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Stochastické meteorologické generátory a regionální klimatické modely: konkurence či spojenci?

(Stochastic Weather Generators and Regional Climate Models: Rivals or Allies?)

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Abstract: The paper demonstrates "collaboration" between the stochastic weather generator SPAGETTA (WG) and Regional Climate Models (RCM) in analysing impacts of Climate Change (CC). In the first part of the paper, the generator is compared with the ensemble of 19 RCMs in terms of their ability to reproduce 11 spatial temperature and precipitation indices in eight European regions; the indices are based on registering days and spells exhibiting spatially significant occurrence of dry, wet, hot or cold weather, or possible combination of dry-or-wet and hot-or-cold conditions. The obtained results indicate that both methodologies provide weather series of comparable quality. In the second part of the paper (which was done only for the Central Europe region), the WG parameters are modified using the RCM-based CC scenarios and the synthetic weather series representing the future climate are produced. This experiment is based on a set of CC scenarios, which consist of changes in selected combinations of following characteristics: (1) mean temperature, (2) temperature variability, (3) daily average precipitation (considering only wet days), (4) probability of wet day occurrence, (5) spatial lag-0 and lag-1day correlations of temperature and precipitation series. The synthetic series generated for each version of the CC scenario are analysed in terms the above mentioned spatial validation indices, the stress was put on effect of each of the five component of the CC scenario on individual validation indices. The results of the experiment indicate that the changes in temperature means is the main contributor to the changes in the validation obviously, except for the purely precipitation-based indices. Positive changes in the lag-0 and lag-1day correlations of both temperature and precipitation are the second most significant contributor to the changes in the validation indices.

Keywords: generators – regional climate models – temperature – precipitation – validation – compound indices

Abstrakt: Článek demonstruje „spolupráci" prostorového stochastického meteorologického generátoru SPAGETTA (WG) a regionálních klimatických modelů (RCM) při analýze dopadů změny klimatu (ZK). V první části je porovnán generátor se sadou 19 RCM modelů prostřednictvím jejich schopnosti reprodukovat 11 prostorových teplotních a srážkových indexů v osmi evropských regionech; indexy jsou založeny na registraci dnů a období s prostorově významným výskytem sucha, srážek, horka, zimy, a možných teplotně-srážkových kombinací. Na základě získaných výsledků je konstatováno, že obě metodologie dávají srovnatelně kvalitní výsledky. V druhé části experimentu (ta je provedena pouze pro oblast Střední Evropy) je generátor, jehož parametry jsou modifikovány scénáři změny klimatu odvozenými z RCM simulací, použit ke generování syntetických řad reprezentujících změněné klima. V experimentu je použita sada scénářů, které zahrnují změny vybraných kombinací následujících charakteristik: (1) průměrná teplota, (2) variabilita teploty, (3) průměrný úhrn srážek (průměr pouze ze srážkových dnů), (4) četnost výskytu srážkových dnů a (5) prostorové korelace a autokorelace teplotních i srážkových časových řad. Syntetické řady pro každý scénář jsou analyzovány prostřednictvím výše uvedených indexů, přičemž je sledován (mimo jiné) vliv změn jednotlivých charakteristik zahrnutých ve scénářích změny klimatu na jednotlivé indexy. V souladu s očekáváním bylo zjištěno, že výrazně největší vliv mají změny průměrných teplot – samozřejmě vyjma ryze srážkových indexů. Druhou nejvýznamněší charakteristikou, která významně ovlivňuje validační indexy, jsou změny korelací, které dle scénářů ZK pro Střední Evropu budou převážně pozitivní.

Klíčová slova: generátory – regionální klimatické modely – teplota – srážky – validace – sdružené indexy

1. Introduction

Various weather-dependent models (e.g. agricultural crop growth models or hydrological rainfall-runoff models are used in analysing impacts of the Climate Change (CC). For their simulations, these models require realistic multi-dimensional weather time series representing present and future climate in one or more locations. To create such weather series, one of the two approaches is commonly used: (1) Regional Climate Model, or (2) Stochastic Weather Generator. Both approaches can produce multidimensional (i.e. more than one weather variable) time series representing present and future climates. Both approaches have their advantages and disadvantages. Apparent advantage of the RCMs consists in the fact that they are based on mathematical equations representing physical and chemical processes driving the processes in the atmosphere and thereby forming the weather, which allows to simulate weather variables in arbitrary set of grid-points at any radiation forcing related to chosen emission scenario. Unfortunately, considering the complexity of the equations and necessity to run it at high spatial and temporal resolution (to adequately simulate weather forming processes), the simulations with RCMs are very slow so that it takes days, weeks or even months to produce sufficiently long weather series required as inputs to the weather-dependent models. In contrast with RCMs, the stochastic weather generators are based on using statistical and stochastic modelling (often including autoregressive models and Markov chains models). In the first step, parameters of the generator are derived from the calibration time series (mostly being the observational data). Subsequently, the generator may produce synthetic time series with a speed several orders faster that RCMs, so that one can get a large number of realisations of time series having statistical structure similar to observational data. To produce time series representing the future climate, parameters of the generator are modified using the climate change scenarios typically derived from GCM or RCM simulations. The main advantages of the generators are: (1) High speed in producing the synthetic meteorological time series. Ensemble of synthetic series may be used to make an effective probabilistic assessment of outputs from any model fed by the synthetic series. (2) The generators may produce meteorological time series even for the emission scenarios, for which the RCM or GCM simulations are not available. The series may be produced by modifying the WG parameters using the scenarios obtained by pattern scaling approach and MAGICC model (Dubrovsky et al. 2005). (3) In generating the series representing the future climate one may modify only selected WG parameters so that effect of changes in individual climatic characteristics may be assesses (e.g. changes in the means of the weather variables, changes in their variability, changes in precipitation sums or in precipitation occurrence, etc.).

The present paper aims to demonstrate that the two above mentioned methodologies (WGs and RCMs) need not be considered to be competitors, but rather as two complimentary methodologies which may effectively collaborate when used together. In our two experiments we use spatial weather generator SPAGETTA (Dubrovsky et al. 2020) and outputs rom 19 RCM simulations available from CORDEX database. In the first part of the paper (experiment #1), we show results of the validation tests, in which the WG and RCMs were validated in terms of their ability to reproduce a set of spatial temperature and precipitation indices. It is shown that the performance of both approaches is similar and none of them is a clear winner. In the second experiment, we demonstrate how the two methodologies may be used together: The RCM simulations are used to derive climate change scenarios consisting of changes in selected climatic characteristics, and afterwards the generator is used to analyse effect of changes in individual climatic characteristics.

2. Data

In our experiments, we employ time series *(*time step = 1 day) of daily average temperature and daily precipitation sums for grid = points in 8 target regions shown in Fig. 1. The data come from two sources. First, to calibrate our spatial weather generator and as a reference weather series representing present climate conditions, we use E-OBS gridded data for 1971–2000 period. Second, ensemble of 19 RCM simulations are taken from CORDEX database. We took RCM simulations for RCP8.5 emission scenario (1971–2000 representing the baseline climate and 2070–2099 representing the future climate), which implies that the RCM simulated time series exhibit signal-to-noise ratio which is highest of all emission scenarios – this will allow more robust analysis of climate change impacts. The RCM-based climate change scenarios consist of changes in WG parameters derived from the two periods: 2070–2099 vs. 1971–2000. Considering the limitations of our generator, which may produce spatial data only for a limited number of grid-points, we took only every second column and every second row from each of the two datasets. While the first experiment was made for 8 EU regions shown in Fig. 1, the second experiment was made fonly for the Central Europe region.

3. Methodology

The present version of our parametric stochastic weather generator SPAGETTA is an updated version of the generator described in Dubrovsky et al. (2020). The generator was based on a single-site parametric weather generator M&Rfi, which is an improved version of the Met&Roll single-site generator described and validated in in Dubrovsky (1997) and Dubrovsky et al. (2000, 2004). In M&Rfi, precipitation occurrence is modelled by the first order Markov chain, non-precipitation variables by the multivariate 1st order autoregressive model and precipitation amount on wet days by Gamma distribution. M&Rfi was converted into the SPAGETTA spatial generator by using the spatialization technique proposed by Wilks (1998, 2009).

The present experiment consists of two experiments which both together may be described as a sequence of following steps:

1. Daily time series of temperature and precipitation for the 8 regions (Fig. 1) and two periods (1971–2000, 2070–2099; the second time slice is applied only with RCMs) are created from E-OBS and 19 RCMs.

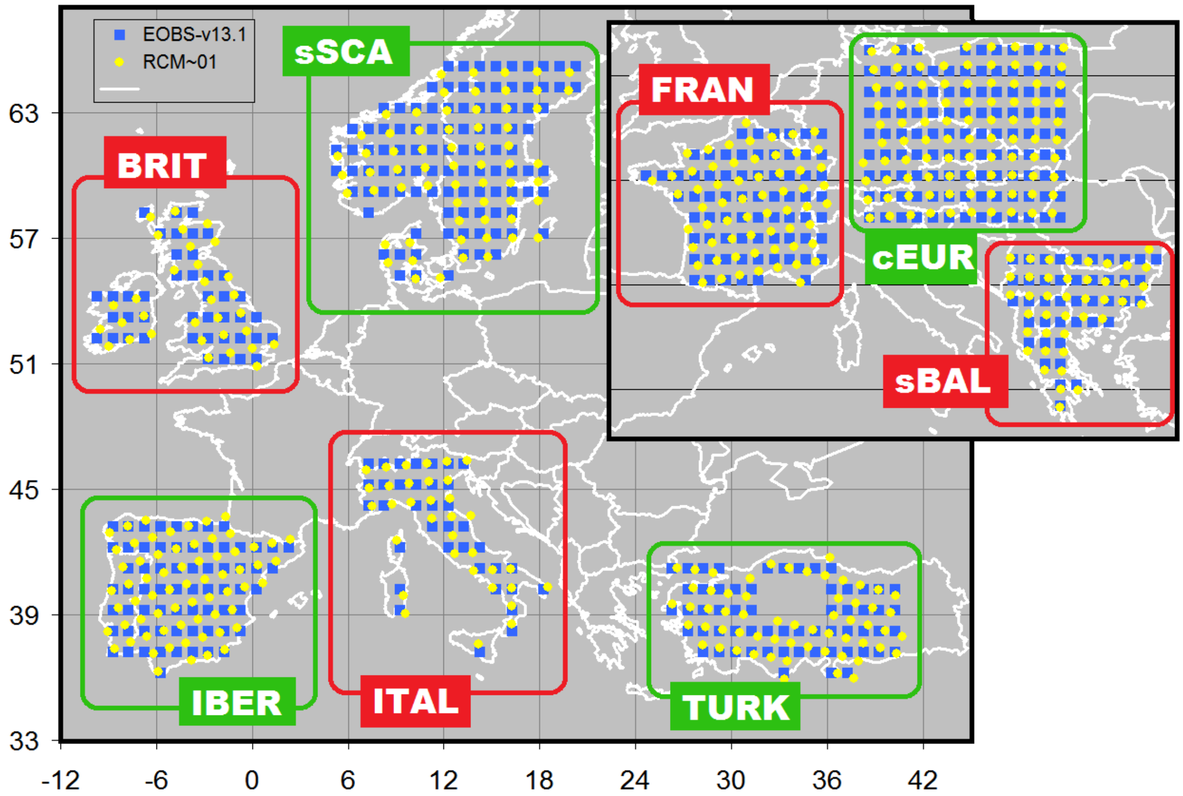

Fig. 1 Eight target regions used in the experiment. The blue squares and yellow circles represent E-OBS and RCM grid-points employed in the experiment.

2. WG is calibrated with E-OBS data for the 8 regions.
3. Synthetic weather series representing the present climate are generated using the WG parameters obtained in Step 2.
4. To complete the First Experiment (Comparison of WG vs. RCM), a set of spatial climatic characteristics derived from the synthetic series (produced in Step 3) and the RCM series (made in step 1) are compared with those derived from the reference E-OBS series.
5. RCM-based climate change scenarios are constructed by comparing WG parameters derived from the future vs. reference time slices, separately from all 19 RCMs included in our database. The complete climate change scenarios consist of changes in following characteristics: *A* = changes in temperature means, *S* = changes in temperature variability, *O* = changes in frequency of days with non-zero precipitation amount, *R* = changes in mean precipitation amount (considering only on wet days!), *C* = changes in spatial lag-0 and lag-1day spatial correlations of temperature and precipitation (both variables are considered separately).
6. To produce synthetic weather series representing future (2070–2099) climate, the generator is run using WG parameters modified with CC scenarios obtained in step 5. To assess effect of changes in individual climate characteristics, couple of CC scenarios are assumed: *A, S, R, O, C, ASP* and *ASPC*, where letters in the acronyms indicate which groups of WG parameters are modified by the CC scenario (see previous paragraph for the descriptions). Having modified WG parameters, weather series representing the future climate are produced with each of the 7 CC scenario.
7. To complete the Second Experiment (results are shown here only for cEUR; more complete set of figures is planned to be published in Dubrovsky et al. 202Xb),

synthetic series representing the future climates are analysed for occurrences of the 11 types of the Days and the Spells: the Day is defined as a **Dry**/**Wet**/**Xwet** day when the Dry/Wet/XWet day is registered at least at $PthrshP*N_G$ grid-points (N_G is numer of grid-points in the given region and *Pthrsh* is reasonably high percentage. **Hot** or **Cold** Day is registered when the temperature is higher than *Tthrsh* at least at $PthrshT*N_G$ grid-points. Apart from these 5 types of Days, additional 6 types of Days is obtained by combining 3 types of precipitation days with 2 types of temperature days: **Hot-Dry**, **Hot-Wet**, **Hot-Xwet**, **Cold-Dry**, **Cold-Wet**, **Cold-Xwet**.

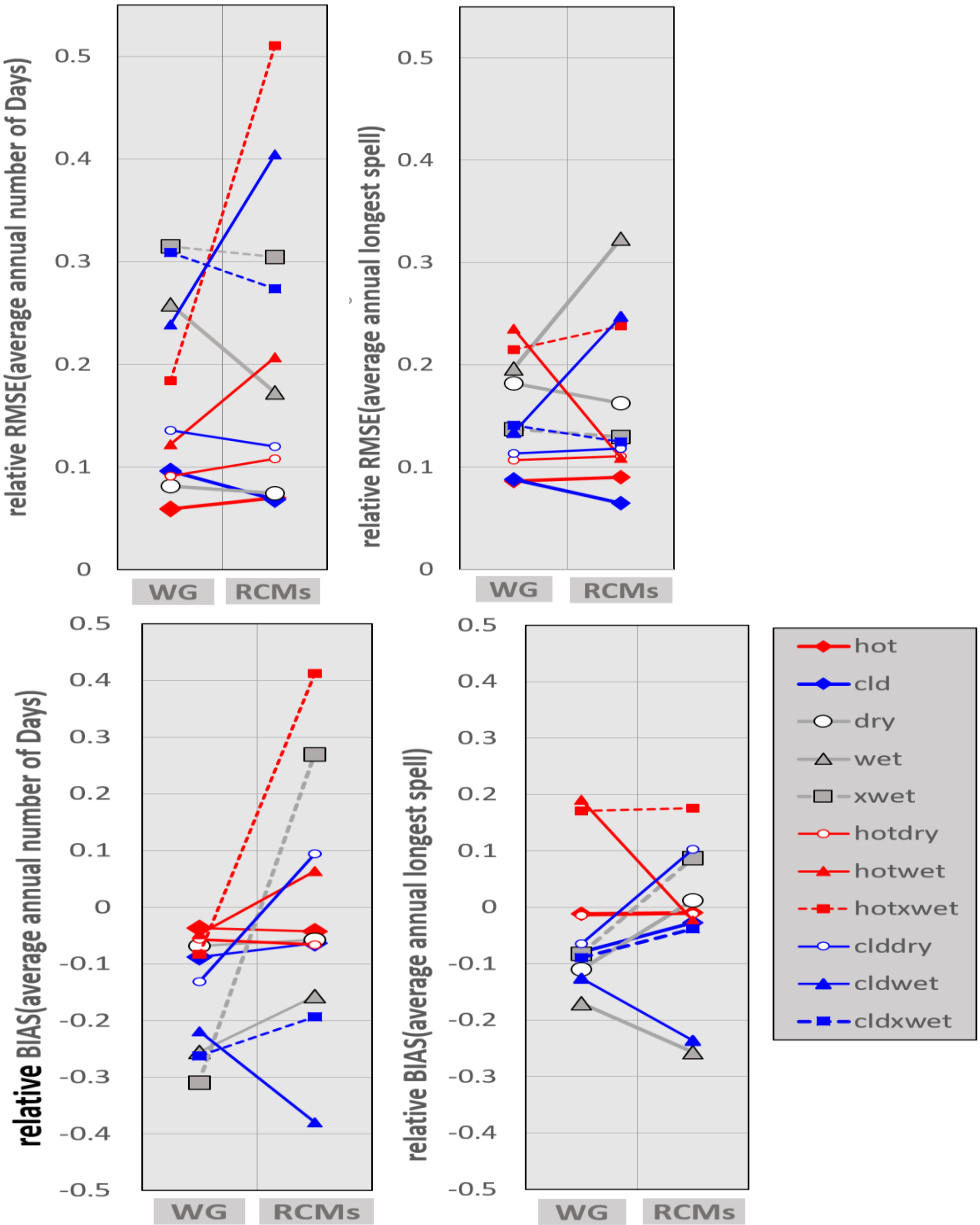

Fig. 2 Performance of the generator and ensemble of 19 RCMs in reproducing the 11 validation characteristics – "Days" are on the left, "Spells" are on the right (The Days and the Spells are defined in the text). The performance is shown in terms of the relative RMSE (top graphs) and relative BIAS (bottom) (both RMSE and BIAS are based on eight values related to eight target regions shown in Fig. 1) comparing the means of the validation indices derived from synthetic series (or RCM series) vs. the means derived from E-OBS.

4. Results and Discussion

4.1 Comparison of Weather Generator with Regional Climate Models

The results obtained while comparing performance of the generator with RCMs were processed in many ways. The results are going to be published in Dubrovsky et al. (202Xa), here we show (Fig. 2) only comparison of WG and RCMs in terms of their ability to represent mean values of the 11 validation indices (see the above paragraph) – relative RMSE and relative mean Bias (based on 8 values comparing WG or RCM vs E-OBS in 8 target regions) for the frequency of Days and mean annual maximum length of the Spells are shown in Fig. 3. The graphs shown in the figure indicate:

(A) RMSE: For „Days“, RCMs show higher (compared to WG) RMSE for indices related to hot weather (red symbols), while RCMs are better in representing indices related to cold weather (blue symbols) – except for the cold-wet Days, which are better reproduced by WG. Purely precipitation indices (Wet, Dry and Xwet Days) are better reproduced by RCMs. As for the „Spells“, the pattern of the results is not so simple. One may see, that the performance of WG in reproducing various type of Spells is better balanced within the set of the 11 indices (in other words, the performance of WG is more similar for individual indices) in comparison with RCMs; RCMs shows much higher differences across the 11 indices.

(B) Bias: WG tends to underestimate the means of the most of the spatial validation indices (both Days and Spells). Similarly to RMSE, RCMs exhibit larger dispersion of the mean biases of the 11 indices. Biases of some indices are positive, some of them are negative, but in terms of the absolute values of the biases, RCMs shows worse performance scores than the generator.

Overall, considering performance of RCMs and WG as represented by RMSE and the mean Bias for both Days and Spells, our results indicate that the performance of the generator and RCMs are comparable, none of the two methodologies is an apparent winner. In other words, both methodologies may be considered as legitimate approaches to producing weather inputs for climate change impact experiments.

4.2 Effect of changes in WG parameters on selected spatial climatological indices

Although the second experiment was also performed for all 8 regions, we present here (Figs. 3 and 4) results related only to Central Europe region (cEUR). In this experiment, the CC scenarios were based on RCM simulations for RCP8.5 emissions. The CC scenarios for the Central Europe shown in Fig. 3 indicate: (i) Temperature will increase in all seasons – differences between the seasons are not great, but it may be noted that the highest increase is projected for winter and the lowest for spring. (ii) Temperature variability will increase in summer while it will decrease in winter and in spring (less significantly than in winter). (iii) Precipitation amounts on wet days will increase in all seasons, the lowest increse will be in summer, the highest in winter. (iv) Probability of wet day occurrence will increase in winter and spring but decrease in summer and autumn. (4) Both lag-0 and lag-1day correlations of both temperature and precipitation will increase in all seasons – except for the slight decrease of lag-1day correlation of temperature in spring and autumn.

As a result of the climate change, our spatial validation indices will change their means (Fig. 4). The highest effect comes apparently from changes in TEMP means. Interestingly, effect of the three other characteristics (temperature variability, frequency of wet days and precipitation amount on wet days) have small effects, while changes in spatial correlation is significantly positive and gets the second rank just behind the effect of change in the temperature means.

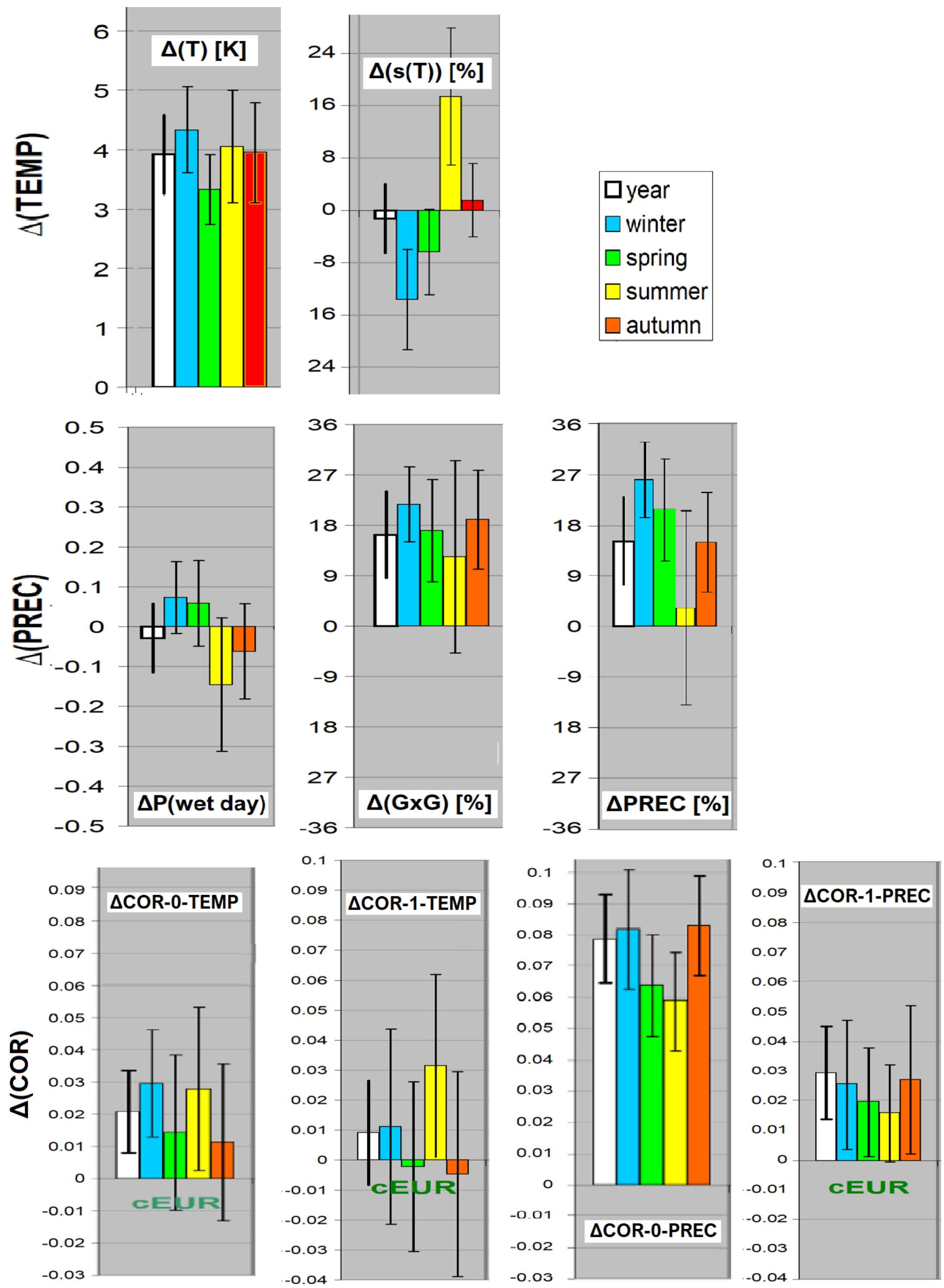

Fig. 3 Climate change scenarios for cEUR region derived from 19 RCM simulations. The bars with the whiskers show average plus/minus standard deviation from the 19 values. Individual bars show annual and seasonal changes in (1: top row) temperature averages and variability (standard deviation of temperature deviations from its mean annual cycle), (2: middle row) probability of wet day occurrence, mean precipitation sum on wet day and monthly precipitation amounts, and (3: bottom row) lag-0 and lag-1day spatial correlations of temperature and precipitation.

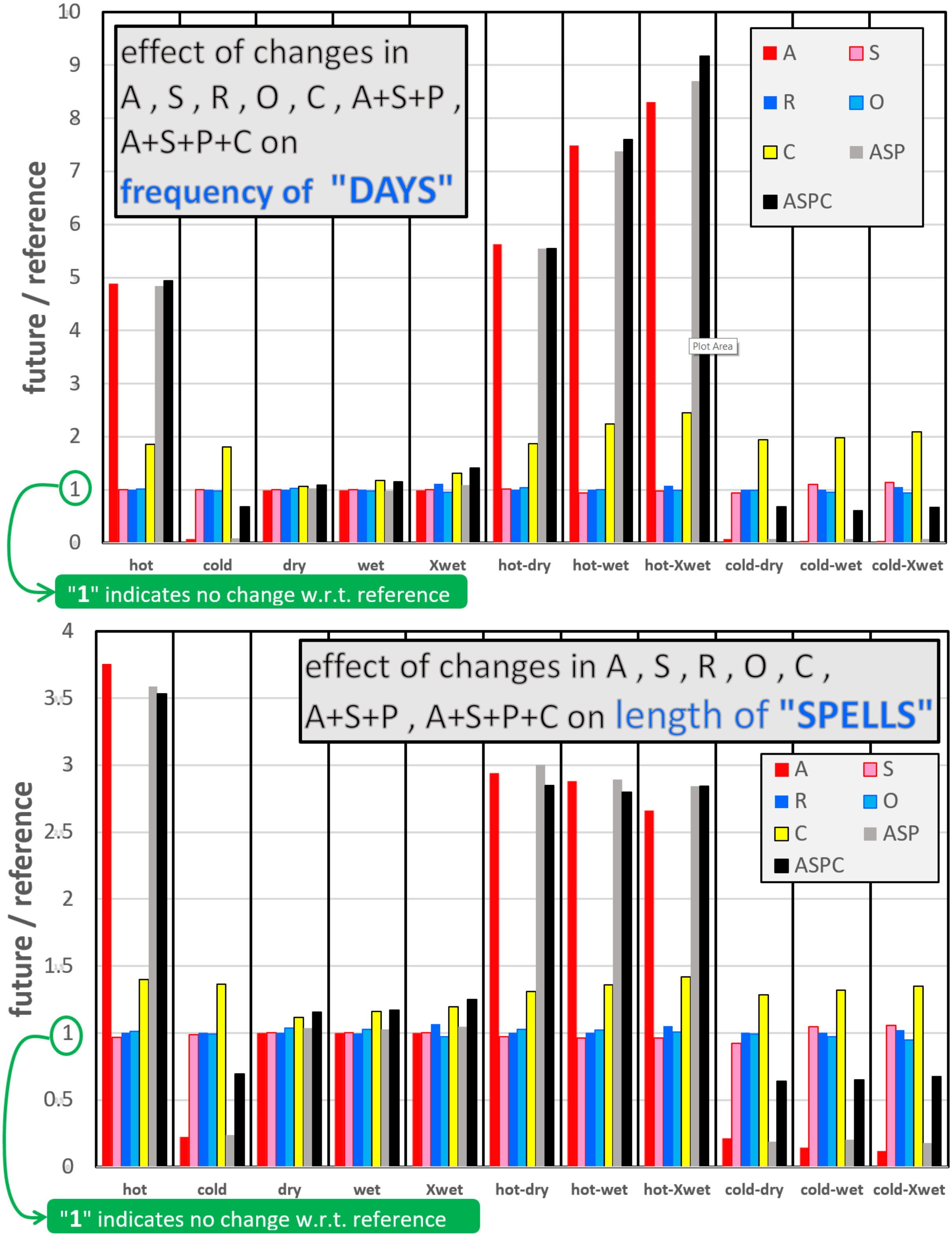

Fig. 4 Changes in the means (the ratios with respect to the values for the reference period) of the 11 spatial validation indices under 7 types of CC scenario (A, S, R, O, C, ASP and ASPC types are explained in the text). Changes in the Days are shown in the top graph, changes in the Spells are shown in the bottom graph.

5. Conclusion

The present paper focused on a demonstration of effective co-existence of two common downscaling approaches used to prepare meteorological inputs to various models (e.g.

agricultural crop growth models and hydrological rainfall-runoff models) used in assessing possible impacts of climate change or climate variability on various weather-dependent processes. In the first experiment we have shown that the two „competing“ approaches have good performance in reproducing various spatial climatic characteristics and none of the two is a winner. In the second part of the paper we have shown how the generator may be effectively used to show effects of changes in individual statistical characteristics of multisite weather series.

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