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Comparison of temperature indices for three IPCC SRES scenarios based on RegCM simulations for Poland in 2011–2030 period

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Abstract

The regional climate model RegCM3 is used to investigate potential future changes of temperature indices in Poland for the period 2011–2030. The model is forced by ECHAM5/MPI-OM GCM data from World Data Centre (WDCC) database for the 1971–1990 reference period and 2011–2030 projection period under SRES B1, A1B and A2 emission scenarios. Model output statistics methods are used to transform simulated minimum and maximum temperature data into realistic data. Selected indices of temperature extremes and their differences between the scenario simulations and the reference were calculated, for all scenarios, for the entire period and for each season. Results show a mean yearly increase in the number of summer and hot days and a decrease in the number of frost and ice days. Highest decline in the number of frost and ice days in autumn and an increase in spring is noticed. An highest increase in the number of summer and hot days is seen in summer. Future projections of these indices are relevant for studies on climate change impact in agriculture, tourism, health, transportation, road and building infrastructure.

Keywords: RegCM, temperature indices, climate modeling, Poland, SRES

1 Introduction

The Special Report on Emission Scenarios (SRES) by the Intergovernmental Panel on Climate Change (IPCC) (NAKIĆENOVIĆ et al., 2000) delivered a set of alternative paths for greenhouse gases (GHG) and SO_2 emissions. Global climate models, based on different emission scenarios, have been used to simulate future changes of various parameters and aspects describing Earth's climate system. High resolution future climate change projections are necessary for the development of adaptation and mitigation strategies (SHUKLA et al., 2009). Resolution of global climate models (GCMs) is too low and such features as topography and landuse type are highly smoothed. To simulate climate characteristics on the local-to-regional scale, the use of downscaling technique is necessary. A regional climate model (RCM) is such tool, which, driven by initial and boundary conditions (ICBC) from GCM, dynamically downscales global output to higher resolutions (GIORGI and MEARNS, 1999). Even though RCM resolution increased over last decade (CHRISTENSEN and CHRISTENSEN, 2007; JACOB et al., 2014) the inaccuracies still exist and comes mainly from driving model, numerical schemes, physical and subgrid scale processes parametrizations (LEUNG et al., 2003). To force impact studies, RCM output has to be transformed into realistic data by a chosen bias correction method. We use model output statistics (MOS) approach (MARAUN et al., 2010) which was successfully applied for temperature by e.g. WILCKE et al. (2013), VAUTARD et al. (2014) or PIOTROWSKI and JĘDRUSZKIEWICZ (2013). The aim of this paper is to compare changes of selected temperature indices for Poland for 2011–2030 with reference to 1971–1990, based on bias-corrected simulations performed with the RegCM (REGional Climate Model) for SRES B1, A1B and A2 scenarios. Each scenario assumes a distinctly different direction for future developments of the world and resulted GHG emissions. A1B is a variant of A1 family. B1 and A1 scenarios assume population rising to 9 billion in 2050 and then declining. A1B has balanced emphasis on all energy sources. Both assume rapid economic growth but B1 with rapid changes towards a service and information economy. A2 postulates a world with self-reliant nations, continuously increasing population and regionally oriented economic development. A2 results in highest temperature increase by 2100, A1B is moderate and B1 predicts lowest global temperature change. By 2030, GHG emissions and temperature changes projected by these scenarios are small but distinguishable. Most of published downscaling results base on A1B scenario which describes only one of divergent futures. The scope of this work is

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to compare results for these three scenarios focused on Polish territory simulated by RegCM.

2 Methodology

2.1 The model

The regional climate model RegCM (version 3.1) was used to investigate potential future changes of thermal indices in Poland for the period 2011–2030. The first year of the simulation served as spin-up time. Dynamics and physics of this model are described in detail by Elguindi et al. (2007). The RegCM has generally proved its good performance in simulating temperature field for Europe and observed differences in winter come mainly from boundary forcing and in summer from internal model physics (Giorgi et al., 2004). Torma et al. (2008) showed that simulated daily temperature has correlation coefficient of 0.9 with observations. The model appears efficient in simulation of daily minimum temperature Halenka et al. (2006). The same study suggests to use higher model resolution in order to reduce daily maximum temperature bias. According to that recommendation we have chosen 25 km horizontal resolution which is compromise between representation of topography and upper limit of the ratio of driving data versus model resolution suggested by Giorgi and Mearns (1999). According to that study the domain boundaries were chosen not to cross high mountains. Resulted model's domain had a size 146×96 grid points, used Lambert conformal conic projection and was centred at the geographical centre of Poland (Fig. 1). Eighteen sigma-pressure coordinate vertical layers were topped at 5 hPa. The model used the biosphere-atmosphere transfer scheme (BATS) (Yang and Dickinson, 1996) supplied by Global Land Cover Characterization (GLCC) land use and The United States Geological Survey (USGS) elevation data at 10-minutes resolution. For convective precipitation, the scheme developed by Grell (1993) and Arakawa and Schubert (1974) was employed. The model was forced by ICBC from run 1 of ECHAM5/MPI-OM (Roeckner et al., 2005) in the 1970–1990 reference period and 2010–2030 projection period under SRES B1, A1B and A2 emission scenarios.

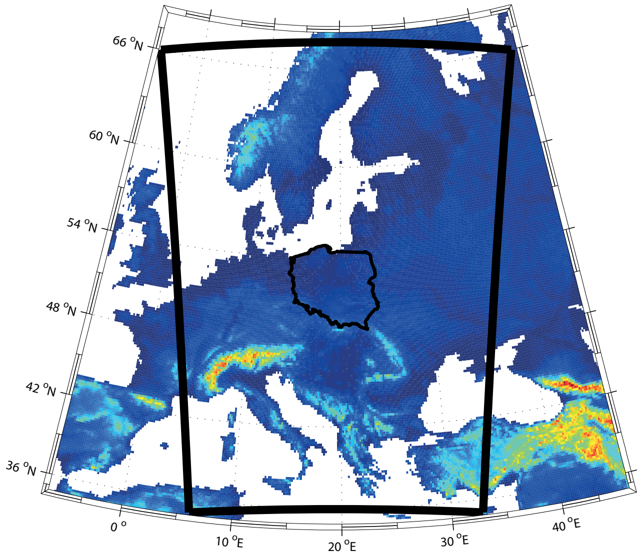


Figure 1: The RegCM computational domain for the study. Overlay is height above sea level.

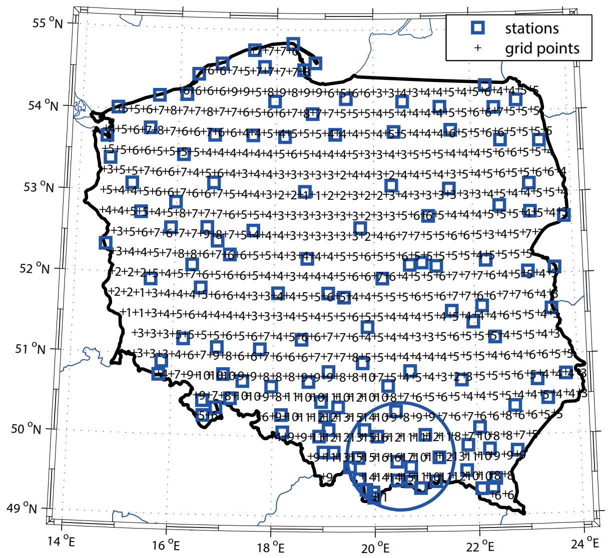


Figure 2: Vertical grid (black crosses) taken for model and observational data averaged within 75 km radius. Blue squares indicate station locations and number near every grid point is amount of stations around the radius (the one for selected grid point is shown).

2.2 Model output statistics methodology

Models do not reproduce a reality in a perfect way. There is always a difference between a modelled and observed climate. Thus, validation is necessary. Usually, it is performed on monthly or seasonal data. The validation procedure relies on a comparison of gridded data, which represent spatial averages, and station data, which are point values. A simple comparison of grid point values with the nearest station data is not recommended. The spatial correlation between gridded data is stronger than that between station data because of the numerical constraints in the GCMs and RCMs. The density of an observation network is less homogeneous than that of a gridded network. Usually, the density of gridded data in RCMs is much greater than that of observed data. Thus, a simulated climate is smoother than the actual climate it is simulating, and the low extremes are overestimated and the high extremes are underestimated. Model output statistics method suggested by Déqué (2007) were used to transform simulated data into realistic data. Daily mean observed and modelled (reference and scenario) temperature data were collected from an area 75 km in radius around every point of a regular grid 0.25 °×0.25 ° (Fig. 2) to produce cumulative distribution function. Then, the 10th and 90th percentiles, representing minimum and maximum temperature, respectively, were calculated, corrected to the height of this grid point (a lapse rate of 0.6 °C/100 m was assumed). Assuming constant lapse rate for temperature correction is frequently utilized procedure in impact studies with use of dynamical downscaling results (e.g. Endler and Matzarakis (2011) or Bordoy and Burlando (2012)). The radius of 75 km ensured availability of at least one observational station around each grid point. This procedure resulted in three sets of data: gridded observed data, modelled data for 1971–1990 and modelled data for 2011–2030, all on the same 0.25°×0.25° regular grid, calculated separately for whole year and four seasons. On the Figs. 3 and 4 mean bias between modelled and observed temperatures is presented. The strongest biases are seen for summer (cold bias) and for winter (hot bias). On yearly average daily minimum temperature is hot biased and maximum temperature is cold biased. It could influence the projections of temperature indices but previous studies (Giorgi and Coppola, 2010; Knutti et al., 2009) have checked that the dependency of the mean regional climate change signal on the model regional bias is almost negligible for temperature. Supported by that we focus only on differences between scenario and reference period.

2.3 Temperature indices

The number of days with extreme temperatures exceeding certain thresholds were calculated on a geographical grid. The temperature indices used in the study were defined by the Joint CCl/CLIVAR/JCOMM Expert Team on Climate Change Detection and Indices (ETCCDI, see http://www.clivar.org/organization/etccdi/etccdi.php) as follows:

- frost days (fd): number of days where T_{min} (daily minimum temperature) < 0 °C
- ice days (id): number of days where T_{max} (daily maximum temperature) < 0 °C
- summer days (sd): number of days where T_{max} > 25 °C

Additionally, hot days (hd): number of days where T_{max} exceeded 30 °C were calculated.

Changes in the number of days between scenario simulations and the reference were calculated, both for the entire period and for each season. Results are presented in the next section.

3 Results

The following subsections describe absolute changes in temperature indices for whole years and seasons. Seasons are shown in different colours, allowing comparison of results for different scenarios.

3.1 Changes in frequency of frost days

The number of days with minimum daily temperature below 0 °C (frost days) is projected to decrease in A1B (up to 7 fewer such days per year) and B1 scenarios (more than 15 fewer days) (Fig. 5). The greatest decrease is simulated for scenario B1, when up to 20 fewer such days can happen, and the greatest increase in scenario A2 (about 5–7 more days). As for individual seasons, only during autumn do all scenarios project a decrease in the number of frost days. In winter, scenario B1 predicts the highest increase, which takes place in southern Poland, and which extends in scenario A2 to eastern Poland, In the spring, scenario B1 forecasts a decrease in the number of frost days.

3.2 Changes in frequency of ice days

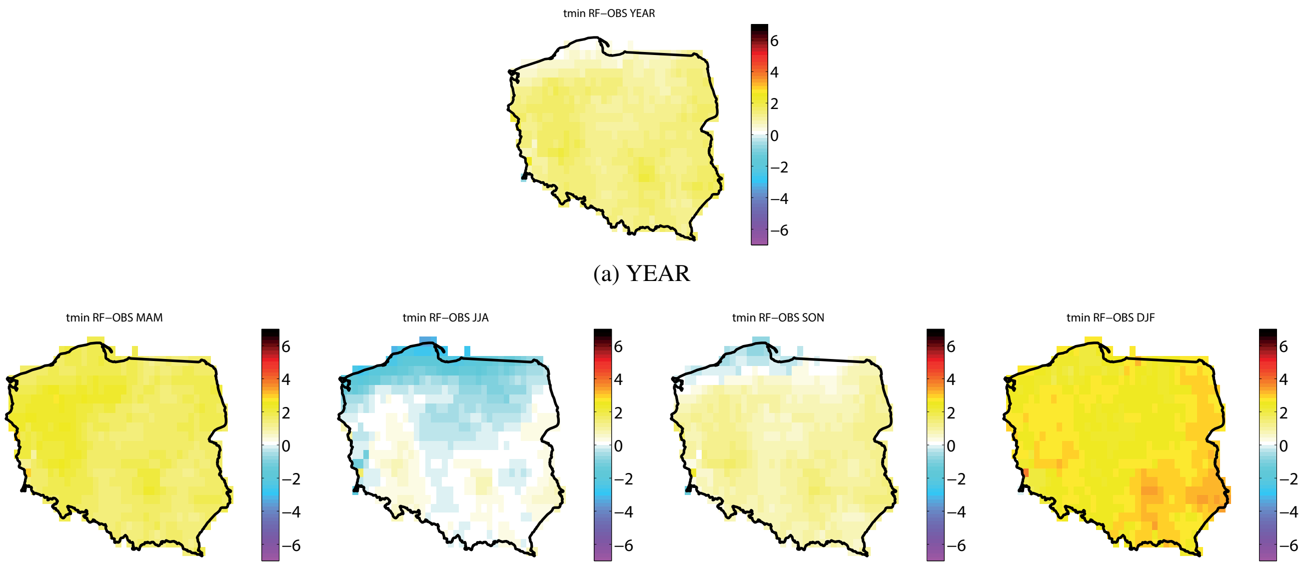
Annual number of days with maximum daily temperature below 0 °C (ice days) is projected to decrease in scenarios A1B (up to 5 fewer days per year) and B1 (up to 15 fewer days per year) but an increase is projected in scenario A2 (up to 10 more days per year) (Fig. 6). In spring, for all scenarios, an increase is expected in such days, with the greatest increase being in scenario A2 and in north-eastern Poland (up to 7 more days). In winter and autumn, the number of ice days will decrease, most rapidly in the winter in the B1 scenario (up to 6 days fewer). An increase is seen only in scenario A2, in south-eastern Poland.

3.3 Changes in frequency of summer days

Annual number of days with maximum daily temperature exceeding 25 °C is expected to increase (up to 5 days more yearly) (Fig. 7). Only scenario B1 predicts a decrease in the occurrence of summer days, in south-eastern Poland. This yearly increase is mainly due to projected intensification of such events in the summer season. In spring and autumn, the number of such days is predicted to decrease, but a slight autumn increase is expected for all of Poland in scenario A2 and in western Poland in scenarios A1B and B1.

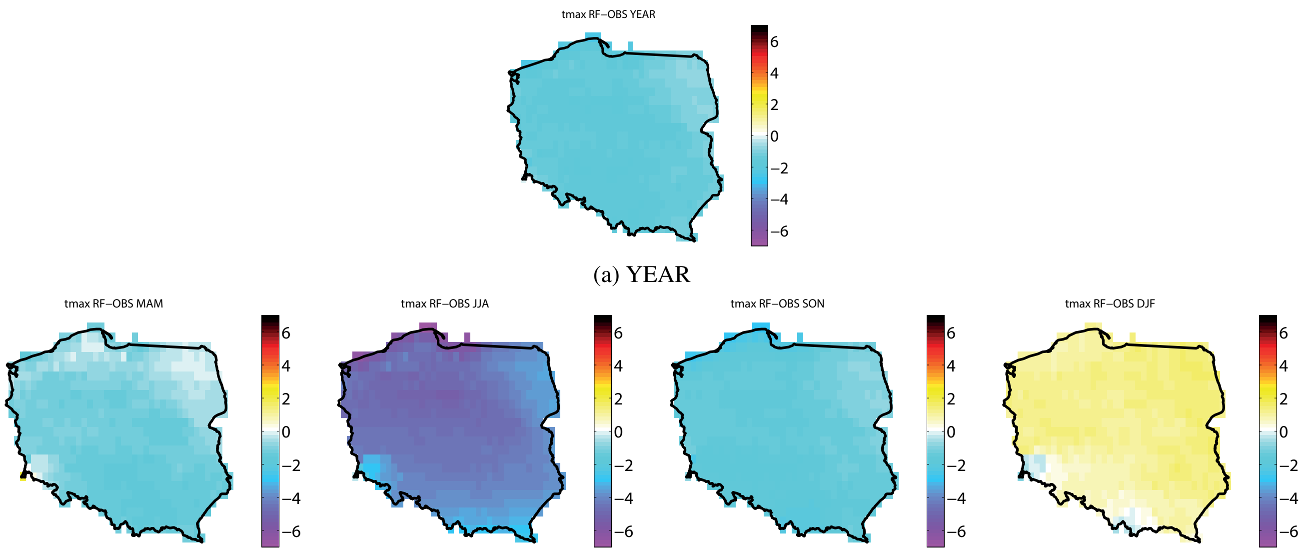
3.4 Changes in frequency of hot days

Annual number of days with maximum daily temperature exceeding 30 °C is expected to increase for all evaluated scenarios, with the exception of B1, which predicts a slight decrease for southern Poland (Fig. 8). Similar increase is predicted in summer (up to nearly 3 days more), while in spring and autumn changes are very small.



(a) YEAR (b) SPRING (c) SUMMER (d) AUTUMN (e) WINTER

Figure 3: Spatial distribution of mean bias of daily minimum temperature for the whole year and seasons.



(a) YEAR (b) SPRING (c) SUMMER (d) AUTUMN (d) WINTER

Figure 4: Spatial distribution of mean bias of daily maximum temperature for the whole year and seasons.

4 Discussion and conclusion

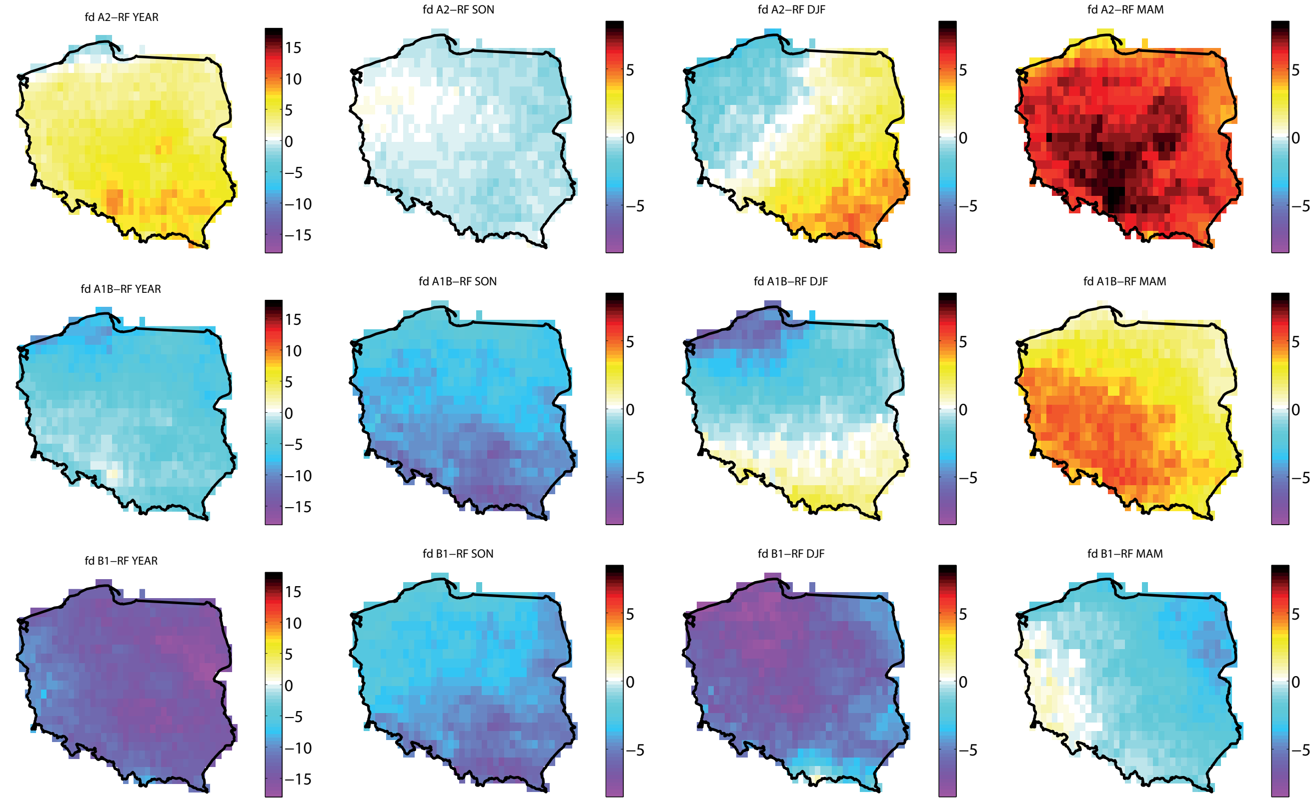
Regional climate simulations have been performed for a reference period (1971–1990) and for B1, A1B and A2 scenarios (2011–2030). Output has been corrected into practical data by use of MOS methodology. Projections of temperature indices for Polish territory have been presented as annual and seasonal changes relative to the reference period. CO_2 emissions for different scenarios do not differ significantly for the 2011–2030 period. This explains the qualitative similarity of projections for the three scenarios. Tables 1–4 summarize results as percentage changes averaged over Poland. Following global temperature change, it is expected that the number of frost and ice days will decrease and the number of summer and hot days will increase. Surprisingly,

Table 1: Mean percentage change of frost days for whole year and seasons

	YEAR	MAM	JJA	SON	DJF
A2	3.55	21.04	–	−2.26	1.49
A1B	−3.99	10.83	–	−22.12	−2.04
B1	−12.08	−6.51	–	−22.89	−8.53

Table 2: Mean percentage change of ice days for whole year and seasons

	YEAR	MAM	JJA	SON	DJF
A2	6.31	92.81	–	8.56	0.86
A1B	−6.76	50.71	–	−34.72	−6.79
B1	−15.49	11.85	–	−34.74	−13.48



(a) YEAR (b) AUTUMN (c) WINTER (d) SPRING

Figure 5: Average differences in the number of days with $T_{\min} < 0\,°\mathrm{C}$ (frost days) between scenario simulations (A2 – upper row, A1B – middle row, B1 – bottom row) and the reference one for the whole year and seasons.

Table 3: Mean percentage change of summer days for whole year and seasons

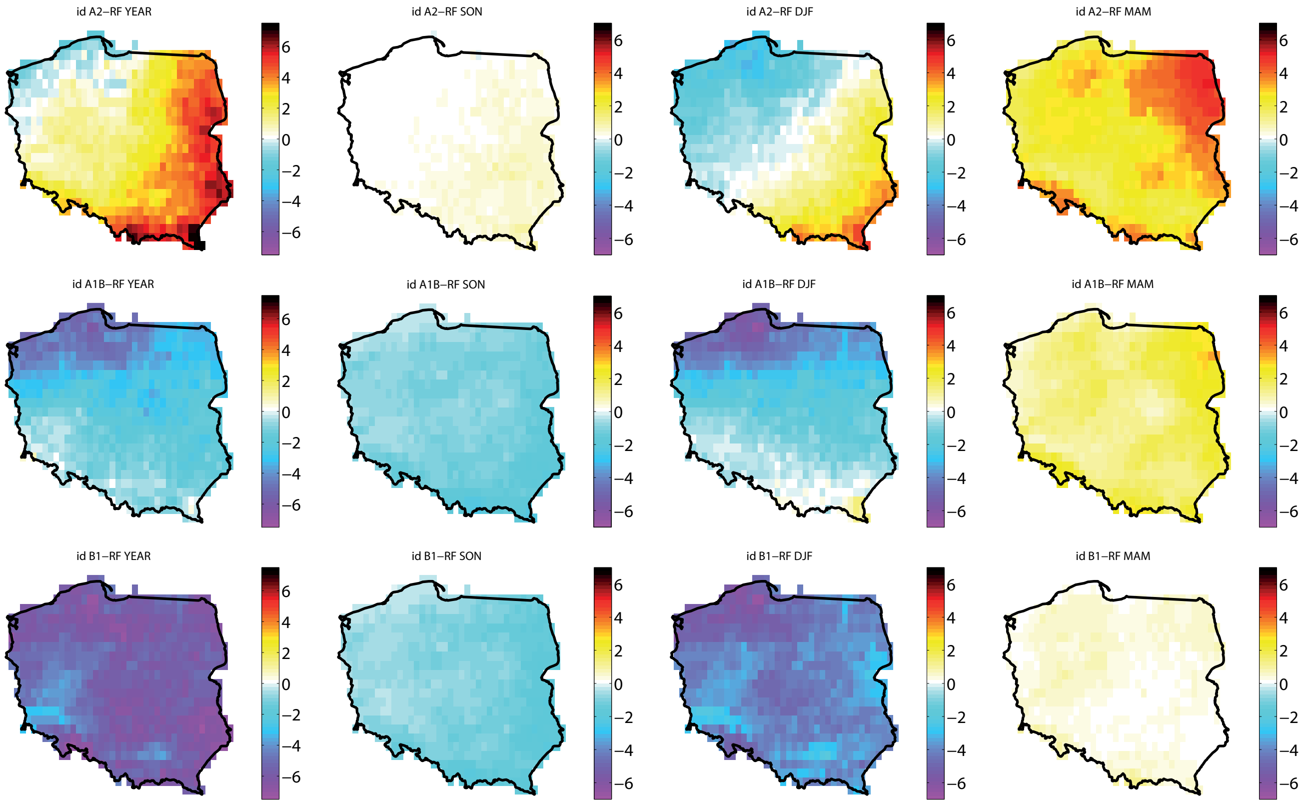
	YEAR	MAM	JJA	SON	DJF
A2	13.05	−21.04	16.95	16.66	–
A1B	11.91	−1.57	15.09	−8.23	–
B1	4.24	−2.12	6.82	−19.61	–

Table 4: Mean percentage change of hot days for whole year and seasons

	YEAR	MAM	JJA	SON	DJF
A2	36.87	−39.42	39.98	34.70	–
A1B	35.60	−0.79	38.02	−14.60	–
B1	14.39	−1.70	15.97	−34.44	–

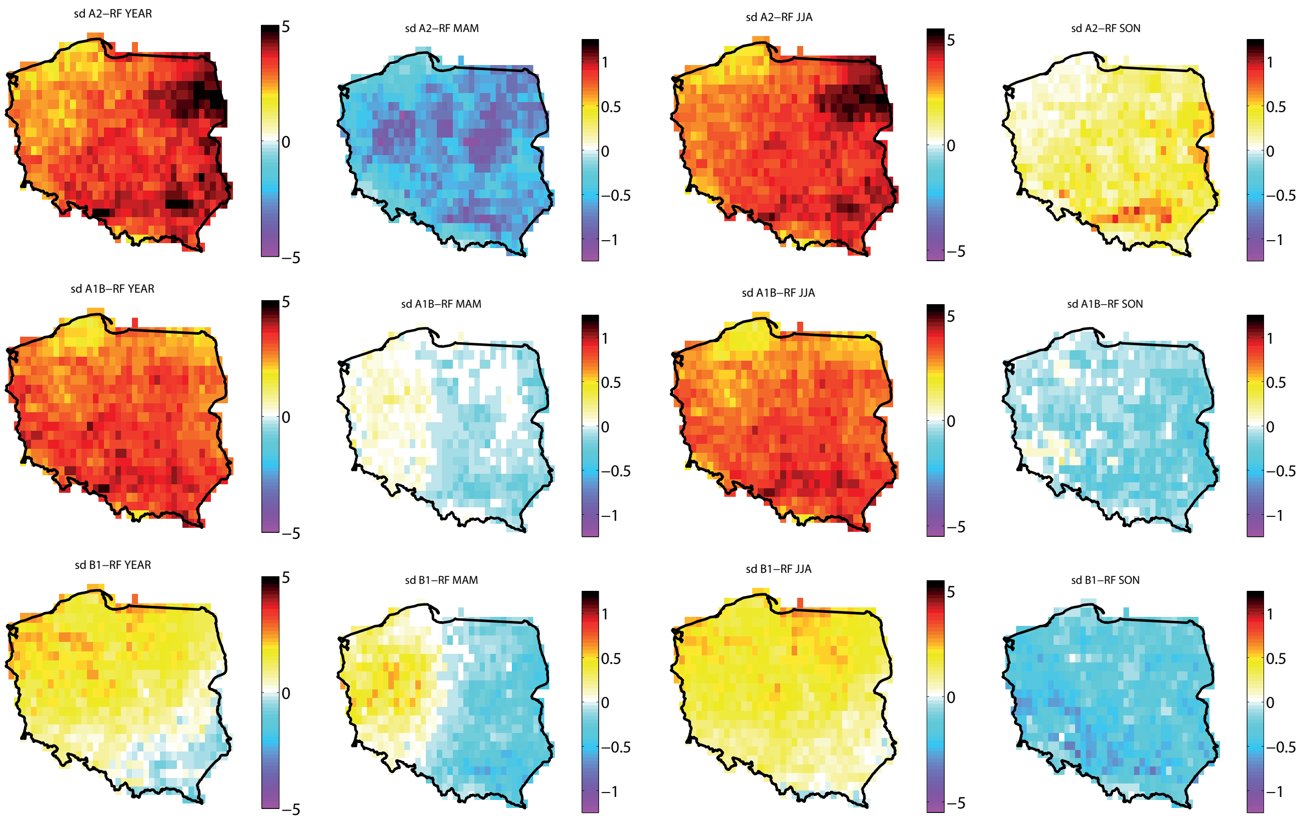
the exception is scenario A2, which projects an increase in the number of frost and ice days. However, these results are partly supported by Niehörster et al. (2008), who showed that, although differences among the three scenarios are insignificant, multi-model mean warming for the 2011–2030 period and A2 scenario is lowest (see Fig. 2 of that publication). For the period 1946–99, trends per decade in the annual number of frost days and summer days were detected as negative and positive, respectively, by Klein Tank and Können (2003). More intriguing are results for seasonal changes of temperature indices. In spring, an increase in frost and ice days is predicted, as opposed to winter. This result is supported by Elguindi et al. (2013), who found negative trend in the ENSEMBLES Observations gridded dataset (E-OBS) data for minimum temperature. In the autumn season the number of summer and hot days is projected to decrease. This results is in good agreement with studies by Jones et al. (2001) and Klein Tank et al. (2005) who found autumn cooling over Europe. Projected annual increase of summer and hot days is caused mainly by the increase in the number of such days in the summer season. This result is contributed to by intensification of heat wave occurrences at the beginning of the 21st century (Domonkos et al., 2003; Kyselý, 2010). Our results show slight increase in the number of summer and hot days in spring regardless of observed earlier spring (Schwartz et al., 2006). Nevertheless, Stine et al. (2009) have shown that IPCC's models do not reproduce the change in phase of annual surface of surface temperature.

The information on the projected changes of the indices could be utilized in several ways from communicating the public and stakeholders up to the development of necessary climate change adaptation and mitigation strategies. Besides some benefits of climate change it significantly alter potential impacts on



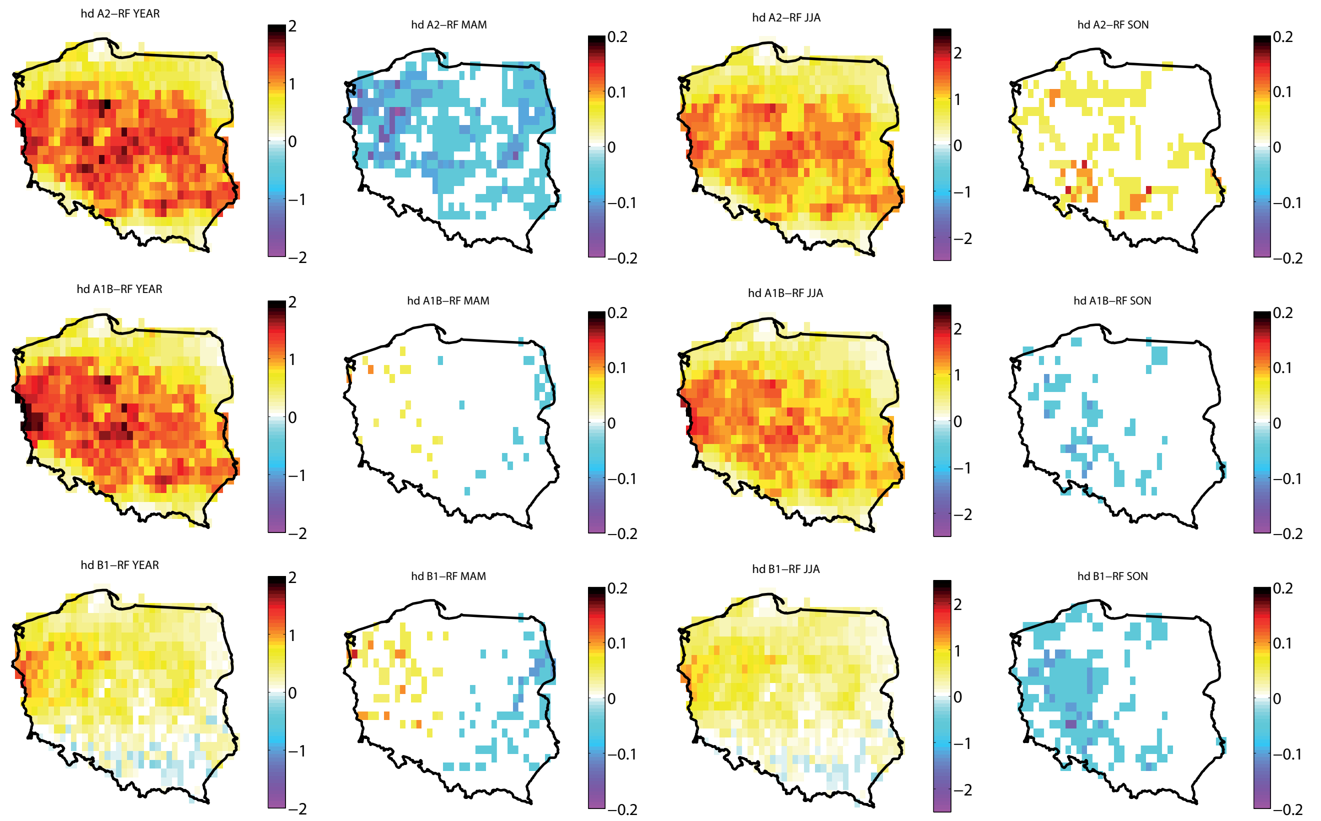
(a) YEAR (b) AUTUMN (c) WINTER (d) SPRING

Figure 6: Average differences in the number of days with $T_{max} < 0\,°C$ (ice days) between scenario simulations (A2 – upper row, A1B – middle row, B1 – bottom row) and the reference one for the whole year and seasons.



(a) YEAR (b) SPRING (c) SUMMER (d) AUTUMN

Figure 7: Average differences in the number of days with $T_{max} > 25\,°C$ (summer days) between scenario simulations (A2 – upper row, A1 – middle row, B1 – bottom row) and the reference one for whole year and seasons.



(a) YEAR (b) SPRING (c) SUMMER (d) AUTUMN

Figure 8: Average differences in the number of days with $T_{max} > 30\,^{\circ}C$ (hot days) between scenario simulations (A2 – upper row, A1B – middle row, B1 – bottom row) and the reference one for whole year and seasons

many sectors. Observed earlier onset of growing season (Inouye, 2008) may lead to an increased risk of frost plant damage (Kreyling et al., 2012). Change in the number of ice days can affect the road infrastructure (Mateos et al., 2012) and housing sector (Lisø et al., 2007) due to freeze-thaw process. The transport is also influenced by increased number of hot days which e.g. increases thermal loading on road pavements (Peterson et al., 2008). The numbers of summer and hot days are relevant in public health (Basu, 2009) and tourism sectors (Lise and Tol, 2002).

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