PROJECTED CHANGES OF CLIMATE MEANS AND VARIABILITY IN THE UPPER AND MIDDLE DANUBE CATCHMENT WITH RESPECT TO THE HYDROLOGICAL RISKS

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ABSTRACT. - Projected Changes Of Climate Means And Variability In The Upper And Middle Danube Catchment With Respect To The Hydrological Risks. Present climate conditions endure a wide set of risks especially for hydrology and water management. The projected changes of climate possibly contribute to some of them with likely increasing extremities in several diurnal and longer-time anomalies. The present study comprises the changes of temperature and precipitation means and of diurnal standard deviations, as projected by 17 contemporary GCMs along a temperate latitude belt, including the Alpine Carpathian region. The 45-50° N belt is selected, exhibiting wide variety of lowlands and mountains, warm and cold sectors of oceans. The MAGICC/SCENGEN version 4.1 software (Wigley et al., 2003) is used to obtain and synchronise the model outputs. The aim of the study is to assess the quality and divergence of regional simulations, and to see the geographical differences within the geographical belt, with special regard to the upper and middle Danube catchment. Results related to 2025 are demonstrated, expecting a moderate IPCC greenhouse-warming scenario. Some hydrological consequences of the projected changes in the behaviour of the means and of the diurnal standard deviations are also outlined. They mainly increase the risks caused by long-term negative and short-term positive extremes of water supply in the Alpine-Carpathian region of our focus.

1. Introduction

The IPCC Third Assessment Report (2001) suggests, among others, that similarly to many regions of the World, eastern and central European countries could become vulnerable to the global warming. Many investigations support these findings e.g. in the Carpathian Basin: next to rising temperature means, severe shortage of precipitation occurred in the last few decades, therefore, ecosystems is facing to high risk of ecological changes, as well.

Since climate is widely accepted as changing phenomenon, risk and uncertainty is also related to this paradigm. Although, both terms exhibit strict mathematical fundaments (e.g. Morgan, M.G., and M. Henrion, 1990), both the probabilities and the individual damage (sometimes called function of loss, or benefit, depending on the processes or events) is difficult to quantify. Diversity of

factors affect both values, interdependence of these factors, their variability, structural and dynamical complexity largely obstacle the exact estimation of these values, too.

Due to the quantitative uncertainties with these exact terms of decision, and also due to the aim of getting wider acknowledgement all practical consequences by the decision-makers and by the public, there is a clear intention to translate everything into the everyday language (Patt and Schrag, 2003). On the other hand, since not far not all parameters of the decision matrices, that tackle the risks and uncertainties, can objectively delimited in the practice, expert judgements are sometimes also involved (Morgan and Keith, 1995)

Parallel to the changes of precipitation, that are not unequivocal in space (e.g. Mika and Bálint, 2000), frequent extreme events (e.g., floods with fast runoff and persistent droughts) may occur, result in unstable climate conditions and increased vulnerability of water management in the region. Similar estimations of precipitation and runoff tendencies and extremes are forwarded by Pándi and Mika (2003), considering the much smaller Transylvanian Basin of the Carpathians. Special attention is turned to some types of hydrological risk under principally changing environment by Sorochovski and Pándi (2002a,b) Direct statistical relation between local soil moisture, expressed by Palmer Drought Severity Index, is demonstrated e.g. by Mika (1998). These studies, among others, highlight the importance of climate change scenarios for the region even from this, the risk and uncertainty point of view.

Local climate change is, however, strongly influenced by several geographical features such as mountains, which are not well represented in global climate models because of their coarse resolution. Limited resolution of the current Ocean Atmosphere General Circulation Models (OAGCMs) is a major constraint of involving climate projection into long-term planning of flood-mitigation construction and water resource management. Nevertheless, until coupled mezo-scale models become widely verified and accepted tool, these models are the only physical approaches to estimate regional features of the expected global warming.

In this paper results of 17 GCMs are presented. The model outputs are obtained and synchronised by the MAGICC/SCENGEN 4.1 diagnostic software tool (Wigley et al, 2003). The aim of the investigation was to compare changes and variability in temperature and precipitation along the selected temperate latitude belt which includes majority of the Danube catchment. The presented results focus on two climate elements, the temperature and precipitation for the year 2025, compared to the 1961-1990 reference period.

After description of the investigated region of the study (Section 2) and introduction of the MAGICCC/SCENGEN software (Section 3), results of the GCM-analyses follow in Section 4. Likely consequences of the expected risks on hydrology and water management are listed in the Conclusions (Section 5).

2. The investigated regions

The investigated belt is set between the 45-50°N latitudes. It has been chosen first because it includes the Danube catchment, and it also contains a wide variety of lowlands and mountains, warm and cold sectors of oceans, what makes the comparative research more conducive.

In favour of comparability and transparency, 10 sample area has been defined within the temperate belt. Every entitled area contains 5-5 rectangles of 5° long. x 5° lat. sized fields (Figure 1).

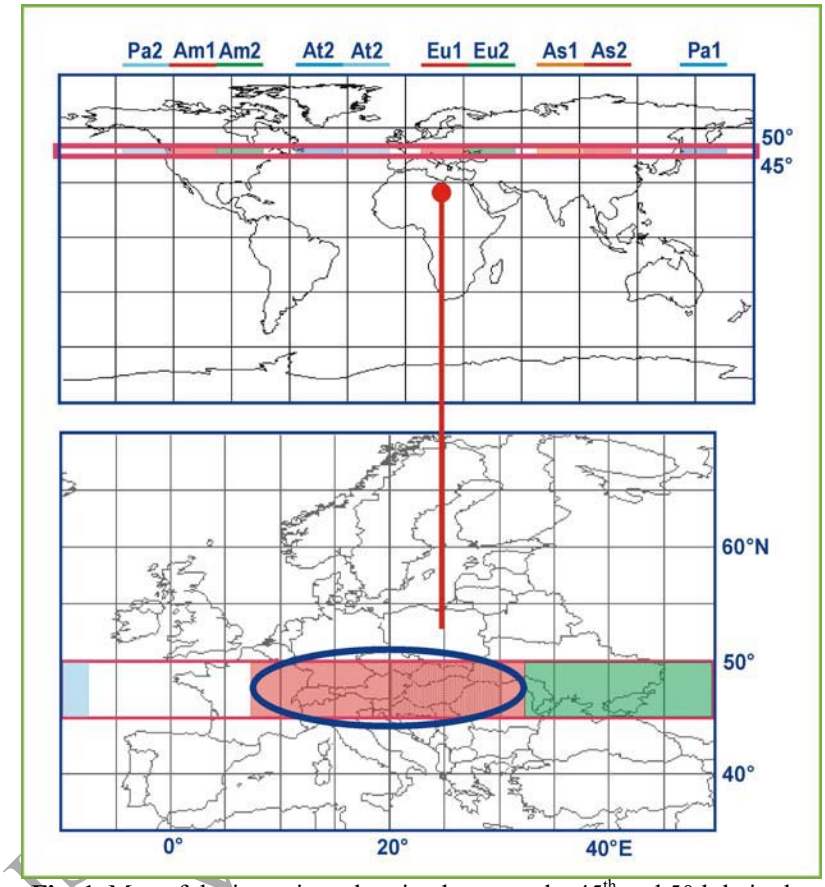


Fig. 1. Map of the investigated region between the 45th and 50th latitudes
Pa1 and Pa2 : the Pacific: (1) cold resp.(2) warm current
Am1 and Am2 : North-America: (1) mountains resp. (2) plains and lakes
At1 and At2 : the Atlantic: (1) cold resp.(2) warm current
Eu1 and Eu2 : Europe: (1) mountains (the Alps, the Carpathians) resp. (2) plains
As1 and As2 : Asia: (1) table-land, mountains resp. (2) mountains
The highlighted Eu1 region represents the Danube catchment.

In terms of the Danube catchment the so-called, Eu1 sector is considered which is set between the 7.5 – 32.5 °E longitudes. The region contains parts of France, Italy, Switzerland, Germany, Austria, Hungary, Poland, Slovenia, Czech Republic and Slovakia. With regard to the geographical features, the area includes the Alps, the Po plain, large part of the Tatra Mountains, the Carpathians, the Carpathian Basin, the Polish lowland, the Transylvanian Basin and the table-land of Podolia.

3. The MAGICC/SCENGEN software

In order to generate climate scenario on local and regional scales, a relatively simple tool, namely, the MAGICC/SCENGEN software package (Wigley et al., 2003, Hulme et al., 1995, Hulme et al., 2000) was applied. The program has several versions. We used the latest one, the MAGICC/SCENGEN 4.1, released in September 2003. The 4.1 version of the Climate Scenario Generator differs from the former 2.4 (Wigley et al., 2000) not only with the improvement of the software, but it is based on more recent set of GCM results. All these newer GCMs were evaluated by the Third Assessment Report of the IPCC (2001).

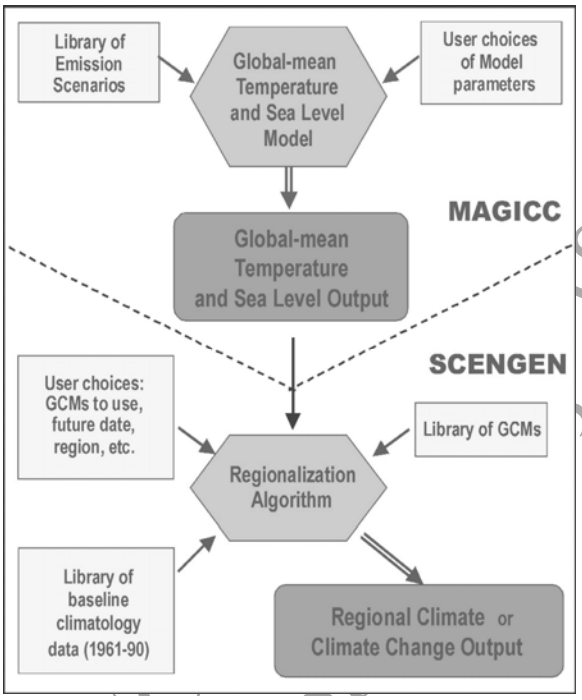


Fig. 2. A schematic diagram showing the main inputs, operations and outputs of MAGICC/SCENGEN 4.1 (Wigley et al. 2003)

The global section of the package, the MAGICC, is based on an upwelling diffusion energy balance model calibrated by global sensitivity of the GCMs outputs and it applies several IPCC emission scenarios (see Figure 2). For a selected belt, a statistical analysis based on a large number of GCM output fields may reduce the existing high uncertainty of climate prediction. In this paper 17 GCMs treated by the package are considered (Table 1).

Results related to the year 2025 are mainly demonstrated, expecting a moderate IPCC greenhouse-warming scenario. Differences between the individual model outputs are not reflected in the present study.

Of course, there are more sophisticated techniques to join introduce existing uncertainty of the model outputs themselves into the risk assessment (Giorgi and Mearns, 2002; Murphy et al., 2004), but the view of the authors is that the current AOGCMs are too imperfect to represent any part of the adequate physical uncertainty. Hence, such a variety of the results would not reflect the major source of regional uncertainty, i.e. the lack of mezo-scale effects, rather the differences among the models resulted just by different treatment of the macro-scale processes of the atmosphere, oceans, etc. by the models.

Table 1. List of Coupled Atmosphere - Ocean GCMs used in IPCC TAR (IPCC, 2001)

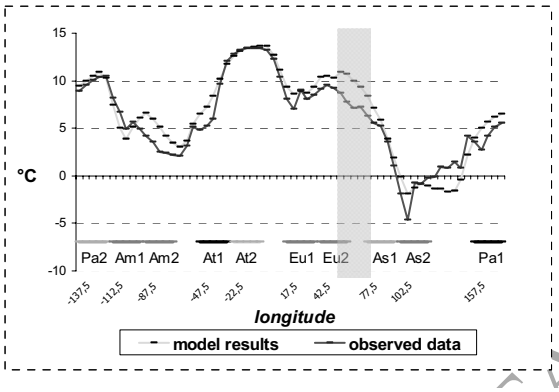
Model	Country	Atmospheric resolution	Ocean resolution
ARPAGE	France	(3,9 x 3,9) L19	(2,0 x 2,0) L31
BMRC	Australia	(3,2 x 5,6) L17	(3,2 x 5,6) L12
CCSR/NIES2	Japan	(5,6 x 5,6) L20	(2,8 x 2,8) L17
CGCM	Canada	(3,8 x 3,8) L10	(1,8 x 1,8) L10
COLA	USA	(4,0 x 4,0) L18	(3,0 x 3,0) L20
CSIRO	Australia	(3,2 x 5,6) L 9	(3,2 x 5,6) L21
CSM	USA	(2,8 x 2,8) L18	(2,0 x 2,4) L45
DOE PCM	USA	(2,8 x 2,8) L18	(0,7 x 0,7) L32
ECHAM/OPYC	Germany	(2,8 x 2,8) L19	(2,8 x 2,8) L11
GFDL	USA	(2,3 x 3,8) L14	(1,9 x 2,2) L18
GISS1	USA	(4,0 x 5,0) L 9	(4,0 x 5,0) L13
GOALS	China	(4,5 x 7,5) L 9	(4,0 x 5,0) L20
HadCM	UK	(2,5 x 3,8) L19	(1,2 x 1,2) L20
IPSL/CM	France	(5,6 x 3,8) L15	(2,0 x 2,0) L31
MRI	Japan	(2,8 x 2,8) L30	(2,0 x 2,5) L23
NCAR	USA	(4,5 x 7,5) L 9	(1,0 x 1,0) L20
NRL	USA	(2,5 x 2,5) L18	(1,0 x 2,0) L25

4. Results

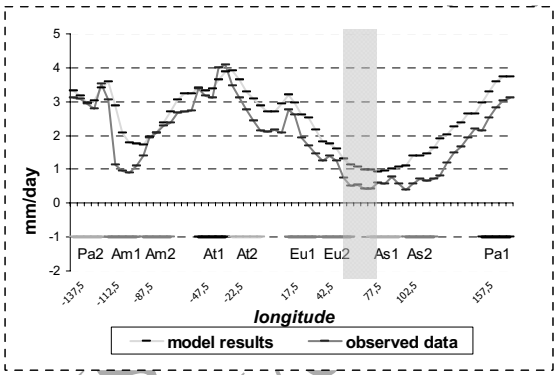
4.1 Model validation

Comparison of observed and modelled data is of high importance since this is one of the best methods to examine climate models. Fig. 3 presents the comparison of recent climate based on observed data between 1961 and 1990, and the averaged results of the 17 GCM runs.

Average of the 17 GCMs captures the longitudinal differences of the annual mean temperature and precipitation fairly well along the belt in the present climate, but with typical overestimation of the actual values, especially in case of precipitation. The best approach of the observed values can be seen at the regions of Atlantic and Pacific oceans (At2 and Pa2), both in case of temperature and precipitation. In the region of the Danube catchment temperature is overestimated by the GCMs by 1-2°C so as the precipitation by 0.5-1 mm.



Temperature



Precipitation

Fig. 3. Recent climate based on observed data (1961-1990) and averaged results of 17 GCM runs. The highlighted Eu1 region represents the Danube catchment.

4.2. Regional changes of the averages

This chapter contains comparisons of the future states of climate in 2025 to the ones, simulated by 17 OAGCMs as present (1961-1990) climate. Results averaged from the 17 models are indicated. This average difference for the global mean temperature is 0,63 K.

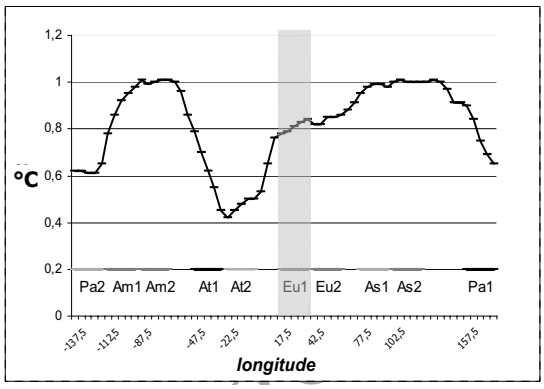
Concerning the change in temperature by 2025 (Fig.4 and 5), contrast between the oceans and continents are well outlined, for warming is much slighter above the oceans than above the continents in the given belt. Change in annual precipitation amount is estimated to be positive by 2025 except the region of western and central Europe in

the investigated 45-50 N latitudinal belt (Figure 4). Seasonal changes are rather diverse along the belt. The most expressed warming occurs in winter with ca. 1 K above and eastward from the two large continents of the 45-50 latitudinal belt. The smallest warming is seen above the cold North-Atlantic current with 0.5 K, only.

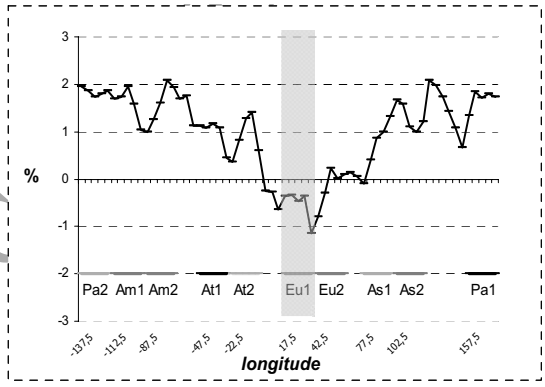
In case of the upper and middle Danube catchment, temperature is expected to increase by 0.8 ^{o}C until 2025, which is equal to the mean change in the whole belt. Concerning precipitation, Danube catchment region belongs to the narrow zone of the belt with decreasing annual precipitation amount. The yearly decrease is mainly owing to the 4-6% decrease in summer precipitation, while at winter 3% increase is expected in the seasonal total.

Considering the seasonal temperature changes in the Danube catchment region of the belt, the warming is definitely higher than the 0.63 K global mean in all seasons. In summer the surplus is more than 50%, so almost 1 K between 2025 and 1961-1990. In the other seasons, especially in the transient ones (spring and autumn) the proportion between the local and the global warming is just slightly higher than one.

Precipitation changes are positive almost everywhere in annual mean (Fig. 5) and majority of the seasons (Fig.6). Decreasing precipitation is expected in the Atlantic-European section of the 45-50 ^{o}N belt. No decrease is expected, however, in winter along the belt. In this season even the Atlantic Ocean is characterised by a slight increase. In summer a relatively wide area of the Atlantic-European section from the belt suffers from decreasing precipitation by a few percent.



Temperature



Precipitation

Fig. 4. Estimated annual changes of temperature and precipitation by 2025 based on 17 GCM runs. The highlighted Eu1 region represents the Danube catchment

For the Danube catchment section of the belt, even the sign of the changes differ from among the seasons. Clearly increasing precipitation is received for

winter with clearly decreasing values in summer. This latter season is characterised by a wide section of decreasing precipitation totals from the mid-Atlantics to the Ural-mountain. In the transitive seasons the signs are also opposite (increase in spring but decreasing in autumn, but both latter changes are les than one percent. The sum of the four seasonal changes is slightly negative, as it is seen still in Fig. 4.

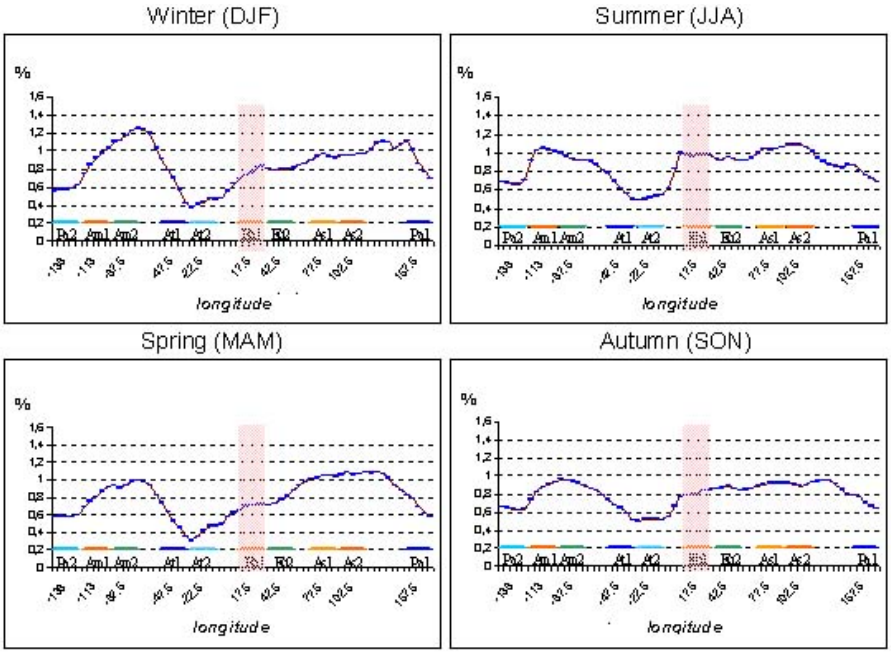


Fig. 5. Estimated seasonal changes of temperature by 2025 based on 17 GCM runs. The highlighted Eu1 region represents the Danube catchment.

4.3. Regional changes of diurnal standard deviatio*n*

According to the average of the 17 models, the annual mean values of diurnal standard deviation are increasing for both the temperature and, in overwhelming majority of the longitudes, for precipitation, as well. No clear difference is seen in changes of diurnal standard deviation of either the temperature or the precipitation between the continents and the oceans along the latitudinal belt (Figure 7).

The longitudinal structure of the annual and also of the seasonal changes (Figure 8) is mainly irregular with exception of the temperature in the winter season. The latter one can be characterised by a three-wave structure along the 45–50 ^{o}N belt. No clears difference is seen, however, between changes in the standard deviation between the continents and the oceans.

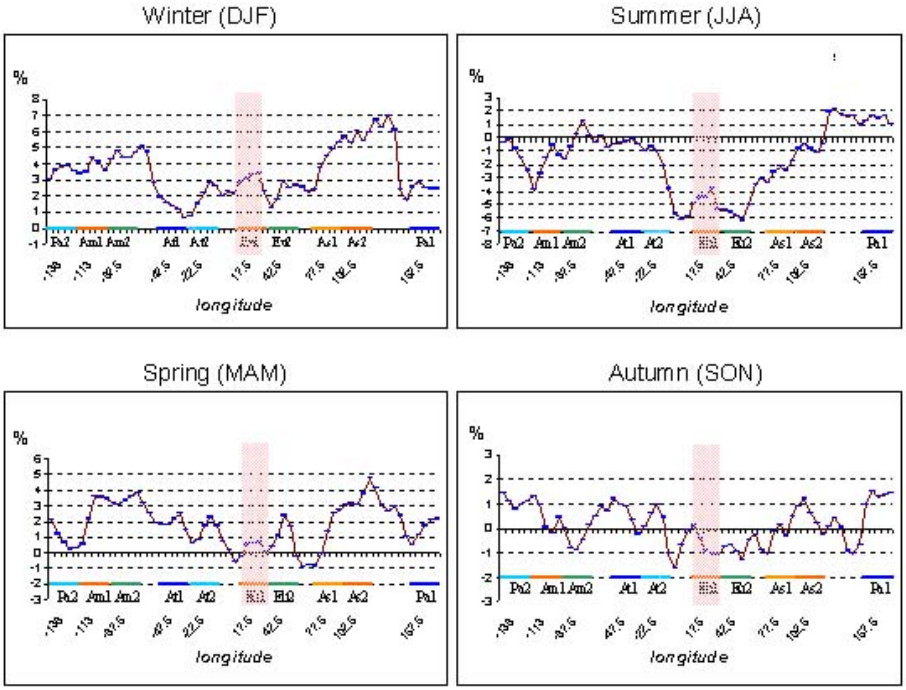


Fig. 6. Estimated seasonal changes of precipitation by 2025 based on 17 GCM runs.
The highlighted Eu1 region represents the Danube catchment.

Seasonal changes of diurnal standard deviations for precipitation are positive almost everywhere in autumn, winter and spring, and even in summer where some decreasing tendency spots can clearly be identified, the average change along the belt is still positive.

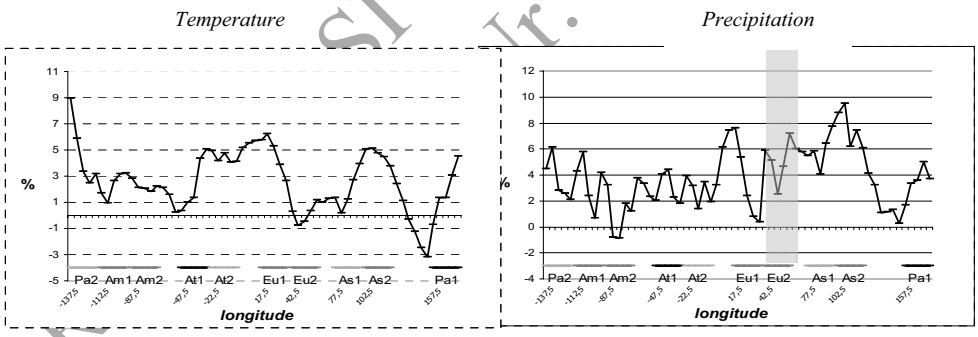


Fig. 7. Annual mean change of diurnal standard deviation
by 2025 based on 17 GCM runs
The highlighted Eu1 region represents the Danube catchment.

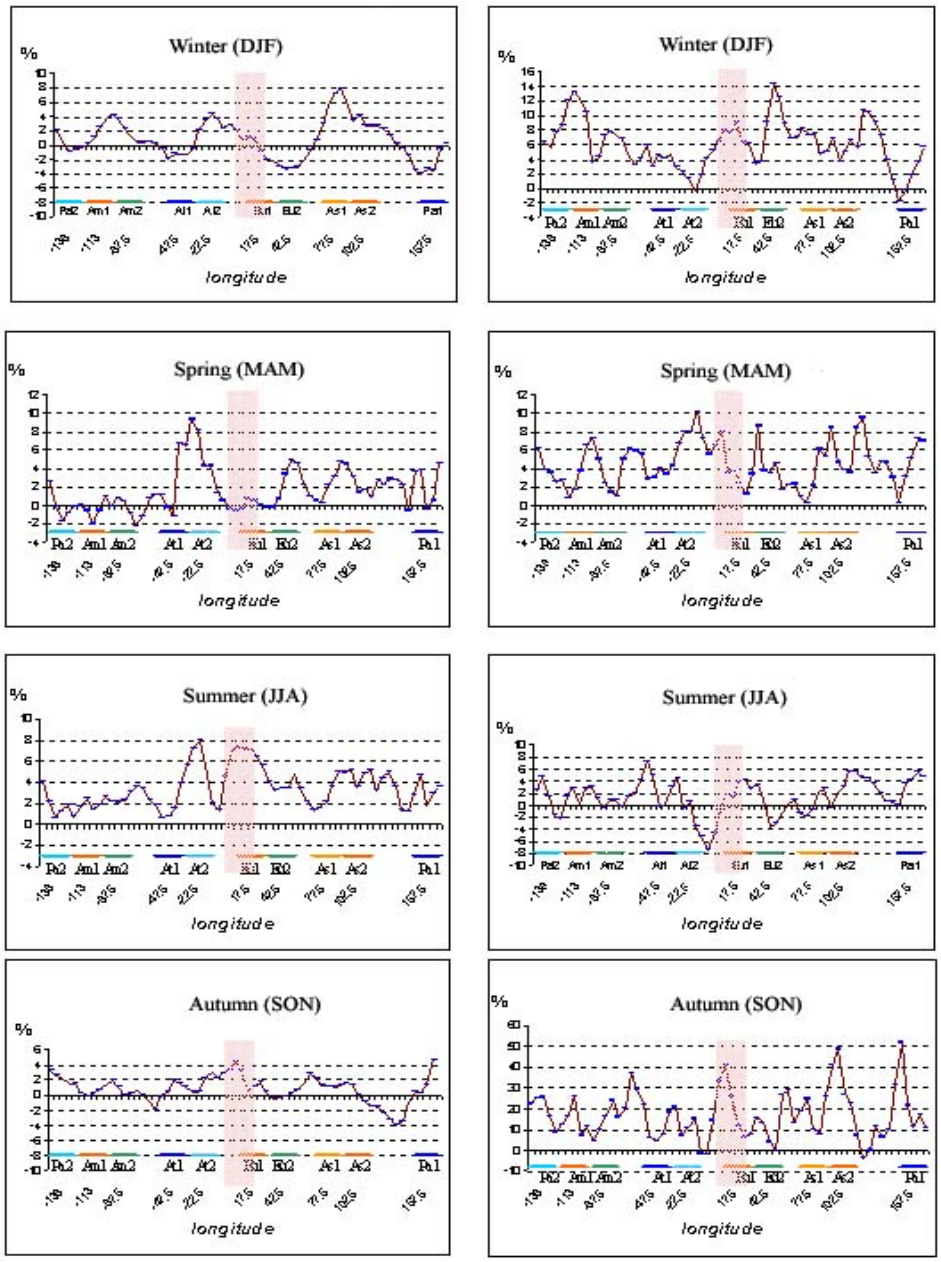


Fig. 8. Seasonal changes of diurnal standard deviation of temperature by 2025 based on 17 GCM runs.
The highlighted Eu1 region represents the Danube catchment.

Fig 9. Seasonal changes of diurnal standard deviation of precipitation by 2025 based on 17 GCM runs.
The highlighted Eu1 region represents the Danube catchment.

In the area of the Danube catchment, the increasing tendency of standard deviations is valid for all seasons of the year, but, with steep decreasing of the changes from the west to the east of the region, except summer. This means, that western parts of the catchment are among the regions with most radical increase in variability, and, hence, in frequency of diurnal extremities. In its eastern sectors the tendencies are close to unchanged variability until 2025. The annual average change of the diurnal precipitation is positive, but not strong in its absolute value.

Conclusions

Results of 17 coupled ocean-atmosphere GCMs were analysed and annual mean results were presented in the 45-50 N latitudinal belt, including the Danube catchment region. Due to space limitations the annual and seasonal mean changes were presented. Some further comparisons, as well, as characterisation of the inter-model variability, are given by Máthé (2005). This comparison supports the assessment given by Chapter 9 of the IPCC (2001) establishing that similarity in the patterns of changes is just partial, especially in case pf precipitation. Hence, strong differences may be enveloped by the averages derived from the 17 GCM experiments.

These averaged temperature and precipitation averages show significant differences within the given 45-50 N latitudinal belt. The present climate is fairly well reproduced by the 17 GCMs. The concept of continentality can be well applied for the changes of temperature, since the warming is much slighter above the oceans than above the continents in the given belt. Annual precipitation changes exhibit positive sign, except western and central Europe in the belt. In overwhelming majority of the longitudes, increase of the diurnal variability is typical in both climate variables, with no clear differences according to the type of the underlying surface in the 45-50 N latitudinal belt.

As concerns the region of the Danube catchment, it is tends to become warmer and drier in annual average, but the increase of variability indicates possible increase of flooding, too. The presented results do not markedly differ from those synthesised by using the previous MAGICC/SCENGEN 2.4 version that were based on 16 prior-1996 GCM outputs (Schlanger, 2002), despite the clear development of the GCMs, concerning their horizontal resolution and atmosphere-ocean coupling, etc.

Approaching to the end of the study, we try to outline some consequences of the projected changes to the present set of risks to hydrology and water management. Both soil moisture content and the runoff from a region is determined by both hydrological and thermal processes, which govern the income and outcome components of the balance, respectively. Hence, we follow the order of seasons, from winter to the autumn. In this respect, the Alpine-Carpathian region is considered, only.

The increasing seasonal amount of precipitation and of its diurnal variability, parallel to the increasing temperature may increase the likelihood of intra-seasonal winter flooding, which, until recently was not a frequent event in the region. On the other hand, it is not easy to judge how the increasing precipitation amount and seasonal temperature would affect the snow accumulation, i.e. the main cause of late spring floods in this mountainous region. These changes in both thermal and hydrological factors of the water balance project no unequivocal changes in the winter soil moisture saturation.

In spring, three factors of snowmelt change towards unpleasant directions: The slight increase of precipitation and of its diurnal variation, parallel to increase of diurnal temperature variability project increasing risk of fast snowmelt in spring. Only the general increase of spring temperature give some hope in this respect, since the period of snow accumulation may become shorter. The given signs of these four components of soil moisture balance also point at increasing possibility of most frequent dry-outs of soils, similar to that occurred in Hungary in 2003, when the May month was officially announced to be drought affected and the stock-exchange responded with 20% increase of cereal prices.

In summer the strong increase of temperature and clear decrease of precipitation unequivocally point at significant decrease of soil moisture and, generally, at less available freshwater in average. Frequency of drought events would also increase according to all signs and probability. On the other hand, however, the increase of diurnal standard deviation of precipitation and temperature (the latter indicates increased variability of clear and cloudy days, as well) indicate that parallel to overall drier climate strong precipitation and flash flood type risks would not become less frequent.

In autumn further warming and slightly less precipitation may lead to prolongation of some drought events. On the other hand, this may support longer convective precipitation period, also enhanced by increased standard deviation of precipitation and temperature, too.

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