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APPLICATION OF DIFFERENT WEATHER PATTERN CLASSIFICATIONS TO SIMULATED FUTURE CLIMATE CONDITIONS FOR CENTRAL EUROPE

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1. INTRODUCTION

The main goals of the presented research were (i) to compare weather pattern classification methods for Central Europe (COST733 domain 07 covering 43-58°N, 3-26°E) using observed and simulated present climate (1961-1990), and (ii) to analyze the climate change effects on weather patterns for the same region using different classification methods. The observed climate was represented by the ECMWF ERA40 datasets (Uppala et al., 2005).

The simulation experiments were accomplished for future climate conditions (2071-2100) using two emission scenarios (A2 and B2) in the frame of the EU-project PRUDENCE (Prediction of Regional scenarios and Uncertainties for Defining EuropeaN Climate change risks and Effects, Christensen and Christensen, 2007). High resolution (50 km × 50 km) simulated daily values of meteorological variables (mean sea level pressure, temperature, precipitation) were obtained from the regional climate model (RCM) outputs of the Danish Meteorological Institute (DMI).

DMI used the HIRHAM4 RCM (Christensen et al., 1996) with 50 km horizontal resolution (the RCM has been developed jointly by DMI and the Max-Planck Institute in Hamburg), for which the boundary conditions were provided by the HadAM3H/HadCM3 (Rowell, 2005) global climate model of the UK Met Office. The simulations were accomplished for present day conditions using the reference period 1961-1990 (the model performance of HIRHAM4 is analyzed by Jacob et al., 2007) and for the future conditions in 2071-2100 using scenario A2 and B2. According to the A2 global emission scenario, fertility patterns across regions converge very slowly resulting in continuously increasing world population. Economic development is primarily regionally oriented, per capita economic growth and technological changes are fragmented and slow. The projected CO_2 concentration may reach 856 ppm by the end of the 21st century (Nakicenovic and Swart, 2007), which is about triple of the pre-industrial concentration level (280 ppm). The global emission scenario B2 describes a world with intermediate population and economic growth, emphasizing local solutions to economic, social, and environmental sustainability. According to the B2 scenario, the projected CO_2 concentration is likely to exceed 600 ppm (Nakicenovic and Swart, 2007), which is somewhat larger than a double concentration level relative to the pre-industrial CO2 conditions.

2. WEATHER PATTERN CLASSIFICATION

For the weather pattern classification we used the COST733 classification software (version 0.19-17). 12 different classification methods (grouped into (i) optimization algorithms, (ii) leader algorithms, (iii) PCA based methods, and (iv) threshold based methods as shown in Table I, and described in details by Philipp et al., 2010) were applied to the ERA40 daily mean sea level pressure database for 1961-1990 using 9, 18, and 27 weather pattern types.

Table I: Applied classification methods.
The main features of these classification techniques are described in Philipp et al. (2010)

Optimization algorithms	
DKMEANS	k-means clustering by dissimilar seeds
KMEANS	k-means clustering
SANDRA	simulated annealing and diversified randomization clustering
SANDRAS	classification of sequences of days with SANDRA
HCLUST	hierarchical clustering
Leader algorithms	
LUND	classical leader algorithm
KH	Kirchhofer types
PCA based algorithms	
TPCA	principal component analysis in t-mode
KRUIZ/P27	Kruizinga empirical orthogonal function types
PCAXTR	principal component analysis extreme scores
Threshold based algorithms	
LIT	Litynski advection and circulation types
GWT	Grosswetter-types or Prototype classification

Figs. 1 and 2 presents the 1961-1990 circulation pattern centroids for DKMEANS and LUND classification techniques, respectively, when using 9 different circulation types. In case of the DKMEANS technique, the most frequent types were Nos. 1 and 2 (exceeding 15%), and in case of the LUND technique,

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the most frequent types were Nos. 6 and 9 (exceeding 23%).

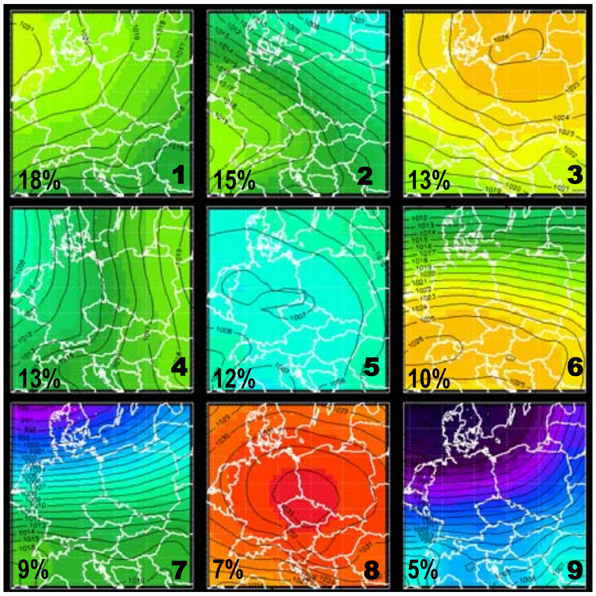

Fig. 1. Centroids of 9 circulation patterns for DKMEANS method using ERA40, 1961-1990 period, region 07. The percentage values in the lower left corner indicate the relative frequency of the corresponding pattern.

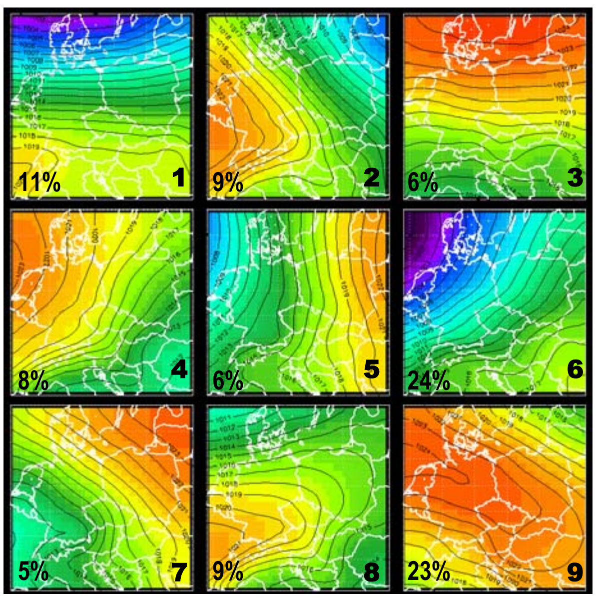

Fig. 2. Centroids of 9 circulation patterns for LUND method using ERA40, 1961-1990 period, region 07. The percentage values in the lower left corner indicate the relative frequency of the corresponding pattern.

The different classification techniques may be compared and evaluated using various measures (Beck and Philipp, 2010). Here, only two applied criteria for separability and within-type variability of classifications are discussed, namely the explained variation (EV, expressed as percentages) and the within-type standard deviation (WSD) calculated for the mean sea level pressure (MSLP) field in Figs. 3 and 4, respectively.

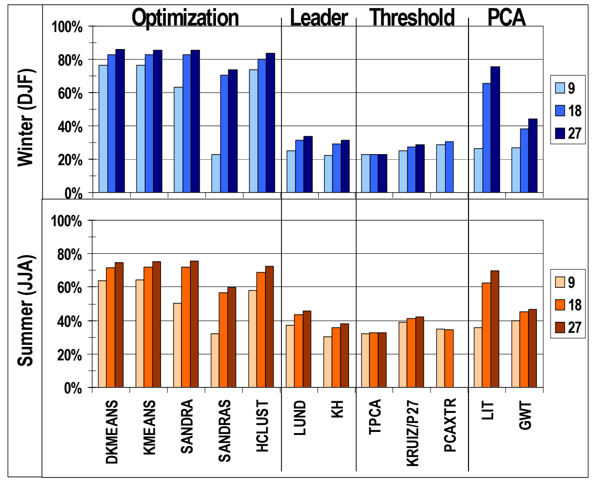

Fig. 3. Seasonal explained variance of MSLP fields, 1961-1990, winter (upper panel) and summer (lower panel).

As far as EV, evidently, the larger the total number of patterns, the better the performance of the classification. Furthermore, the winter performance is better than the summer performance in case of the optimization algorithms and the PCA-based techniques, while for the leader and threshold algorithms the summer EV is larger than the winter EV. The best performing classification methods are the optimization algorithms with larger than 70% EV in winter and 50% EV in summer (Fig. 3).

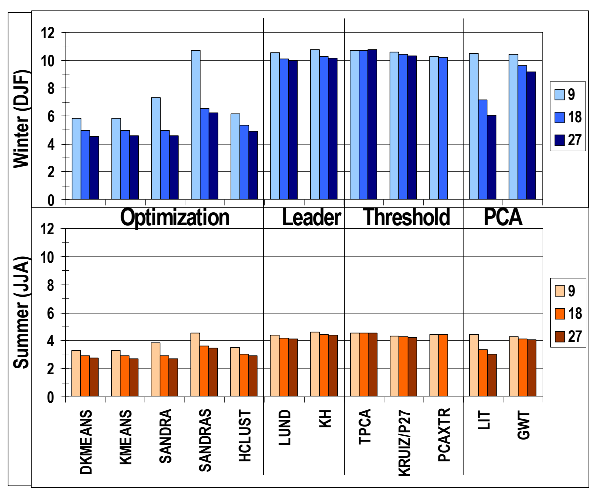

Fig. 4. Seasonal MSLP fields: within-type standard deviation, 1961-1990, winter (upper panel) and summer (lower panel).

In case of WSD, the values are decreasing as the number of circulation patterns increases. For all the classification methods, summer WSD is smaller than winter WSD (Fig. 4), which is due to the smaller overall variability of summer climatic conditions. The best performing techniques are the optimization algorithms (DKMEANS, KMEANS, SANDRA, HCLUST) with less 6 hPa and 4 hPa WSD values in winter and summer, respectively.

3. APPLICATION TO SIMULATED CLIMATE CONDITIONS

The resulting circulation pattern types from 1961-1990 classifications of the mean sea level pressure fields were applied to the classification of the 2071-2100 period for both A2 and B2 scenarios. Frequency distribution changes of circulation pattern types were analyzed in the selected domain by 2071-2100 period for both A2 and B2 scenarios relative to the 1961-1990 reference period. In order to maintain a reasonable extent of this paper, this analysis for only one classification technique is shown here. We selected DKMEANS among the 5 optimization algorithms used in the analysis, and Fig. 5 illustrates the results. The relative frequency values of different circulation pattern types using the DKMEANS classification technique are not projected to change very much for either scenario (the difference does not exceed 3%).

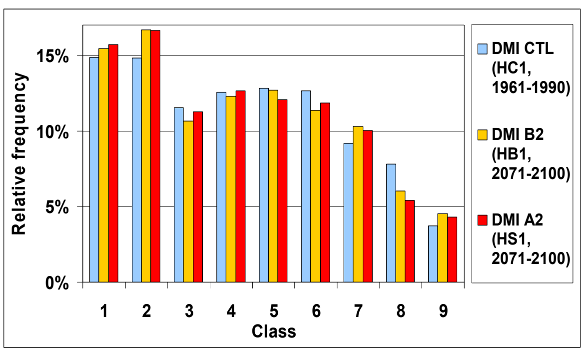

Fig. 5: Projected changes in occurrence frequency of different circulation types using DKMEANS classification technique

Furthermore, temperature anomaly and precipitation pattern changes were evaluated in the Carpathian basin (covering 45-49°N, 14-27°E) for each circulation pattern types using all the selected classification techniques.

Spatial distributions of mean summer temperature anomaly associated to each circulation pattern type using DKMEANS classification technique are illustrated in Fig. 6 for the reference period (1961-1990), the B2 scenario (2071-2100), and A2 scenario (2071-2100). The same sequence is used in Fig 7 for mean winter temperature anomaly. "0" on the empty map indicates circulation pattern types, which did not occur during the simulation (in the specific season). The spatial average of temperature anomalies are calculated and shown below the maps for the entire region (upper row) and Hungary (lower row). Negative/positive values indicate circulation pattern types resulting colder/warmer than usual temperature in the Carpathian basin (1961-1990 reference monthly mean temperature fields were used to define the usual temperature patterns). For both seasons future anomaly fields will be warmer by the end of the 21st century than the present climate due to the regional warming (Bartholy et al., 2007, 2008). Fig. 8 summarizes the spatial mean winter and summer increase of temperature anomaly for Hungary. In case of B2 scenario the winter/summer warming is about 1.5-3 °C/2-5 °C, and it is even larger for A2 scenario (2.5-5 °C/3-5.5 °C). The largest warming is projected for circulation pattern types 8 in winter, and 8 (B2) and 9 (A2) in summer.

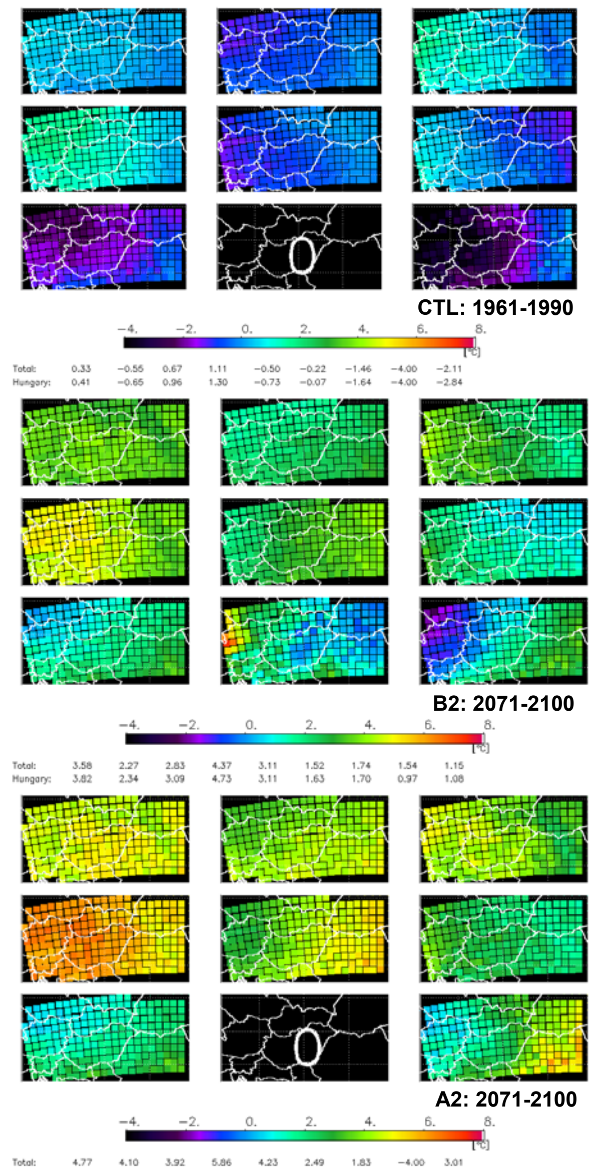

Fig. 6: Simulated mean summer temperature anomaly for each circulation pattern type using DKMEANS classification technique.

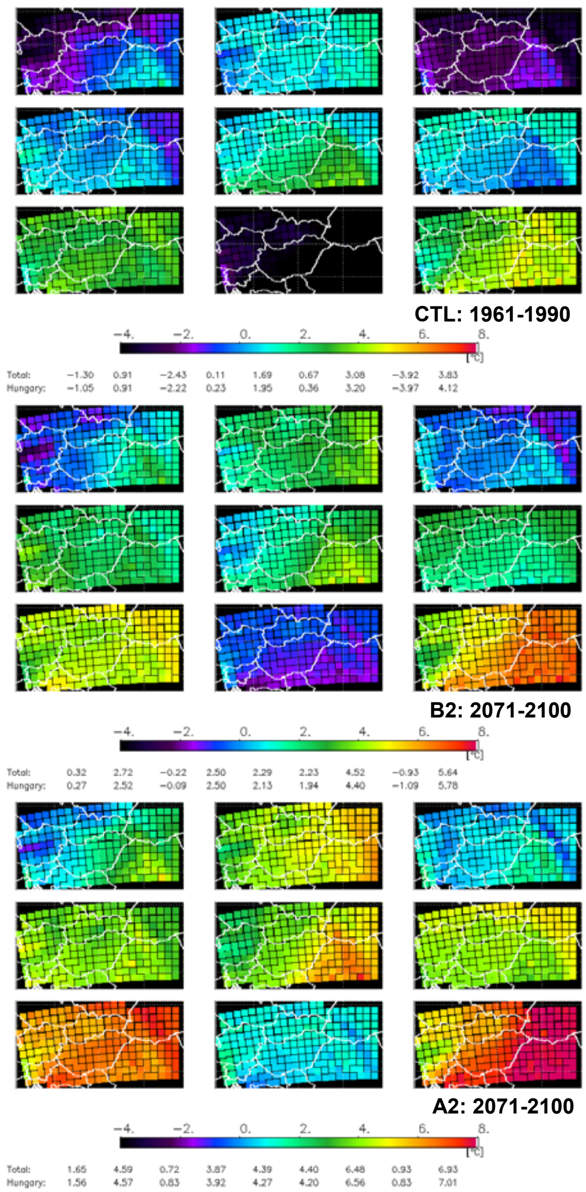

Fig. 7: Simulated mean winter temperature anomaly for each circulation pattern type using DKMEANS classification technique.

Spatial distributions of mean summer daily precipitation associated to each circulation pattern type using DKMEANS classification technique are illustrated in Figs. 9 and 10 for the reference period (1961-1990), the B2 scenario (2071-2100), and A2 scenario (2071-2100), respectively. The same sequence is used in Figs. 11 and 12 for mean winter daily precipitation. Similarly to the temperature, the spatial average of daily precipitation values are calculated and shown below the maps for the entire region (upper row) and Hungary (lower row). Large/small values indicate circulation pattern types resulting wet/dry conditions in the Carpathian basin.

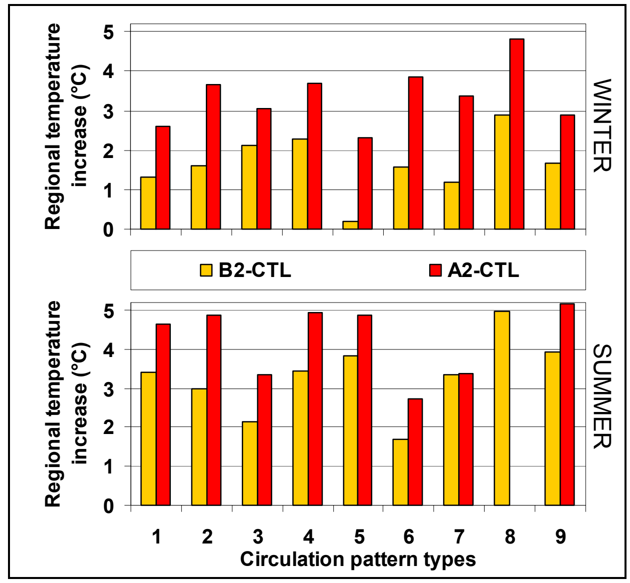

Fig. 8: Projected mean seasonal temperature anomaly changes in Hungary by 2071-2100 for each circulation pattern type using DKMEANS classification technique (compared to CTL, 1961-1990).

Precipitation is far more variable in space and time than temperature; it is well-known and evident if we compare precipitation and temperature anomaly maps. Furthermore, the topography of the regions is key factor in determining the precipitation, thus, in the higher elevated Carpathian and Alps mountains the precipitation is larger than in the lowlands of Hungary.

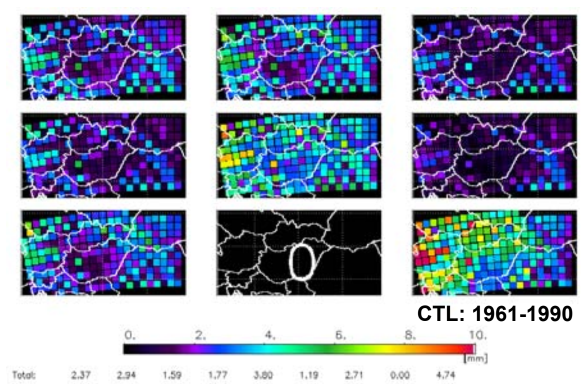

Fig. 9: Simulated mean precipitation for each circulation pattern type using DKMEANS classification technique (CTL: 1961-1990 summer).

Fig. 13 summarizes the spatial mean seasonal precipitation change for Hungary for each circulation pattern type using DKMEANS classification technique. The results suggest that winter/summer is expected to become wetter/drier compared to the reference period, 1961-1990, which was also found in previous studies (e.g., Bartholy et al., 2007).

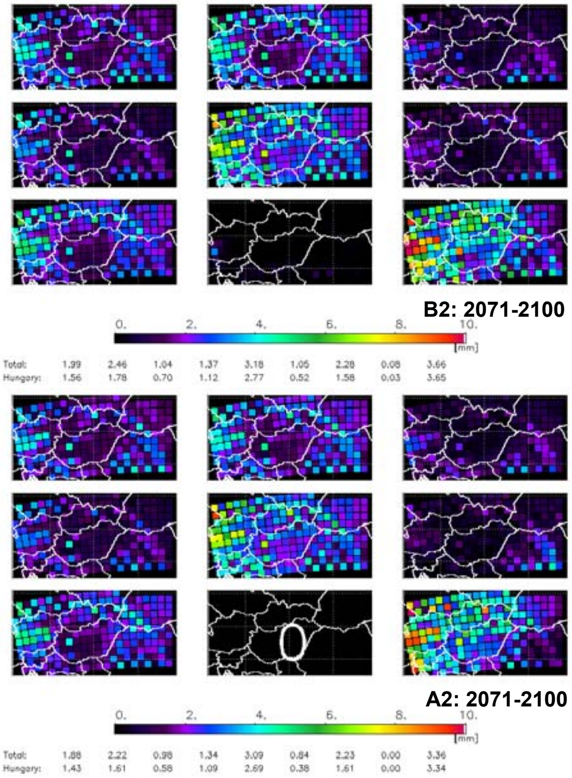

Fig. 10: Simulated mean summer precipitation anomaly for each circulation pattern type using DKMEANS classification technique.

According to the maps of Fig. 11, circulation pattern types 5, 1 and 9 are associated with wet winter climatic conditions in Hungary at the present (1961-1990), and as the upper panel of Fig. 13 illustrates, they are projected to become even wetter in the future (2071-2100 in case of either scenario).

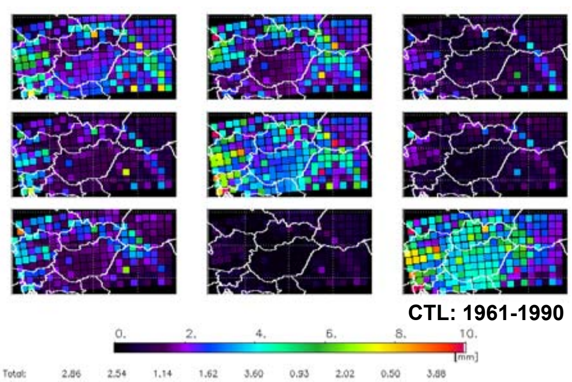

Fig. 11: Simulated mean precipitation for each circulation pattern type using DKMEANS classification technique (CTL: 1961-1990 winter).

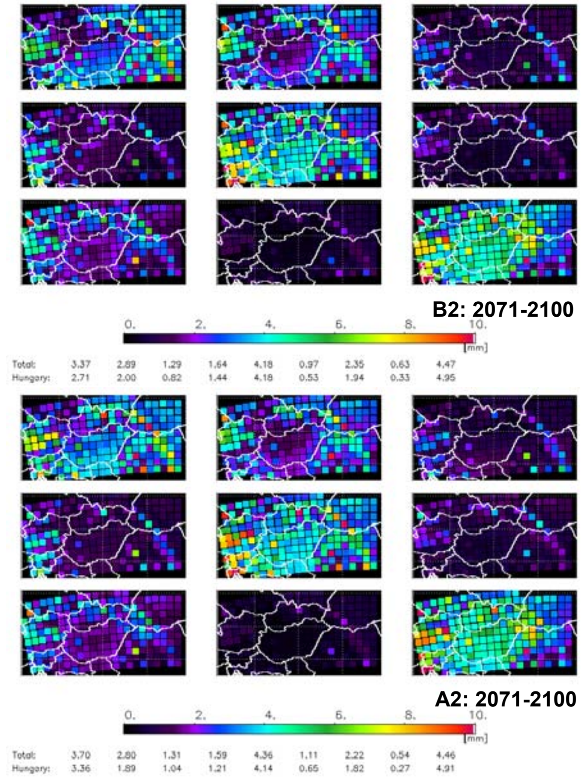

Fig. 12: Simulated mean winter precipitation anomaly for each circulation pattern type using DKMEANS classification technique.

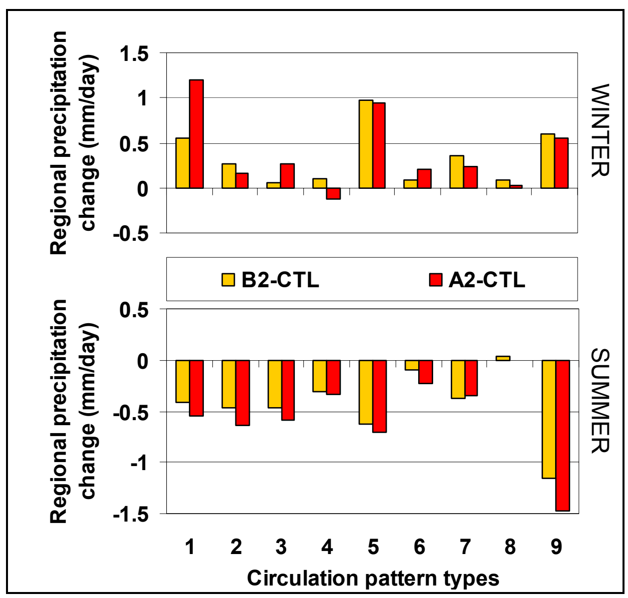

Fig. 13: Projected mean seasonal precipitation anomaly changes in Hungary by 2071-2100 for each circulation pattern type using DKMEANS classification technique (compared to CTL, 1961-1990).

As far as the summer drying, the largest changes are projected in case of circulation pattern type 9 (the decrease is likely to exceed 1.1 and 1.4 mm/day for B2 and B2 scenario, respectively). This circulation type showing a strong zonal/cyclonic isobar structure in Fig. 1, was the wettest one in Hungary during the reference period (1961-1990). However, circulation patterns associated with past dry summers are also expected to become even drier by the end of the 21st century (as shown in the lower panel of Fig. 13). The projected drying trend for A2 is generally larger than that for B2, which might be due to the larger warming trend of A2 (IPCC, 2007).

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REFERENCES

Bartholy, J., Pongracz, R., Gelybo, Gy., 2007: Regional climate change expected in Hungary for 2071-2100. *Applied Ecology and Environmental Research,* 5, 1-17.

Bartholy J., Pongracz R., Gelybo Gy., Szabo P., 2008: Analysis of expected climate change in the Carpathian basin using the PRUDENCE results. *Idojaras*, 112, 249-264.

Beck C., Philipp A., 2010: Evaluation and comparison of circulation type classifications for the European domain. *Physics and Chemistry of the Earth*, in press

Christensen, J.H., Christensen, O.B., 2007: A summary of the PRUDENCE model projections of changes in European climate by the end of this century. *Climatic Change*, 81, 7-30.

Christensen, J.H., Christensen, O.B., Lopez, P., Van Meijgaard, E., Botzet, M., 1996: The HIRHAM4 Regional Atmospheric Climate Model. Scientific Report 96-4, 51p. Copenhagen, DMI.

IPCC, 2007: *Climate Change 2007 – The Physical Science Basis*. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Edited by S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K. B. Averyt, M. Tignor, and H. L. Miller. Cambridge University Press, Cambridge, UK and New York, NY, USA. 996p.

Jacob, D., Bärring, L., Christensen, O.B., Christensen, J.H., de Castro, M., Déqué, M., Giorgi, F., Hagemann, S., Hirschi, M., Jones, R., Kjellström, E., Lenderink, G., Rockel, B., Sánchez, E., Schär, Ch., Seneviratne, S.I., Somot, S., van Ulden, A., van den Hurk, B., 2007: An inter-comparison of regional climate models for Europe: Model performance in Present-Day Climate. *Climatic Change*, 81, 21-53. doi:10.1007/s10584-006-9213-4.

Nakicenovic, N., Swart, R., Eds., 2000: *Emissions Scenarios.* A Special Reports of IPCC Working Group III, Cambridge University Press, Cambridge, UK. 570p.

Philipp A., Bartholy J., Beck C., Erpicum M., Esteban P., Fettweis X., Huth R., James P., Jourdain S., Kreienkamp F., Krennert T., Lykoudis S., Michalides S., Pianko K., Post P., Rassilla Álvarez D., Schiemann R., Spekat A., Tymvios F.S., 2010: COST733CAT - a database of weather and circulation type classifications. *Physics and Chemistry of the Earth*, in press

Rowell, D.P., 2005: A scenario of European climate change for the late 21st century: seasonal means and interannual variability. *Climate Dynamics,* 25, 837-849.

Uppala, S.M., Kallberg, P.W., Simmons, A.J., Andrae, U., da Costa Bechtold, V., Fiorino, M., Gibson, J.K., Haseler, J., Hernandez, A., Kelly, G.A., Li, X., Onogi, K., Saarinen, S., Sokka, N., Allan, R.P., Andersson, E., Arpe, K., Balmaseda, M.A., Beljaars, A.C.M., van de Berg, L., Bidlot, J., Bormann, N., Caires, S., Chevallier, F., Dethof, A., Dragosavac, M., Fisher, M., Fuentes, M., Hagemann, S., Holm, E., Hoskins, B.J., Isaksen, L., Janssen, P.A.E.M., Jenne, R., McNally, A.P., Mahfouf, J.-F., Morcrette, J.-J., Rayner, N.A., Saunders, R.W., Simon, P., Sterl, A., Trenberth, K.E., Untch, A., Vasiljevic, D., Viterbo, P., Woollen, J., 2005: The ERA-40 re-analysis. *Quart. J. R. Meteorol. Soc.,* 131, 2961-3012. doi:10.1256/qj.04.176.