	2050	2075	2100	2025	2050	2075	2100	2025	2050	2075	2100
Low	1	5	3	4	-3	-2	-7	-5	2	-16	-21	-21	2	-2	0	-5	-1	-2	-4	-5
Mean	0	1	2	-1	-5	-6	-10	-13	-7	-17	-27	-37	-1	-4	-9	-13	-3	-5	-8	-13
High	-2	-1	1	-3	-7	-10	-13	-22	-24	-18	-33	-53	-3	-7	-17	-23	-6	-7	-12	-21

	INCIDENT SOLAR RADIATION [%]																			
	DJF				MAM				JJA				SON				ANNUAL			
	2025	2050	2075	2100	2025	2050	2075	2100	2025	2050	2075	2100	2025	2050	2075	2100	2025	2050	2075	2100
Low	0	0	1	1	1	2	4	4	2	3	6	6	1	1	5	5	1	2	5	4
Mean	1	1	2	2	2	3	5	6	3	4	7	8	2	3	6	7	2	3	5	6
High	2	2	2	3	3	4	6	9	4	6	8	11	3	5	7	10	3	4	6	9

	SCALAR WIND SPEED [%]																			
	DJF				MAM				JJA				SON				ANNUAL			
	2025	2050	2075	2100	2025	2050	2075	2100	2025	2050	2075	2100	2025	2050	2075	2100	2025	2050	2075	2100
Low	2	1	1	0	0	3	2	3	-2	0	2	2	-1	-6	-2	-5	0	0	1	0
Mean	3	2	1	0	2	4	2	3	0	1	2	2	-1	-4	-1	-3	1	1	1	1
High	3	3	3	1	5	5	3	4	3	2	2	3	0	0	-1	0	3	2	2	1

SOUTH-EASTERN AND CENTRAL PART OF MACEDONIA / SUB-MEDITERRANEAN

If we compare empirical downscaling projections for the region of the south-eastern Macedonia with prevailing sub-Mediterranean climate impact (represented by Gevgelija and Nov Dorjan) and for the central Macedonia under a combination of continental and sub-Mediterranian climate impacts (represented by Veles, Skopje – Petrovec, Strumica and Štip), a less intensive temperature change is evident for the first one in winter and more intensive in summer and autumn. Changes of air temperature in spring are comparable in both sub-regions. In both sub-regions the highest increase of air temperature is expected in summer. The difference between winter and summer increase in air temperature is especially evident for south-eastern region. The expected changes in precipitation are similar for both sub-regions. Practically no change in precipitation is expected in winter season and a decrease in precipitation in all other seasons. More detailed results for these two regions are presented in Table 4.

SOUTHERN AND SOUTH-WESTERN PART OF MACEDONIA / CONTINENTAL

Both, southern (represented by Bitola and Prilep) and south-eastern (represented by Ohrid and Resen) parts of Macedonia are under the prevailing continental climate impacts according to the classification proposed by Ristevski (2006). The climate change projections for these two regions are quite different although not very remote to each other. In case of southern region represented by Bitola and Prilep the projections of precipitation change are very similar to the regions with prevailing or partial sub-Mediterranean climate impacts. Almost no change of precipitation is expected in winter and decrease in other seasons, the strongest in summer. A slightly stronger signal in temperature change is expected for this region in comparison to regions with sub-Mediterranean climate impacts. The difference is especially evident in projections for winter period. On the contrary, projections of temperature changes for the south-western region represented by Ohrid and Resen are much lower than for region represented by Bitola and Prilep. Additionally even a slight increase of precipitation is expected for winter, but an evident decrease in other seasons. The different response of these two regions on large scale climate variability could be related to the proximity of large water bodies (lake Prespa and lake Ohrid) in case of Resen and Ohrid stations. On the other hand we need to be aware that our projections are based on empirical models that could be biased by an artificial signal invoked in the data used for model calibration. For example, there are some well known problems with the data in case of Bitola station (see Trajanovska et al., 2004) that might bias the projection models. Details on projections of changes of selected local climate variables for stations Bitola and Prilep, as well as Ohrid and Resen can be found in Table 5.

EASTERN PART OF MACEDONIA / CONTINENTAL

For representatives of eastern part of Macedonia with prevailing continental climate impacts, stations Berovo and Kriva Palanka were used. The annual pattern of expected temperature change in this region is similar to the pattern for continental region in southern part of Macedonia, but the intensity of the change is slightly lower. A comparison to Bitola and Prilep also shows a slight increase of precipitation is expected in winter, but decrease in all other seasons, most intensive in relative sense in summer. In summer as well as in autumn, an increase in daily air temperature range is expected. Details on projections of changes of selected local climate variables for stations Berovo and Kriva Palanka can be found in Table 6.

NORTH-WESTERN PART OF MACEDONIA / ALPINE

For all three climate subtypes under the mountainous influence (mountain/continental, sub-Alpine, Alpine) that can be found in north-weastern part of Macedonia and are represented by stations Lazaropole, Popova Šapka and Solunska Glava, the projections of air-temperature change and precipitation are very similar. An increase of precipitation for a few percent till the end of 21st century is expected in winter and a more intense decrease in all other seasons. The expected air temperature change is the strongest in this region of the country. The highest increase in air temperature is expected in summer, but the difference between seasons is not large. More detailed results for these two climatic regions are presented in Table 6.

Table 4: Projected changes of average daily air temperature (°C) and precipitation (%) for central part of Macedonia under a combination of sub-Mediterranean and continental climate impacts (represented by locations Veles, Strumica, Skopje-Petrovec, Štip) and for south-eastern part of Macedonia under the sub-Mediterranean climate impacts (represented by locations Gevgelija and Nov Dojran). Values are presented separately for different seasons with regards to the reference period 1990 and are based on projections of results from four GCMs (CSIRO/Mk2, HadCM3, ECHAM4/OPYC3, NCAR-PCM) scaled to six emission scenarios (SRES A1T, A1Fl, A1B, A2, B1, and B2). Mean: average across different emission scenarios and different GCMs, Low/High: minimum/maximum across different scenarios averaged across different GCMs.

	Central part of Macedonia under the combination of sub-Mediterranean and continental climate impacts																			
	AVERAGE TEMPERATURE [°C]																			
	DJF				**MAM**				**JJA**				**SON**				**ANNUAL**			
	2025	2050	2075	2100	2025	2050	2075	2100	2025	2050	2075	2100	2025	2050	2075	2100	2025	2050	2075	2100
Low	0.9	2.0	2.5	3.1	1.0	1.8	2.4	3.0	1.1	2.2	3.2	3.7	0.9	1.6	2.3	2.7	1.0	1.9	2.6	3.1
Mean	1.0	2.3	3.2	4.3	1.1	2.1	3.1	4.3	1.4	2.6	4.0	5.4	1.0	1.8	3.0	3.9	1.1	2.2	3.3	4.5
High	1.2	2.6	4.0	6.0	1.3	2.5	3.9	6.1	1.7	2.9	5.1	7.6	1.1	2.1	3.8	5.5	1.2	2.5	4.2	6.3
	PRECIPITATION [%]																			
	DJF				**MAM**				**JJA**				**SON**				**ANNUAL**			
	2025	2050	2075	2100	2025	2050	2075	2100	2025	2050	2075	2100	2025	2050	2075	2100	2025	2050	2075	2100
Low	2	6	4	4	-4	-3	-8	-6	-1	-10	-14	-15	0	-4	0	-6	-1	-3	-5	-6
Mean	0	1	2	-1	-5	-7	-11	-14	-6	-11	-18	-23	-1	-6	-11	-17	-3	-6	-9	-13
High	-3	-2	1	-3	-8	-11	-15	-24	-15	-13	-22	-33	-2	-8	-20	-27	-6	-8	-13	-21
	South-eastern part of Macedonia under the sub-Mediterranean and continental climate impacts																			
	AVERAGE TEMPERATURE [°C]																			
	DJF				**MAM**				**JJA**				**SON**				**ANNUAL**			
	2025	2050	2075	2100	2025	2050	2075	2100	2025	2050	2075	2100	2025	2050	2075	2100	2025	2050	2075	2100
Low	0.9	1.8	2.3	2.8	1.0	1.8	2.4	3.0	1.3	2.5	3.6	4.2	1.0	1.8	2.5	3.0	1.1	2.0	2.7	3.2
Mean	1.0	2.1	2.9	3.8	1.1	2.1	3.1	4.3	1.5	2.9	4.5	6.0	1.1	2.0	3.3	4.3	1.2	2.3	3.4	4.6
High	1.1	2.4	3.6	5.3	1.3	2.5	3.9	6.0	1.9	3.3	5.7	8.5	1.2	2.3	4.1	6.0	1.3	2.6	4.3	6.5
	PRECIPITATION [%]																			
	DJF				**MAM**				**JJA**				**SON**				**ANNUAL**			
	2025	2050	2075	2100	2025	2050	2075	2100	2025	2050	2075	2100	2025	2050	2075	2100	2025	2050	2075	2100
Low	-1	4	0	1	-3	-3	-9	-8	1	-7	-10	-11	2	-1	0	-5	-1	-1	-4	-5
Mean	-2	0	-1	-3	-6	-8	-13	-17	-4	-9	-14	-19	1	-4	-9	-14	-3	-5	-9	-12
High	-4	-3	-2	-5	-9	-13	-17	-27	-12	-11	-18	-27	-1	-6	-17	-25	-5	-7	-12	-20

*Table 5: Projected changes of average daily air temperature (°C) and precipitation (%) for **southern part of Macedonia under continental climate impacts** (represented by locations Bitola and Prilep) and for **south-western part of Macedonia as well under the continental climate impacts** (represented by locations Ohrid and Resen). Values are presented separately for different seasons with regards to the reference period 1990 and are based on projections of results from four GCMs (CSIRO/Mk2, HadCM3, ECHAM4/OPYC3, NCAR-PCM) scaled to six emission scenarios (SRES A1T, A1Fl, A1B, A2, B1, and B2). **Mean:** average across different emission scenarios and different GCMs, **Low/High:** minimum/maximum across different scenarios averaged across different GCMs.*

	DJF				MAM				JJA				SON				ANNUAL			
Southern part of Macedonia under the continental climate impacts **AVERAGE TEMPERATURE [°C]**																				
	2025	2050	2075	2100	2025	2050	2075	2100	2025	2050	2075	2100	2025	2050	2075	2100	2025	2050	2075	2100
Low	1.1	2.4	3.1	3.8	1.1	2.0	2.7	3.4	1.2	2.4	3.4	3.9	1.0	1.9	2.6	3.1	1.1	2.2	3.0	3.6
Mean	1.2	2.7	3.9	5.3	1.2	2.3	3.4	4.8	1.5	2.7	4.3	5.7	1.1	2.1	3.4	4.5	1.2	2.5	3.8	5.1
High	1.4	3.2	5.0	7.4	1.4	2.8	4.4	6.9	1.9	3.1	5.4	8.0	1.2	2.4	4.4	6.4	1.4	2.9	4.8	7.2
PRECIPITATION [%]																				
	2025	2050	2075	2100	2025	2050	2075	2100	2025	2050	2075	2100	2025	2050	2075	2100	2025	2050	2075	2100
Low	0	4	0	1	-3	-3	-8	-7	1	-10	-13	-14	0	-3	0	-6	-1	-3	-4	-6
Mean	-1	-1	-1	-3	-5	-7	-11	-14	-5	-12	-17	-22	-1	-5	-10	-15	-3	-5	-9	-13
High	-3	-3	-1	-6	-8	-10	-14	-22	-15	-14	-22	-31	-2	-6	-18	-26	-6	-8	-13	-21
South-western part of Macedonia under the continental climate impacts **AVERAGE TEMPERATURE [°C]**																				
	2025	2050	2075	2100	2025	2050	2075	2100	2025	2050	2075	2100	2025	2050	2075	2100	2025	2050	2075	2100
Low	0.8	1.8	2.3	2.8	0.9	1.7	2.2	2.8	0.9	1.7	2.5	2.9	0.8	1.4	2.0	2.4	0.9	1.7	2.3	2.7
Mean	0.9	2.0	2.9	3.9	1.0	1.9	2.9	4.1	1.1	2.0	3.1	4.2	0.9	1.6	2.7	3.5	0.9	1.9	2.9	3.9
High	1.0	2.3	3.7	5.4	1.2	2.3	3.6	5.8	1.3	2.3	4.0	5.9	0.9	1.9	3.4	4.9	1.1	2.2	3.7	5.5
PRECIPITATION [%]																				
	2025	2050	2075	2100	2025	2050	2075	2100	2025	2050	2075	2100	2025	2050	2075	2100	2025	2050	2075	2100
Low	3	8	9	9	-3	-2	-7	-5	1	-8	-11	-12	-1	-4	0	-6	-1	0	-1	-2
Mean	2	3	7	5	-5	-5	-9	-12	-3	-9	-13	-18	-2	-5	-10	-15	-2	-3	-5	-8
High	0	0	6	2	-7	-8	-12	-20	-12	-10	-16	-25	-3	-7	-18	-25	-3	-5	-7	-14

*Table 6: Projected changes of average daily air temperature (°C) and precipitation (%) for **eastern part of Macedonia under continental climate impacts** (represented by locations Kriva Palanka and Berovo) and for **north-western part of Macedonia under the prevailing Alpine impacts** (represented by locations Lazaropole, popova {apka, and Solunska Glava). Values are presented separately for different seasons with regards to the reference period 1990 and are based on projections of results from four GCMs (CSIRO/Mk2, HadCM3, ECHAM4/OPYC3, NCAR-PCM) scaled to six emission scenarios (SRES A1T, A1Fl, A1B, A2, B1, and B2). **Mean:** average across different emission scenarios and different GCMs, **Low/High:** minimum/maximum across different scenarios averaged across different GCMs.*

*Eastern part of Macedonia under the continental climate impacts*																				
**AVERAGE TEMPERATURE [°C]**																				
	DJF				MAM				JJA				SON				ANNUAL			
	2025	2050	2075	2100	2025	2050	2075	2100	2025	2050	2075	2100	2025	2050	2075	2100	2025	2050	2075	2100
Low	1.0	2.1	2.7	3.3	1.0	1.8	2.4	3.0	1.1	2.2	3.1	3.6	0.9	1.7	2.4	2.9	1.0	2.0	2.7	3.2
Mean	1.1	2.4	3.4	4.6	1.1	2.1	3.1	4.3	1.3	2.5	3.9	5.2	1.0	1.9	3.2	4.2	1.1	2.2	3.4	4.6
High	1.3	2.8	4.3	6.4	1.3	2.5	3.9	6.1	1.7	2.8	5.0	7.4	1.2	2.2	4.0	5.8	1.3	2.6	4.3	6.4
**PRECIPITATION [%]**																				
	DJF				MAM				JJA				SON				ANNUAL			
	2025	2050	2075	2100	2025	2050	2075	2100	2025	2050	2075	2100	2025	2050	2075	2100	2025	2050	2075	2100
Low	5	9	11	11	-3	-2	-6	-5	0	-8	-11	-12	-2	-6	-1	-6	-1	-2	-3	-4
Mean	2	4	8	6	-4	-5	-9	-11	-4	-10	-14	-20	-2	-7	-11	-15	-2	-5	-7	-10
High	0	1	7	3	-6	-8	-12	-19	-13	-11	-18	-28	-3	-9	-19	-25	-6	-7	-10	-17
*North-western part of Macedonia under the prevailing Alpine climate impacts*																				
**AVERAGE TEMPERATURE [°C]**																				
	DJF				MAM				JJA				SON				ANNUAL			
	2025	2050	2075	2100	2025	2050	2075	2100	2025	2050	2075	2100	2025	2050	2075	2100	2025	2050	2075	2100
Low	1.2	2.4	3.0	3.7	1.2	2.2	2.9	3.7	1.3	2.5	3.5	4.1	1.0	1.9	2.7	3.2	1.2	2.3	3.0	3.7
Mean	1.2	2.7	3.8	5.2	1.3	2.5	3.7	5.3	1.5	2.8	4.5	5.9	1.1	2.2	3.6	4.7	1.3	2.6	3.9	5.3
High	1.4	3.2	4.9	7.3	1.5	3.0	4.8	7.5	1.9	3.2	5.6	8.3	1.3	2.6	4.6	6.7	1.5	3.0	5.0	7.4
**PRECIPITATION [%]**																				
	DJF				MAM				JJA				SON				ANNUAL			
	2025	2050	2075	2100	2025	2050	2075	2100	2025	2050	2075	2100	2025	2050	2075	2100	2025	2050	2075	2100
Low	3	9	9	10	-2	-1	-5	-4	0	-7	-11	-12	-1	-4	0	-5	0	-1	-2	-2
Mean	2	4	7	5	-4	-4	-7	-10	-4	-9	-13	-18	-2	-5	-9	-14	-2	-3	-5	-8
High	0	1	6	2	-5	-6	-10	-17	-11	-10	-16	-26	-2	-7	-17	-24	-4	-5	-8	-15

UNCERTAINTIES IN REGIONAL CLIMATE CHANGE PROJECTIONS

We need to be aware, that any future climate change study on a global, regional, or local level is and will be attributed to some uncertainty. The basic sources of uncertainty, which can not be avoided from the very beginning of climate change scenario development, are the assumptions about future socio-economic development and related emissions of greenhouse gasses and sulfur dioxide. Such scenarios are used in simulations of future climate with GCMs. Different GCMs respond slightly different to identical concentrations of greenhouse gasses and sulfate aerosols, which introduces additional uncertainty to the simulations of future climate. Such climate model shortcomings are another source of uncertainty and are mainly related to a crude description of unresolved processes using statistical parameterization schemes (Benestad, 2002). To consider this uncertainty, at least to some level, the results of different GCMs were used in our study. GCMs are able to simulate reliably the most important features of the global climate on a large-scale (Zorita and Storch, 1999), but fail on a regional or even a local-scale, mostly due to the low horizontal resolution and limited description of sub-grid processes (Grotch and MacCracken, 1991). As different approaches can be used to bridge the gap between large-scale and scale of an impact study, the selection of the method can also introduce some uncertainty, especially if projection models are used in the extrapolation mode. In our case only one downscaling method was used, so the uncertainty related to selection of method was not evaluated. Both parameterizations schemes in RCMs and empirical models are based on the range of observed values, which could be exceeded in the future. The observation datasets commonly contain errors, as found also in the case of local meteorological data available for our study. Such errors can bias the developed projection models and related projections of future climate change, especially as the models are often used in an extrapolation model. Good quality observations of present climate and procedures for quality checking of the data are basic needs for any future climate change study. The results of regional/local projections are commonly used further in impact models, which introduce additional uncertainty to the final results. And at the end an expert opinion on results is needed, which is often not derived simple from the obtained results.

Due to the mentioned sources of uncertainties we have to keep in mind that the projections of future climate are not exact predictions but indices in which direction the climate change might develop. One of the questions with regards to the uncertainty is the accuracy that should be used when reporting such "uncertain" projections or using them in impact studies. As the range of uncertainty for future projections usually arise with a time distance from present as well as with the magnitude of projected change, it is not reasonable to consider projections with a constant accuracy over the entire period of 21st century. A reasonable approach would be for example to use air temperature projections with an accuracy of 0.1°C for the period 2025, 0.2°C for the period 2050, 0.3° for the period 2075 and 0.5° for the period 2100. In case of precipitation projections, which are even more uncertain than air temperature projections, higher accuracy than 5% for the entire period of 21st century is not reasonable.

Different assumptions and limited descriptions of real processes within the entire procedure of developing the regional climate change scenarios contribute to the uncertainty in final results. Some of these uncertainties will probably be reduced in the future by gaining new knowledge on climate system response to the changes in the atmospheric composition, and about response of climate dependent processes and activities to climate variability.

Better description of model physics and better horizontal resolution of GCMs will reduce the importance of downscaling approaches and the uncertainties related to that, and will probably also reduce the inter-model differences. More reliable estimates of the climate systems response to the changed boundary conditions (concentrations of greenhouse gasses and different aerosols) will be available even on a regional or local level. Different laboratory and field experiments will deepen the knowledge about response and adaptation capability of different organisms or entire ecosystems to the changed environmental conditions. But still at least the problem of reasonable estimation of climate boundary conditions change in the future will always remain as a basic source of the uncertainty in any climate change impact study.

GENERAL CONCLUSSIONS

The direct GCM output projected to Macedonia show more intensive increase in air temperature in summer season than in winter season. The expected change in air temperature in 21st century is much higher that expected global temperature change, but the results of our study are consistent with other available studies that include Macedonian region. Almost no change in precipitation is expected for winter season in general on the area of Macedonia, but quite a strong decrease in summer precipitation. A daily temperature range is supposed to decrease in winter and increase in summer.

The local projections of climate change indicate that different climatic regions of Macedonia will respond slightly different on large-scale climate changes. The continental climate region in south-western part of Macedonia, close to the Ohrid and Prespa lakes, seems to have the weakest response to large-scale climate change in a sense of absolute temperature and precipitation changes, and the north-western part under the prevailing mountain/Alpine climate impact the strongest response. In mentioned regions the difference between a strong increase in temperature in summer season and weaker in winter season is not that evident as in sub-Mediterranean climate region. In general, temperature change projections based on empirical downscaling are higher that those based on direct GCMs, with an exception of summer season as well as all seasons for south-western part of the country. Also the projected relative precipitation decrease for summer period is more dramatic in case of direct GCM output in comparison to the local projections.

Although empirical downscaling projections of climate change on local level present a step forward towards the needed knowledge about how different sub-regions of Macedonia might response to large-scale climate change, we need to be ware of the uncertainties related to the results before using them in impact studies.

Due to the availability of only monthly averages of local and large-scale climate data, only the expected changes of average climate conditions in Macedonia were estimated. No reasonable estimate on changes of variability could be made using available data.

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