14

Regional-Scale Assessment of the Climatic Role of Forests Under Future Climate Conditions

Borbála Gálos[1] and Daniela Jacob[1,2]
[1]*Max Planck Institute for Meteorology, Hamburg*
[2]*Climate Service Center–eine Einrichtung am Helmholtz-Zentrum Geesthacht*
Germany

1. Introduction

1.1 Regional climate projections for Europe

Several natural and anthropogenic processes influence the climate of the Earth. Human affect climate through increasing greenhouse gas concentrations, changing aerosol compositions as well as by land surface changes (IPCC, 2007). There are several recent EU-projects carried out in the last decade, to provide high-resolution climate change projections with focus on future climate changes and their impacts in Europe (Christensen et al., 2007; Jacob et al., 2008; van der Linden & Mitchell, 2009). These studies are based on the results of regional climate model simulations driven by different predefined greenhouse gas emission scenarios. The difference between the simulated climatic conditions for the future and for the present time period is the climate change signal. For the 21st century, projected climate change signals for temperature and precipitation show seasonal and spatial differences in Europe and also vary depending on the applied greenhouse gas emission scenario.

For the period 2021-2050 all regional climate models predict a quite robust (i.e. above the noise generated by the internal model variability and consistent across multiple climate models – Hagemann et al., 2009) surface warming in central and eastern Europe. The annual precipitation shows an increase in the northeastern and a decrease in the southwestern regions. The transition (neutral) zone (e.g. Hungary, Rumania) can be characterized by the largest spread between models (Christensen & Christensen, 2007; Kjellström et al., 2011), where precipitation changes are quite small.

At the end of the 21st century, a warming is expected in all seasons over Europe, which is stronger than in the first half of the 21st century. All models agree that the largest warming for summer is projected to occur in the Mediterranean area, southern France and over the Iberian Peninsula. Less warming is projected over the Scandinavian regions. For winter the maximum warming occurs in eastern Europe (Giorgi et al., 2004; Christensen & Christensen, 2007). For precipitation, the largest increase is projected in winter, whereas the decrease is the strongest in summer. Changes in the intermediate seasons (spring and autumn) are less pronounced. Results of the regional model simulations show a north-south gradient of annual precipitation changes over Europe, with positive changes in the north (especially in winter) and negative changes in the south (especially over the Mediterranean area in summer). The line of zero change moves with the seasons (Kjellström et al., 2011). For southern and central Europe the spatial distribution of the projected temperature and precipitation changes in summer refer to a marked shift towards a warmer and drier climate (Vidale et al., 2007; Beniston, 2009). Recent results from enhanced greenhouse gas emission scenario simulation over Europe suggest that not only the climatic means are changing, but there is also an increase in the inter-annual variability of the future temperature and precipitation values, which leads to higher probability of extremes compared to the present-day conditions (Schär et al., 2004; Giorgi et al., 2004; Seneviratne et al., 2006; Beniston et al., 2007; Kjellström et al., 2007; Vidale et al., 2007; Fischer & Schär 2010).

The most commonly used IPCC-SRES (Intergovernmental Panel on Climate Change – Special Report on Emission Scenarios) emission scenarios for these studies are the B1, A1B, A2. In the first half of the 21st century, the climatic impact of these greenhouse gas emission scenarios are quite similar (van der Linden & Mitchell, 2009). But the temperature difference increases by mid-century with greatest warming in A2 and least warming in B1 (IPCC, 2007).

1.2 Climatic effects of land use and land cover change

Temperature and precipitation play an important role in determining the distribution of the terrestrial ecosystems that in turn interact with the atmosphere through biogeophysical and biogeochemical processes. Vegetation affects the physical characteristics of the land surface, which control the surface energy fluxes and hydrological cycle (biogeophysical feedbacks; Pielke et al., 1998; Brovkin, 2002; Pitman, 2003; Betts, 2007; Anderson et al., 2010). Through biogeochemical effects, ecosystems alter the biogeochemical cycles, thereby change the chemical composition of the atmosphere (Betts, 2001; Bonan, 2002; Pitman, 2003; Bonan, 2004; Feddema et al., 2005). Forests have larger leaf areas and aerodynamic roughness lengths, lower albedo and deeper roots compared to other vegetated surfaces. They sequester carbon thereby alter the carbon storage of land.

Depending on the region, biogeophysical and biogeochemical feedbacks of land cover on climate can amplify or dampen each other (Arora & Montenegro, 2011). Through these land-atmosphere interactions changes of the land cover and land use due to natural and human influence alter climate and hence can lead to the enhancement or reduction of the projected climate change signals expected from increased atmospheric CO_2 concentration (Feddema et al., 2005; Bonan, 2008). Long term studies show that land use and land cover changes have much weaker influence on the atmospheric circulation compared to greenhouse-gas forcings (Betts, 2007; Göttel et al., 2008; Wramneby et al., 2010; Arora & Montenegro, 2011). However, in smaller areas and in regions with strong land-atmosphere interactions the feedback processes can significantly affect and modify the weather and climate, the temperature and precipitation variability (Seneviratne et al., 2006; Seneviratne et al., 2010).

This section focuses on studies of the biogeophysical processes, which represent the contrasting climatic effects of forest cover changes on different regions, seasons and time scales. Changes of vegetation cover under future climate conditions enhance the warming trend in Scandinavian Mountains as well as the drying trend in southern Europe, but mitigate the projected increase of temperature in central Europe (Wramneby et al., 2010). Boreal forests have the greatest biogeophysical effect of all biomes on annual mean global temperature, which is larger than their effect on the carbon cycle (Bonan, 2008). If snow is present, the darker coniferous forest masks the snow cover. It is resulting in lower surface albedo compared to tundra vegetation or bare ground, which leads to higher winter and spring air temperatures (Bonan et al., 1992; Brovkin, 2002; Kleidon et al., 2007; Göttel et al., 2008).

Consequently, the change of vegetation from tundra to taiga under future climate conditions amplifies the global warming. Tropical forests maintain high rates of evapotranspiration. In this region, surface warming arising from the low albedo of forests is offset by the strong evaporative cooling that reduces global temperature increase (Bonan, 2008).

In temperate forests the albedo and evaporative forcings are moderate compared to boreal and tropical forests (Bala et al., 2007; Bonan, 2008; Jackson et al., 2008). Climate model studies for the temperate regions showed that replacing forests with agriculture or grasslands reduces the surface air temperatures (Bonan, 1997; Bounoua et al., 2002; Oleson et al., 2004) and the number of summer hot days (Anav et al., 2010). Other studies show opposite results, where temperate forests cool the air compared to grasslands and croplands and contribute to higher precipitation rates in the growing season (Copeland et al., 1996; Hogg et al., 2000; Sánchez et al., 2007). In the Mediterranean region climatic effects of forest cover change can also vary during the summer months (Heck et al., 2001). In the period from April until mid-July potential vegetation cover conditions led to cooler and moister conditions due to the increase of evapotranspiration. In mid-July soil moisture dropped below the critical value and transpiration was almost completely inhibited. It resulted in dryer and warmer summer accelerating the projected climate change. Teuling et al. (2010) pointed out that the role of the forests in the surface energy and water budget is depending on the selected time scale: in the short term, forests contribute to the increase of temperature, but on longer time scales they can reduce the impact of extreme heat weaves.

These studies indicate that forests can enhance or dampen the climate change signal depending on various contrasting vegetation feedbacks, which can diminish or counteract each other. Furthermore the variability of the climatic, soil and vegetation characteristics as well as the description of the land surface processes in the applied climate model also have an influence on the simulated vegetation-atmosphere interactions.

1.3 Research foci

The climatic feedbacks of land cover changes due to climate change and the regional land use politics as well as the role of the forests in the climate change mitigation on country scale are still unknown. Fine scale studies are essential not only for the assessment of the climate protecting effects of forests, but also for the development of adaptation strategies in forestry, agriculture and water management for the next decades.

In order to address this topic, our sensitivity study is focusing on the climatic effects of afforestation in Europe under future climate conditions based on the following research questions:

- In which regions does the increase of forest cover enhance/reduce the projected climate change?
- How big are the effects of forest cover change on the summer precipitation and temperature relative to the climate change signal?
- Which are the regions, where afforestation is the most beneficial from a climatic point of view?

On country scale, a more detailed case study has been carried out for Hungary. For the end of the 21st century, regional climate model simulations project a significant increase of summer temperature and a decrease of summer precipitation (Bartholy et al., 2007; Gálos et al., 2007;

Jacob et al., 2008; Szépszó, 2008; Radvánszky & Jacob, 2009). From ecological point of view Hungary (in the southeastern part of central Europe) has been selected as study region because here, many of the zonal tree species have their lower limit of distribution (Mátyás et al., 2009; Mátyás, 2010; Mátyás et al., 2010), which are especially sensitive and vulnerable to the increase of the frequency of climatic extremes, primarily droughts. In these forests the more frequent and severe droughts at the end of the 20th century already resulted in growth decline, loss of vitality and the decrease of the macroclimatically suitable area of distribution (Berki et al., 2009). Under the projected climate conditions these species may disappear from this region (Berki et al., 2009; Mátyás et al., 2010; Czúcz et al., 2011).

In the last 50 years, large scale afforestation was carried out in Hungary, which is planned to continue also in the near future. The influence of the historical land cover change on weather and climate has been investigated by Drüszler et al. (2011). For the future, forests can also have an important role in the adaptation to climate change. Therefore this case study is concentrating on the possible mitigation of the strong warming and drying of summers projected for the second half of the 21st century. The assessment of the maximal climatic effects of afforestation is addressing the following research questions:

- Which regions are the most affected by climate change for the end of the 21st century?
- In which part of the country can forests play an important role in reducing the projected tendency of drying?

In order to answer the scientific questions the chapter is organized as follows: in section 2 the applied model and experimental set up and the main steps of the analyses are described. Results are presented in section 3: in 3.1 the sign of the climatic effect of emission change and potential afforestation has been studied for precipitation and temperature. In section 3.2 the most climate change affected regions as well as the areas characterized by the largest climatic effects of forest cover increase have been determined. In section 3.3 the magnitude of the climatic feedbacks of afforestation is analyzed relative to the magnitude of the climate change signal. Section 3.4 introduces the country scale effects of maximal afforestation in Hungary. Results are summarized, conclusions are drawn and the possibilities for the practical application are stressed in section 4.

2. Methods

Regional climate models have the potential to provide detailed information about the future climate on fine horizontal resolution. For studying the climatic feedbacks of land cover change in Europe regional scale analyses are essential because of the differences in the climate sensitivity among regions and the large spatial variability of the land surface properties and the related processes.

2.1 The regional climate model REMO – General characteristics and land surface parameterization

In this study the REgional climate MOdel (REMO) has been applied for Europe, with horizontal resolution 0.22°. REMO (Jacob, 2001; Jacob et al., 2001; Jacob et al., 2007) is a regional three-dimensional numerical model of the atmosphere. It is based on the ‘Europamodell’, the former numerical weather prediction model of the German Weather Service, DWD (Majewski, 1991). The calculation of the prognostic variables is based on the hydrostatic approximation. The physical parameterizations from the global climate model ECHAM4 are implemented at the Max Planck Institute for Meteorology in Hamburg (Roeckner et al., 1996) in the regional model.

Land surface processes in REMO are controlled by physical vegetation properties. For each land cover type the parameter values of leaf area index and fractional vegetation cover for the growing and dormancy season, background albedo, surface roughness length due to vegetation, forest ratio, plant-available soil water holding capacity and volumetric wilting point are allocated in the global dataset of land surface parameters (Hagemann et al., 1999; Hagemann, 2002). In the current model version the vegetation phenology is represented by the monthly varying values of the leaf area index and vegetation ratio. The mean climatology of the annual cycle of background albedo is also implemented (Rechid & Jacob, 2006, Rechid et al., 2008a, 2008b). The other land surface parameters remain constant throughout the year. Land cover change in REMO can be implemented by modification of the characteristic land surface parameters.

2.2 Experimental setup

The simulations have been carried out for Europe (figure 1), with 0.22° horizontal grid resolution. REMO was driven with lateral boundary conditions from the coupled atmosphere–ocean GCM ECHAM5/MPI-OM (Roeckner et al., 2006; Jungclaus et al., 2006).

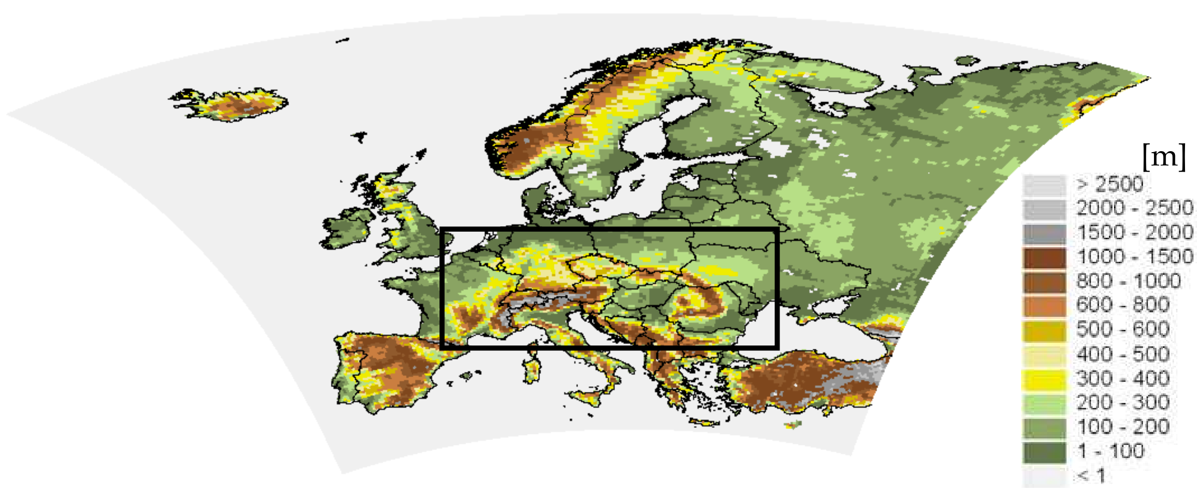


Fig. 1. Simulation domain. The smaller domain applied for the Hungarian case study is marked with rectangle

The following experiments have been performed (table 1):

- *Reference simulation* for the past (1971-1990) with present (unchanged) forest cover.
- *Emission scenario simulation* for the future (2071-2090) with present (unchanged) forest cover applying the A2 IPCC-SRES emission scenario[1] (Houghton et al., 2001; Nakicenovic et al., 2000). This experiment was the reference simulation to the land cover change study.

[1] A2: continuously increasing global population and regionally oriented economic growth that is more fragmented and slower than in other storylines.

- *Potential afforestation* experiment for 2071-2090. The forest cover increase (figure 2) is based on the net primary production map for Europe derived from remotely sensed MODIS (Moderate-Resolution Imaging Spectroradiometer) products, precipitation and temperature conditions from the Wordclim database and soil conditions from the International Institute for Applied Systems Analysis (Kindermann, pers. comm.). The new afforested areas were assumed to be deciduous.

Experiment	*Reference simulation*	*Potential afforestation simulation*
Characteristics	Present forest cover	Afforestation over all vegetated area [a]
Time period	1971-1990 2071-2090	2071-2090
Greenhouse gas forcing	IPCC-SRES emission scenario A2	
Horizontal resolution	0.22°	
Lateral boundaries	ECHAM5/MPI-OM[b]	

[a] based on Kindermann (pers. comm.)
[b] Roeckner et al., 2006; Jungclaus et al., 2006

Table 1. Analyzed data and time periods

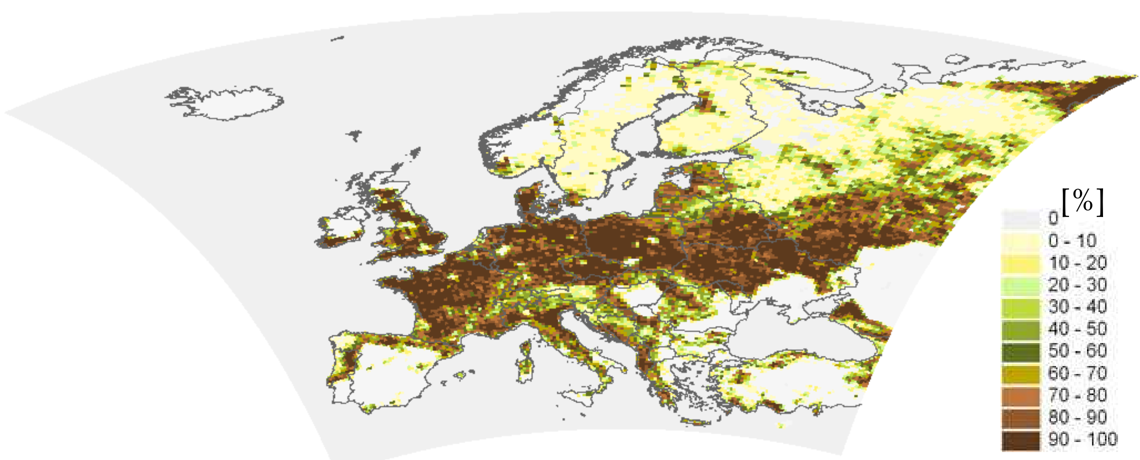


Fig. 2. Increase of the forest cover in the potential afforestation simulation compared to the present forested area in the model

2.3 Main steps of the analyses

These analyses are focusing on the biogeophysical feedbacks of afforestation on the climate. Corresponding to the forest cover increase in all grid boxes the new distribution of the land cover categories has been determined and a new land surface parameter set has been calculated. Simulation results have been analyzed for May, June, July and August. In this study the mean of this period is considered '*summer*' (MJJA), because in these months water availability is especially important for the vegetation growth. The leaf area index of the deciduous forests reaches its maximum, which has a strong control on the land-atmosphere interactions.

Climate change due to emission change has been investigated analyzing the summer precipitation sums and 2m-temperature means for 2071-2090 (without any land cover changes) compared to 1971-1990.

Climate change due to potential afforestation has been calculated comparing the simulation results with- and without forest cover increase for the future time period (2071-2090).

Climate changes due to emission changes and potential afforestation has been determined comparing the results of the potential afforestation experiment (2071-2090) to the reference study in the past (1971-1990). The sign and the magnitude climatic effects of potential afforestation have been analyzed relative to the climate change signal. Regional differences in the climate change altering effect of afforestation have been determined and investigated for two selected regions.

For more detailed analyses, a case study has been prepared for Hungary over a smaller simulation domain (figure 1), applying the same regional climate model and the same steps for data analyses. Climate change due to emission change has been calculated for 2071-2100 compared to the 30-year time period in the past (1961-1990). The A1B IPCC-SRES emission scenario[2] (Houghton et al., 2001; Nakicenovic et al., 2000) has been applied, which represents the average estimation for the analyzed region. To get information about the maximum climatic effects of afforestation and its regional differences, the whole vegetated area of Hungary was assumed to be forest and the new afforested areas are all deciduous. Over the simulation domain (marked in figure 1), forest cover has been changed only in Hungary. The assumed maximal afforestation takes approximately 75 % increase of forest cover in country mean additionally to the existing 20 % forested area (figure 3).

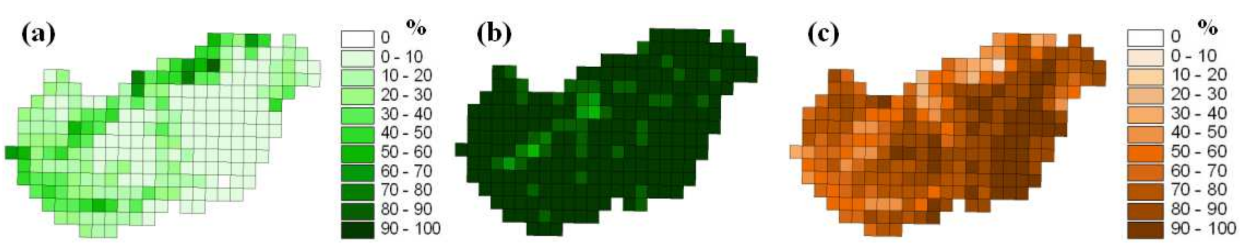


Fig. 3. Forest cover in Hungary in the reference simulation (a) and in the maximal afforestation experiment (b). Increase of forest cover in the maximal afforestation experiment compared to the reference (c). Adapted from: Gálos et al., 2011

A Mann-Whitney–U-Test (Mann & Whitney, 1947) was applied to test the significance of the climatic effects of afforestation and emission change. This is a ranking test, which does not assume a normal distribution.

3. Results

3.1 Sign of the climatic effects of emission change and potential afforestation

The climate change signals without any land cover changes have been analyzed for summer temperature means and precipitation sums in the time period 2071-2090 compared to 1971-1990. Based on the simulation results a positive temperature signal is expected in whole Europe (figure 4a). Increase of temperature is projected to occur with precipitation decrease

[2] A1: very rapid economic growth, global population peaks in mid-century and declines thereafter, and rapid introduction of new and more efficient technologies. The A1 scenario family develops into three groups that describe alternative directions of technological change in the energy system; A1B means a balance across all sources.

in southern and central Europe and in the southern part of Scandinavia, whereas Northeast Europe can be characterized with warmer and wetter conditions (figure 4a).

Figure 4b represents the direction of the temperature and precipitation changes due to afforestation only. Comparing the simulation results with- and without forest cover changes for the future (2071-2090), the cooling and moistening effects of afforestation are dominant in most parts of the temperate zone. Here, the largest amount of forest cover increase has been assumed. Forests have large leaf area and they are aerodynamically rough, that support the more intense vertical mixing compared to other vegetated surfaces. It leads to enhanced ability of evapotranspiration and thereby to the decrease of temperature compared to the reference simulation.

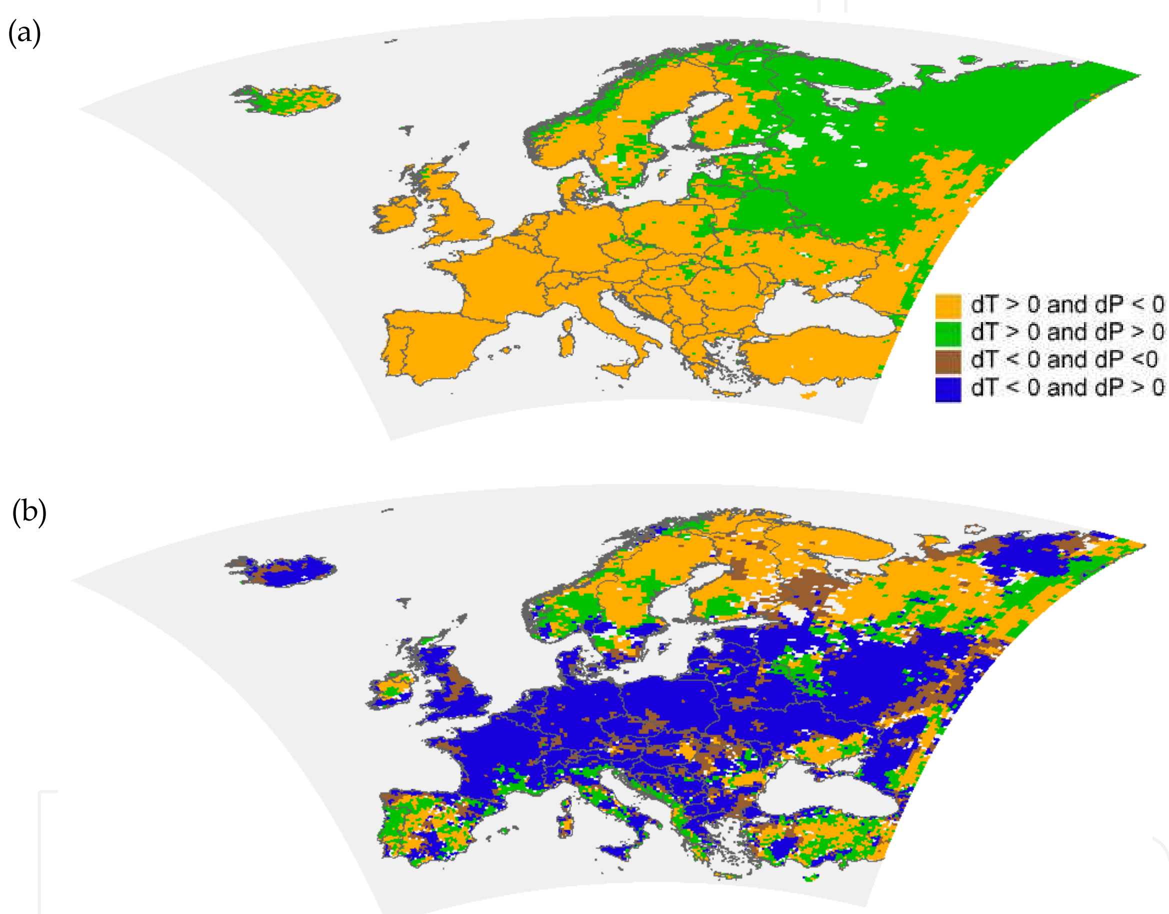


Fig. 4. Climate change signal for temperature (dT) and precipitation (dP) due to emission change (a) and due to potential afforestation (b)

Smaller patches in central and southeast Europe can be characterized also by colder but dryer conditions. Portugal, the Mediterranean coasts and the southern part of the boreal zone show a shift into the warmer and wetter direction (figure 4b). For the Mediterranean region a possible reason for it can be that in this dry area vegetation has deeper roots in the reference simulation than forests in the afforestation experiment. It means in the model that less water is available for cooling through evapotranspiration. Increase of forest cover resulted in higher temperatures and less precipitation in the northern part of Scandinavia and Russia as well as in smaller areas in Spain and around the Black Sea (figure 4b).

From the figure 4 it can be concluded that there are regions, where temperature and/or precipitation changes due to emission change and afforestation show the same sign so that they can enhance each other. In other areas they have the opposite sign, thus depending on their magnitude, afforestation can reduce or fully compensate the effects of the emission change.

3.2 Magnitude of the climatic effect of emission change and potential afforestation

First, those regions have been determined, which are the most affected by climate change for the end of the 21st century. Without any forest cover changes the strongest warming and drying are projected to the Mediterranean area, southern France and over the Iberian Peninsula (figure 5). These signals are in a good agreement with the simulation results of other regional climate models for the same region.

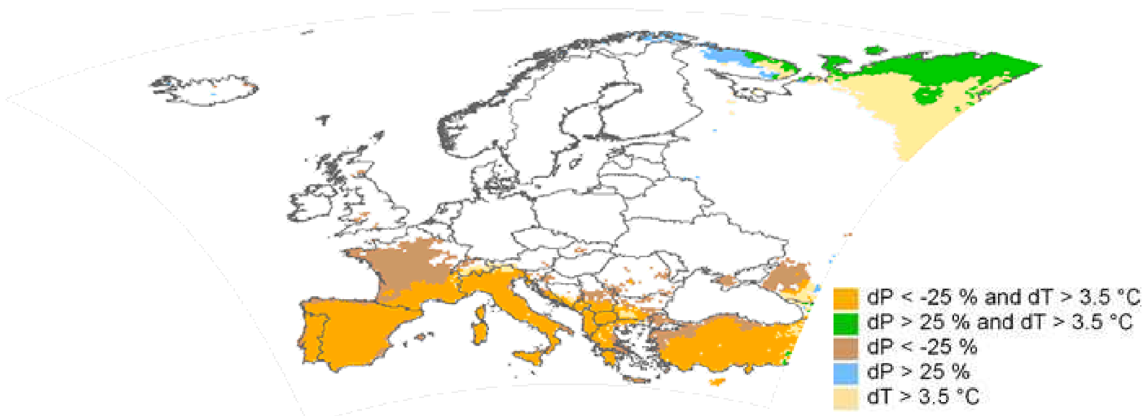


Fig. 5. The regions the most affected by climate change due to emission change (dT: temperature change, dP: precipitation change)

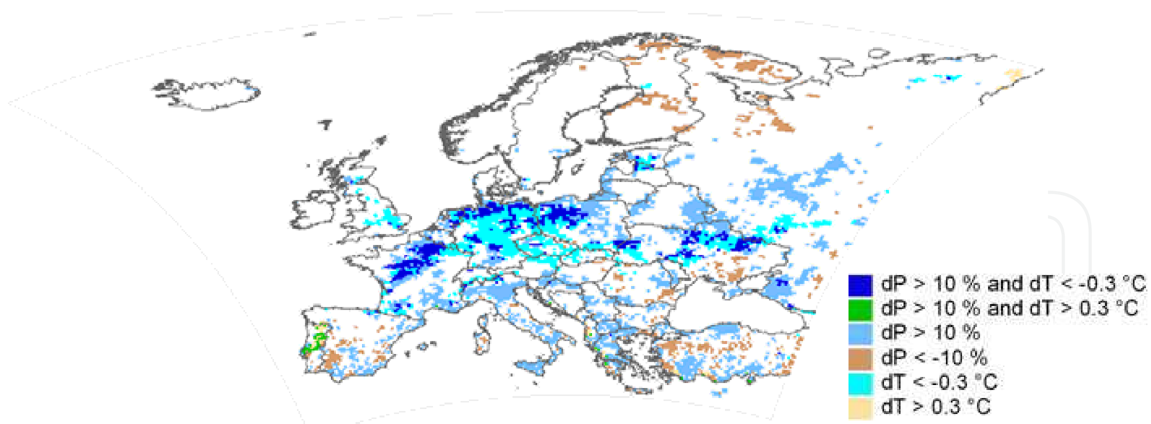


Fig. 6. The regions with the largest effects of forest cover increase on temperature and precipitation (dT: temperature change, dP: precipitation change)

Second, regions, where forest cover increase (without any emission change) has the largest effects on temperature and precipitation have been also identified. For the northern part of central and western Europe temperature decrease due to afforestation can exceed 0.3 °C additionally to more than 10 % increase of the summer precipitation sum (figure 6). The regions characterized by largest cooling and moistening effects of afforestation do not correspond to the areas with the strongest warming and drying due to emission change (figure 5). In many southern European areas afforestation can result in larger than 10 % increase/decrease of summer precipitation sums but these are not statistically significant.

3.3 Sign and magnitude of the climatic feedbacks of potential afforestation relative to the magnitude of the climate change signal

The magnitude of the climatic effects of afforestation has also been analyzed relative to the effect of the enhanced greenhouse gas emissions in order to determine the regions, where forests can play a major role in altering the climate change signal. In figure 7 the values represent the temperature as well as the precipitation signals for afforestation divided by the climate change signal. The reddish colours are referring to the areas, where the changes of the analyzed climatic variables have the same sign for both afforestation and emission change. Whereas in the regions marked with bluish colours they show opposite sign.

(a)

(b)

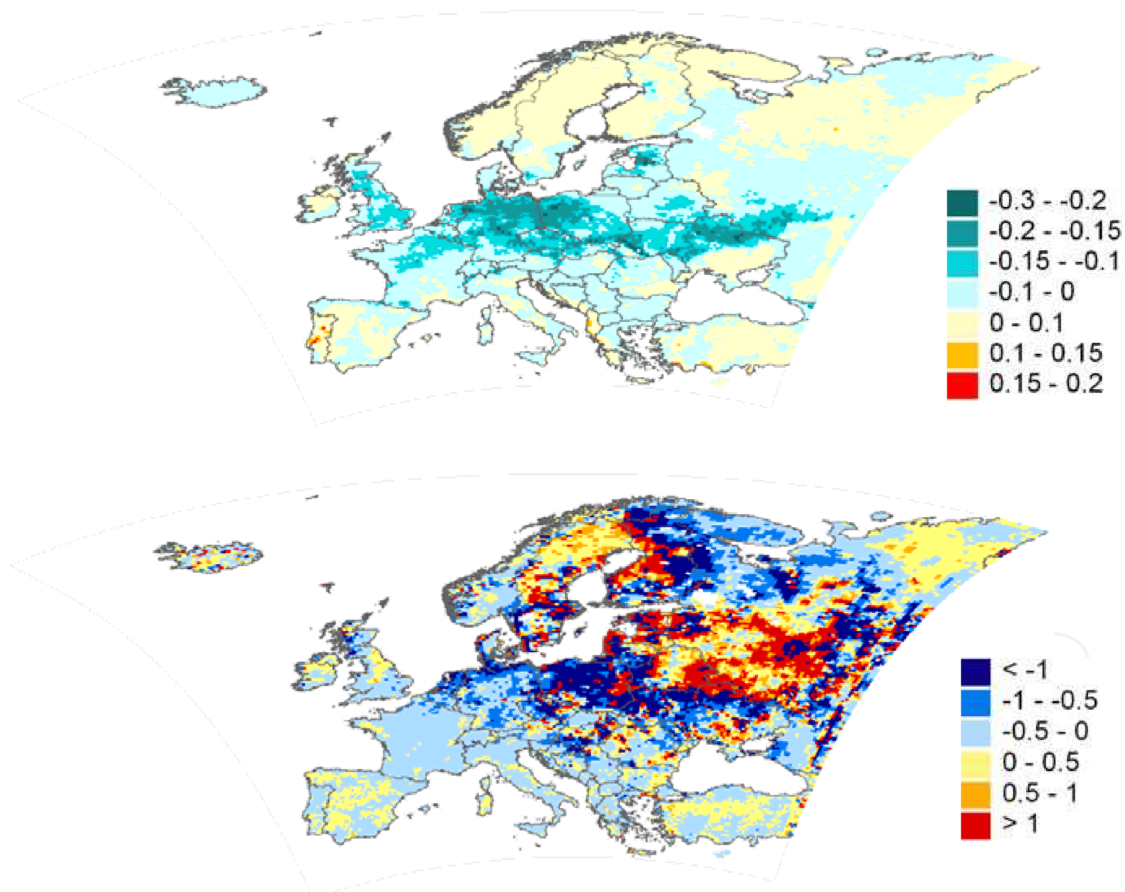


Fig. 7. Climate change signal due to potential afforestation divided by the climate change signal due to emission change for temperature (a) and precipitation (b)

The temperature change signal for potential afforestation is smaller than for emission change in the entire continent (figure 7a). Increase of the forest cover can enhance the climate change signal in the boreal and in the Mediterranean regions but its magnitude is relatively small compared to the effect of the emission change. In the temperate zone afforestation can reduce the projected warming. In northern part of central Europe and Ukraine the effect of afforestation can be 15-20 % of the climate change signal.

The increase of forest cover can amplify the projected precipitation change in Sweden, Spain, Belarus and Russia (figure 7b). Whereas in the northern part of central Europe, Ukraine and eastern Finland the precipitation change signal due to emission change can be reduced by afforestation in more than 50 %. Figure 4 shows a border area between the projected precipitation increase and decrease due to emission change. Here the projected precipitation change is relatively small and not significant. In this zone the magnitude of the precipitation change due to afforestation can exceed the magnitude of the climate change signal (figure 7b).

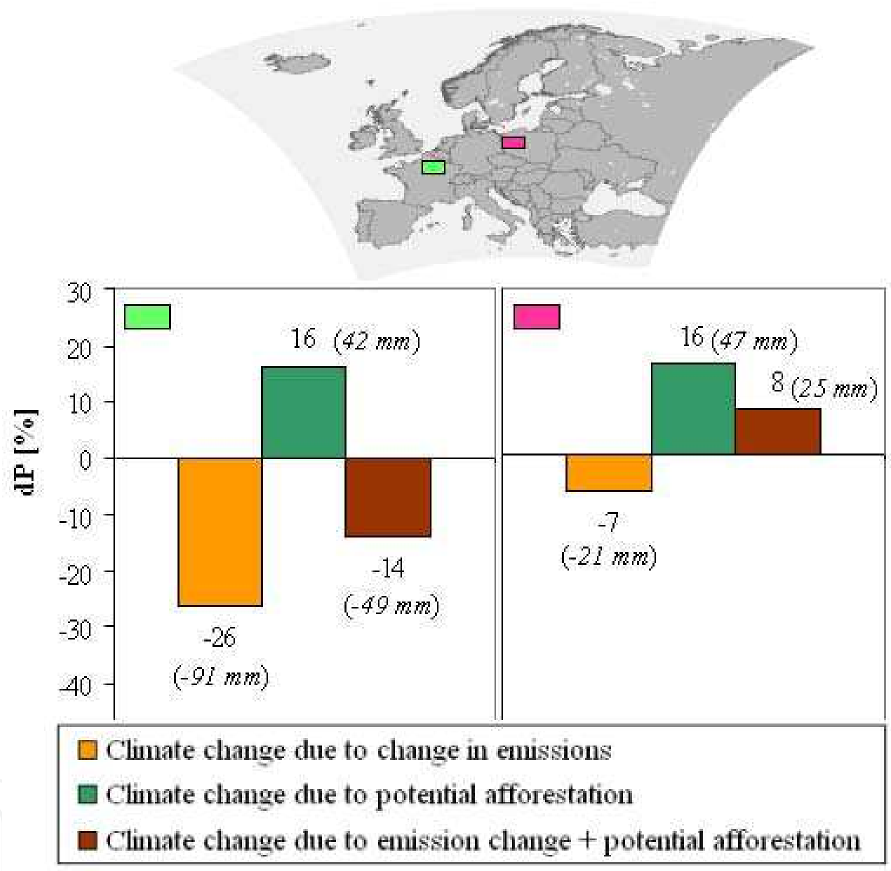


Fig. 8. Change of the summer precipitation sum (dP) due to emission change (2071-2090 vs. 1961-1990), due to potential afforestation (2071-2090) and due to emission change + potential afforestation for the two selected 30 box-regions in France (left) and in northern Poland (right)

Two smaller regions with similar amount of forest cover increase have been selected to represent the regional differences. In the northern part of Poland the changes of the physical properties of the land cover resulted in an increase of evapotranspiration. Due to the increase of latent heat of vaporization, the simulated climate change signal for temperature (2 °C) may decrease by 0.3 °C during the summer months (not shown). This effect of the afforestation is 17 % of climate change signal. Potential afforestation may result in significant increase of the summer precipitation sum by 16 % (47 mm) compared to the reference simulation (figure 8). Due to the enhanced greenhouse gas emissions, a relatively small (-7 %; -21 mm) decrease of precipitation is projected for the period 2071-2090 compared to 1971-1990. Thus the combined effect of afforestation and emission changes led to 8 % (25 mm) increase of precipitation compared to the past time period without any land cover changes (figure 8).

In France, the precipitation change signal for emission change is projected to be larger (-26% -91 mm). Here, the 16 % (42 mm) increase of precipitation due to afforestation can diminish but not fully compensate the significant decrease of precipitation due to emission change (figure 8). If emission changes occur together with potential afforestation, the summer precipitation sum might decrease by 14 % (-49 mm).

3.4 Country scale effects of maximal afforestation in Hungary

A more detailed case study has been carried out for Hungary to assess the regional differences of the climatic role of afforestation within the country. These analyses concentrated on the possible mitigation of the strong warming and drying tendency of summers projected for this region.

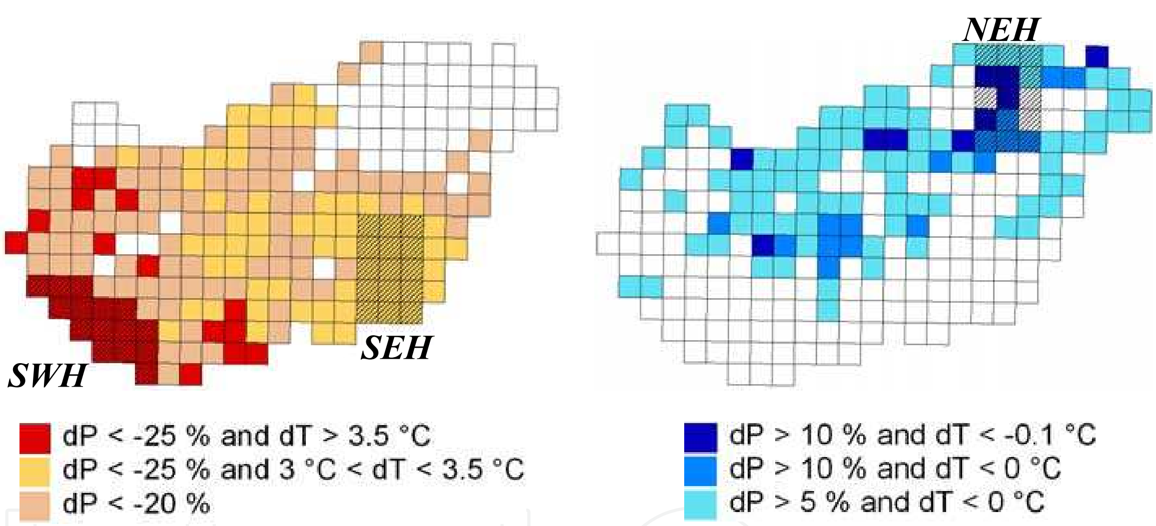


Fig. 9. The areas the most affected by climate change (left) and the spatial distribution of the precipitation-increasing (dP) and temperature-decreasing (dT) effect of maximal afforestation compared to the reference (right). The three investigated regions are hatched: the area the most affected by climate change (southwestern part of Hungary: SWH), the region with the largest amount of afforestation (southeastern part of Hungary: SEH) and the area, where the effect of maximal afforestation on precipitation is the largest (northeastern part of Hungary: NEH)

Based on the applied threshold values for temperature and relative precipitation the southwestern part of Hungary (SWH) can be the most affected by warming and drying. In this area the projected increase of summer temperature can exceed the 3.5 °C and the decrease of the summer precipitation sum the 25 % for the time period 2071-2100 compared to 1961-1990. The least affected are the northeastern areas.

Similarly the region has been determined, which can be characterized by the largest precipitation increase and temperature decrease due to maximal afforestation (figure 9).

Figure 9 shows that the climatic effects of the maximal afforestation are the largest in the northeastern part of Hungary (NEH), which does not correspond to the area with the largest amount of afforestation.

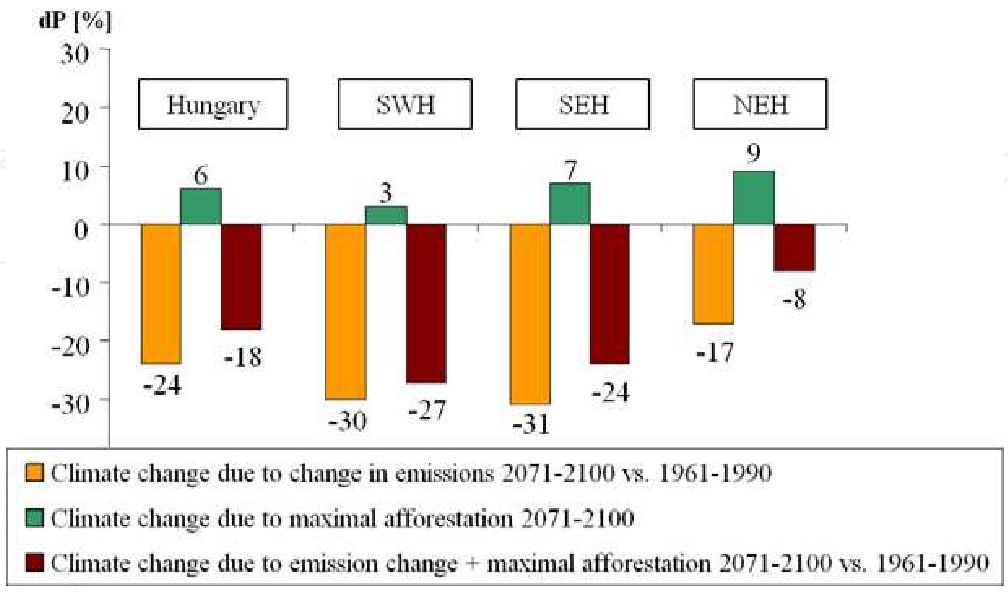


Fig. 10. Change of the summer precipitation sum (dP) due to emission change (2071-2100 vs. 1961-1990), due to maximal afforestation (2071-2100) and due to emission change + maximal afforestation in Hungary and in the three investigated regions (SWH: southwestern part of Hungary, SEH: southeastern part of Hungary, NEH: northeastern part of Hungary). Adapted from: Gálos et al., 2011

For the regions SWH and NEH as well as for the area with the largest increase of forest cover (SEH) the magnitude of the effects of forest cover increase on the summer precipitation sum has been compared to the magnitude of the projected climate change signal. For all three regions and for the whole area of Hungary the precipitation change due to emission changes and the precipitation change due to maximal afforestation have opposite effect (figure 10). This means that the projected climate change signal for precipitation can be reduced by the increase of the forest cover. The magnitude of the climate change altering effect of the maximal afforestation differs among regions. The area of SWH can be characterized by 30 % relative precipitation decrease due to emission change (2071-2100 vs. 1961-1990), which could be hardly compensated by the forest cover increase. In SEH, the significant decrease of summer precipitation can be weakened through the afforestation. In the mountainous region NEH, the projected drying in summer is the mildest (17 %). But also this is the area, where the largest precipitation-increasing (9 %) effect of maximal afforestation is observable. Here, for precipitation, more than half of the projected climate change signal can be relieved with enhanced forest cover (figure 10). These effects can play a major role in mitigating of the probability and severity of droughts in this region (Gálos et al., 2011).

4. Conclusions

A regional scale sensitivity study has been carried out to assess the climatic effects of forest cover increase for Europe, for the end of the 21st century. Applying the regional climate model REMO, the projected temperature and precipitation tendencies have been analyzed for summer, based on the results of the A2 IPCC-SRES emission scenario simulation. For the end of the 21st century it has been studied, whether the effects of the emission changes could be reduced or enhanced by the increased forest cover. The magnitude of the biogeophysical effects of afforestation on temperature and precipitation has been determined relative to the magnitude of the climate change signal due to emission change. The regions have been determined, in which forests play a major role in altering of the projected climate change.

Simulation results of this sensitivity study can be summarized as follows:

a. *Climate change signal due to emission change:*
   - *Sign of the effects:* For the A2 emission scenario, a positive temperature signal is expected in whole Europe, which is projected to occur together with precipitation decrease in southern and central Europe and in the southern part of Scandinavia.
   - *Magnitude of the effects:* The strongest warming and drying are projected for the Mediterranean area, southern France and over the Iberian Peninsula.

b. *Climate change signal due to potential afforestation:*
   - *Sign of the effects:* In most parts of the temperate zone the cooling and moistening effect of afforestation dominates. Portugal, the Mediterranean coasts and the southern part of the boreal zone show a shift into the warmer and wetter direction. Warmer and dryer conditions over larger areas may occur in the boreal region.
   - *Magnitude of the effects:* Afforestation has the largest climatic effects in the northern part of central and western Europe, where the temperature decrease due to afforestation may exceed 0.3 °C additionally to more than 10 % increase of the summer precipitation sum.

c. *Climate change signal due to potential afforestation relative to the emission change:*
   - *Sign of the effects:* In the largest part of the temperate zone precipitation and temperature anomalies due to forest cover increase show the opposite sign than due to emission change, which means that the climate change signal can be reduced by afforestation. Whereas in Sweden, in Spain and in some regions in the eastern part of the continent afforestation can amplify the climate change signal for both investigated variables.
   - *Magnitude of the effects:* The largest climate change mitigating effects of afforestation can be expected in northern Germany, Poland and Ukraine, which is 15-20 % of the climate change signal for temperature and more than 50 % for precipitation. These changes are significant at the 90 % confidence level.

d. *Based on the detailed case study for Hungary:*
   - *Sign of the effects:* The projected climate change signal for precipitation can be reduced assuming maximal afforestation.
   - *Magnitude of the effects:* The strong warming and drying tendency projected for southwest Hungary could be hardly compensated by forest cover increase. But in the northwestern region more than half of the projected climate change signal for precipitation can be relieved with enhanced forest cover.

For Hungary results represent the first regional scale assessment of the climatic role of forests for a long future time period and its role in adapting to climate change.

Based on the simulation results it can be concluded that only large, contiguous forest blocks have robust effect on the climate on regional scale. The climate change altering effects of forest cover change show large spatial differences. In the most climate change affected regions climatic effects of afforestation are relatively small. But in other regions they can play an important role in reducing the probability and severity of climatic extremes (Gálos et al., 2011). These sensitivity studies confirm, that at the end of the 21st century in the regions, which are the most affected by climate change, vegetation feedbacks have weaker influence on the atmospheric circulation in comparison to the greenhouse gas forcing (Betts, 2007; Wramneby et al., 2010) and afforestation is not a substitute for reduced greenhouse gas emissions (Arora & Montenegro, 2011).

For each of the introduced sensitivity studies, one regional climate model has been applied driven by one emission scenario. For the climate change signal, results are in general agreement with earlier studies from the EU-projects PRUDENCE and ENSEMBLES. For the land cover change experiments the simulated sign and magnitude of the climatic effects can largely depend on the description of the land surface properties and processes in the applied climate model as well as the variability of the climatic and soil conditions and vegetation characteristics of the studied region. Therefore more similar fine-scale pilot studies are essential to reduce the uncertainties and to draw appropriate conclusions for decision makers about the role of the forests in the climate change mitigation on country scale.

Practical application of the results

From practical point of view, the investigation of the role of the land surface in the climate system gets even more important with the expected land cover change due to climate change and land use politics that differ among regions. Research into forestry's effect on climate is still relatively new and requires a major expansion to support policy development (Anderson et al., 2010). Our results also pointed out that the changes of forest cover could enhance and reduce the projected regional climate change. Therefore regional scale information is substantial about the climatic feedbacks of the future land cover and land use for the adaptation to the climate change in agriculture, forestry and water management.

Results of these sensitivity experiments contribute to the assessment of the climate change altering effects of forest cover change. It helps to identify the areas, where forest cover increase is climatically the most beneficial and should be supported to reduce the projected climate change. Here, the existing forests should be maintained. Thus the present study provides an important basis for the future adaptation strategies.

Outlook

Further research is essential to get information about the internal model variability and for studying the robustness of the results applying an ensemble of regional climate model simulations. In these sensitivity studies the spatial and temporal changes of vegetation cover due to climate change was not considered. Although the projected precipitation and temperature changes may have severe impacts on the spatial distribution of forests. Especially in the case-study region Hungary the drastic reduction of the macroclimatically suitable area for forests is expected at the forest/steppe limit (Berki et al., 2009; Mátyás et al., 2010; Czúcz et al., 2011). Therefore for the long-term investigation of forest-climate interactions in the future, regional climate modelling is essential with dynamic vegetation scheme and more detailed and improved description of the forest related processes and parameters combining the biogeophysical and biogeochemical effects.

5. Acknowledgements

The authors give special thanks to the Regional Modelling Group of the Max Planck Institute for Meteorology, Hamburg for the fruitful scientific discussions about the simulation results. We thank to Prof. Dr. Csaba Mátyás for his expertise and suggestions regarding to the practical importance of this topic. The authors would like to thank to Georg Kindermann (IIASA, International Institute for Applied Systems Analysis Austria) for providing the forest cover database as well as to Kevin Sieck and Claas Teichmann for the technical guidance during the simulations. The REMO simulations without land cover changes have been carried out in the frame of the EU-project ENSEMBLES. This research was supported by the EC-FP7 project CC-TAME (www.cctame.eu; grant agreement n° 212535) and the TÁMOP 4.2.2-08 joint EU-national research project.

6. References

Anav A., Ruti P.M., Artale V. & Valentini R. (2010). Modelling the effects of land-cover changes on surface climate in the Mediterranean region. *Clim. Res.*, 41, 91-104

Anderson R.G., Canadel J.G., Randerson J.T., Jackson R.B., Hungate B.A., Baldocchi D.D., Ban-Weiss G.A., Bonan G.B., Caldeira K., Cao L., Diffenbaugh N.S., Gurney K.R., Kueppers L.M., Law B.E., Luyssaert S., & O'Halloran T.L. (2010). Biophysical considerations in forestry for climate protection. *Front Ecol Environ*; doi:10.1890/090179

Arora V.K. & Montenegro A. 2011. Small temperature benefits provided by realistic afforestation efforts. *Nature Geoscience* ,doi: 10.1038/NGEO1182, 5pp

Bala G., Caldeira K., Wickett M., Phillips T.J., Lobell D.B. , Delire C. & Mirin A. (2007). Combined climate and carbon-cycle effects of large-scale deforestation. *Proc Natl Acad Sci USA* 104, 6550–6555

Bartholy J., Pongrácz R. & Gelybó Gy. (2007). Regional climate change expected in Hungary for 2071-2100. *Applied Ecology and Environmental Research*, 5, 1-17

Berki I., Rasztovits E., Móricz N. & Mátyás Cs. (2009). Determination of the drought tolerance limit of beech forests and forecasting their future distribution in Hungary. *Cereal Research Communations,* 37, 613-616

Beniston M., Stephenson D.B., Christensen O.B., Ferro C.A.T., Frei C., Goyette S., Halsnaes K., Holt T., Jylhä K., Koffi B., Palutikof J., Schöll R., Semmler T. & Woth K. (2007). Future extreme events in European climate: an exploration of regional climate model projections. *Clim. Change,* 81, 71–95, doi:10.1007/s10584-006-9226-z

Beniston M. (2009). Trends in joint quantiles of temperature and precipitation in Europe since 1901 and projected for 2100. *Geophys. Res. Lett.*, 36, L07707, doi:10.1029/2008GL037119

Betts R.A. (2001). Biogeophysical impacts of land use on present-day climate: near-surface temperature change and radiative forcing. *Atmospheric Science Letters* 1, 23pp, doi: 10.1006/asle.2001.0023

Betts R. (2007). Implications of land ecosystem-atmosphere interactions for strategies for climate change adaptation and mitigation. *Tellus,* 59B, 602-615, doi: 10.1111/j.1600-0889.2007.00284.x

Bonan G.B., Pollard D. & Thompson S.L. (1992). Effects of boreal forests on global climate. *Nature,* 359, 716-718, doi: 10.1038/359716a0

Bonan G.B. (1997). Effects of land use on the climate of the United States. *Climatic Change,* 37, 449–486

Bonan G.B., Levis S., Kergoat L. & Oleson K.W. (2002). Landscapes as patches of plant functional types: an integrating concept for climate and ecosystem models. *Global Biogeochemical Cycles,* 16, 30pp,10.1029/2000GB001360

Bonan G.B. (2004). Biogeophysical feedbacks between land cover and climate. In: *Ecosystems and Land Use Change.*, DeFries R.S., Asner G.P., & Houghton R.A. (eds), 153, 61-72, Geophysical Monograph American Geophysical Union, Washington, D.C.

Bonan G.B. 2008. Forests and climate change: forcings, feedbacks, and the climate benefits of forests. *Science,* 320, 1444–1449, doi: 10.1126/science.1155121

Bounoua L., Defries R., Collatz G.J., Sellers P., & Khan H. (2002). Effects of land cover conversion on surface climate. *Climatic Change,* 52, 29-64

Brovkin V. (2002). Climate-vegetation interaction. *J. Phys.* IV France 12, 57-82, doi: 10.1051/jp4:20020452

Christensen J.H., Carter T.R., Rummukainen M., & Amanatidis G. (2007). Evaluating the performance and utility of regional climate models: the PRUDENCE project. *Clim. Change*, 81, 1-6, DOI 10.1007/s10584-006-9211-6

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. *Clim. Change,* 81, 7-30, doi: 10.1007/s10584-006-9210-7

Copeland J.H., Pielke R.A. & Kittel T.G.F. (1996). Potential climatic impacts of vegetation change: A regional modelig study. *Journal of Geophysical Research,* 101, 7409-7418 doi: 10.1029/95JD02676

Czúcz B., Gálhidy L. & Mátyás Cs. (2011). Present and forecasted xeric climatic limits of beech and sessile oak distribution at low altitudes in Central Europe. *Ann. For. Sci.,* 68(1), 99-108

Drüszler Á., Vig P. & Csirmaz K. (2011). Effects of Historical Land Cover Changes on the Precipitation Distribution in Hungary. *Riscuri Si Catastrofe (Risks and Disasters)*, ISSN: 15845273; I/2011 (in print)

Feddema J.J., Oleson K.W., Bonan G.B., Mearns L.O., Buja L.E., Meehl G.A. & Washington W.M. (2005). The Importance of Land-Cover Change in Simulating Future Climates. *Science,* 310, 1674 –1678, doi: 10.1126/science.1118160

Fischer E.M. & Schär C. (2010). Consistent geographical patterns of changes in high-impact European heatwaves. *Nature Geoscience,* 3, 398-403, doi: 10.1038/NGEO866

Gálos B., Lorenz Ph., & Jacob D. (2007). Will dry events occur more often in Hungary in the *future? Environ. Res. Lett.,* 2, 034006 (9pp), doi: 10.1088/1748-9326/2/3/034006

Gálos B., Mátyás Cs. & Jacob D. (2011). Regional characteristics of climate change altering effects of afforestation. *Environ. Res. Lett.* 6, 044010 (9pp), doi:10.1088/1748-9326/6/4/044010

Giorgi F., Bi X. & Pal J.S. (2004). Mean, interannual variability and trends in a regional climate change experiment over Europe. II: climate change scenarios (2071–2100). *Climate Dynamics,* 23, 839–858, doi: 10.1007/s00382-004-0467-0

Göttel H., Alexander J., Keup-Thiel E., Rechid D., Hagemann S., Blome T., Wolf A. & Jacob D. (2008). Influence of changed vegetation fields on regional climate simulations in the Barents Sea Region Climatic Change. *BALANCE Special Issues,* 87, 35-50

Hagemann S., Botzet M., Dümenil L. & Machenhauer M. (1999). Derivation of global GCM boundary conditions from 1 km land use satellite data. *Report 289* Max-Planck-Institute for Meteorology, Hamburg

Hagemann S. (2002). An improved land surface parameter dataset for global and regional climate models. *Report 336*, Max-Planck-Institute for Meteorology, Hamburg

Hagemann S., Göttel H., Jacob D., Lorenz P. & Roeckner E. (2009). Improved regional scale processes reflected in projected hydrological changes over large European catchments. *Climate Dynamics,* 32, 767–781

Heck P., Lüthi D., Wernli H. & Schär Ch. (2001). Climate impacts of European-scale anthropogenic vegetation changes: A sensitivity study using a regional climate model. *Journal of Geophysical Research,* 106, 7817-7835, doi: 10.1029/2000JD900673

Hogg E.H., Price D.T., & Black T.A. (2000). Postulated feedbacks of deciduous forest phenology on seasonal climate patterns in the Western Canadian interior. *Journal of Climate* ,13, 4229-4243

Houghton J. et al. (ed) (2001). *Climate change 2001 The Scientific Basis.* Intergovernmental Panel on Climate Change (Cambridge: Cambridge University Press)

IPCC (2007). Climate change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change http//:www.ipcc.ch

Jackson R.B., Randerson J.T., Canadell J.G., Anderson R.G., Avissar R., Baldocchi D.D., Bonan G.B., Caldeira K., Diffenbaugh N.S., Field C.B., Hungate B.A., Jobbágy E.G., Kueppers L.M., Nosetto M.D., & Pataki D.E. (2008). Protecting climate with forests *Environ. Res. Lett.,* 3, 044006 (5pp), doi: 10.1088/1748-9326/3/4/044006

Jacob D., Andrae U., Elgered G., Fortelius C., Graham L.P., Jackson S.D., Karstens U., Koepken Chr., Lindau R., Podzun R., Rockel B., Rubel F., Sass H.B., Smith R.N.D., van den Hurk B.J.J.M. & Yang X. (2001). A Comprehensive Model Intercomparison Study Investigating the Water Budget during the BALTEX-PIDCAP Period. *Meteorology and Atmospheric Physics,* 77(1-4), 19-43

Jacob D. (2001). A note to the simulation of the annual and inter-annual variability of the water budget over the Baltic Sea drainage basin. *Meteorology and Atmospheric Physics,* 77, 61-73

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 C., Seneviratne S.I., Sommot 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, 31-52, doi: 10.1007/s10584-006-9213-4

Jacob D., Kotova L., Lorenz P., Moseley Ch. & Pfeifer S. (2008). Regional climate modeling activities in relation to the CLAVIER project. *Quarterly Journal of the Hungarian meteorological Service (Időjárás),* 112, 141-153

Jungclaus J.H., Keenlyside N., Botzet M., Haak H., Luo J-J., Latif M., Marotzke J., Mikolajewicz U. & Roeckner E. (2006). Ocean circulation and tropical variability in the coupled model ECHAM5/MPI-OM. *J. Climate,* 19, 3952–3972

Kjellström E., Bärring L., Jacob D., Jones R., Lenderink G. & Schär C. (2007). Modelling daily temperature extremes: Recent climate and future changes over Europe. *Climatic Change*, 81, 249-265, doi: 10.1007/s105800692205

Kjellström E., Nikulin G., Hansson U., Strandberg G. & Ullerstig A. (2011). 21st century changes in the European climate: uncertainties derived from an ensemble of regional climate model simulations. *Tellus,* 63A(1), 24-40, doi:10.1111/j.1600-0870.2010.00475

van der Linden P. & Mitchell J.F.B. (eds.) (2009). *ENSEMBLES: Climate Change and its Impacts: Summary of research and results from the ENSEMBLES project*. 160pp, Met Office Hadley Centre, FitzRoy Road, Exeter EX1 3PB, UK

Majewski D. (1991). The Europa-Modell of the Deutscher Wetterdienst ECMWF. *Seminar on numerical methods in atmospheric models,* 2, 147-191

Mátyás Cs. (2009). Ecological perspectives of climate change in Europe's continental, drought-threatened Southeast In: *Regional aspects of climate-terrestrial-hydrologic interactions in non-boreal Eastern Europe,* Groisman P.Y., Ivanov S.V. eds, pp 31-42, NATO Science Series, Springer Verl.

Mátyás Cs. (2010). Forecasts needed for retreating forests (Opinion). *Nature*, 464, 1271 doi: 10.1038/4641271a

Mátyás Cs., Berki I., Czúcz B., Gálos B., Móricz N. & Rasztovits E. (2010). Future of beech in Southeast Europe from the perspective of evolutionary ecology. *Acta Silv. & Lign. Hung.*, 6, 91-110

Nakicenovic N. et al. (2000). IPCC Special Report on Emission Scenarios. Cambridge: Cambridge University Press, p 599

Oleson K.W., Bonan G.B., Levis S. & Vertenstein M. (2004). Effects of land use change on North American climate: impact of surface datasets and model Biogeophysics. *Climate Dynamics,* 23, 117–132, doi: 10.1007/s00382-004-0426-9

Pielke R.A., Avissar Sr R., Raupach M., Dolman A.J., Zeng X. & Denning A.S. (1998). Interactions between the atmosphere and terrestrial ecosystems: influence on weather and climate. *Global Change Biology,* 4, 461–475

Pitman A.J. (2003). The evolution off, and revolution in, land surface schemes designed for climate model. *Int. J. of Climatol.* 23, 479-510, doi: 10.1002/joc.893

Radvánszky B. & Jacob D. (2009). The Changing Annual Distribution of Rainfall in the Drainage Area of the River Tisza during the Second Half of the 21st Century. *Zeitschrift für Geomorphologie*, 53, 171195(25)

Rechid D. & Jacob D. (2006). Influence of monthly varying vegetation on the simulated climate in Europe. *Meteorol Z.,* 15, 99-116

Rechid D., Raddatz T.J. & Jacob D. (2008a). Parameterization of snow-free land surface albedo as a function of vegetation phenology based on MODIS data and applied in climate modelling. *Theor. Appl. Climatol.*, 95, 245-255 doi: 10.1007/s00704-008-0003-y

Rechid D., Hagemann S. & Jacob D. (2008b). Sensitivity of climate models to seasonal variability of snow-free land surface albedo *Theor. Appl. Climatol.,* 95, 197-221 doi: 10.1007/s00704-007-0371-8

Roeckner E., Arpe K., Bengtsson L., Christoph M., Claussen M., Dümenil L., Esch M., Giorgetta M., Schlese U. & Schulzweida U. (1996). The atmospheric general circulation model ECHAM-4: Model description and simulation of the present day climate. *Report 218 Max-Planck-Institut für Meteorologie, Hamburg*

Roeckner E., Brokopf R., Esch M., Giorgetta M., Hagemann S., Kornblueh L., Manzini E., Schlese U. & Schulzweida U. (2006). Sensitivity of simulated climate to horizontal and vertical resolution in the ECHAM5 atmosphere model. *J. Clim.* 19, 3771–3791

Sánchez E., Gaertner M.A., Gallardo C., Padorno E., Arribas A. & Castro M. (2007). Impacts of a change in vegetation description on simulated European summer present-day and future climates. *Clim. Dyn.* 29, 319–332, doi: 10.1007/s00382-007-0240-2

Schär C., Vidale P.L., Lüthi D., Frei C., Häberli C., Liniger, M.A. & Appenzeller C. (2004). The role of increasing temperature variability in European summer heatwaves. *Nature* 427, 332–336, doi: 10.1038/nature02300

Seneviratne S.I., Lüthi D., Litschi M. & Schär C. (2006). Land-atmosphere coupling and climate change in Europe. *Nature,* 443, 205–209, doi: 10.1038/nature05095

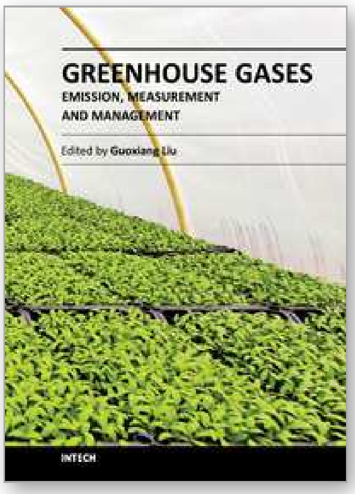
Seneviratne S.I. et al. (2010). Investigating soil moisture-climate interactions in a changing climate: A review. *Earth. Sci. Rev.,* 99, 125-161

Szépszó G. (2008). Regional change of climate extremes in Hungary based on different regional climate models of the PRUDENCE project. *Időjárás,* 112, 265-283

Teuling A.J., Seneviratne S.I., Stoeckli R., Reichstein M., Moors E., Ciais P., Luyssaert S., van den Hurk B., Ammann C., Bernhofer C., Dellwik E., Gianelle D., Gielen B., Gruenwald T., Klumpp K., Montagnani L., Moureaux C., Sottocornola M., & Wohlfahrt G. (2010). Contrasting response of European forest and grassland energy exchange to heatwaves. *Nature Geoscience* 3(10), 722-727

Vidale P.L., Lüthi D., Wegmann R., & Schär C. (2007). European summer climate variability in a heterogeneous multi-model ensemble. *Climatic Change*, 81, 209–232. doi: 10.1007/s10584-006-9218-z

Wramneby A., Smith B. & Samuelsson P. (2010). Hot spots of vegetation-climate feedbacks under future greenhouse forcing in Europe. *J. Geophys. Res.*, 115, D21119, doi:10.1029/2010JD014307



Greenhouse Gases - Emission, Measurement and Management
Edited by Dr Guoxiang Liu

ISBN 978-953-51-0323-3
Hard cover, 504 pages
Publisher InTech
Published online 14, March, 2012
Published in print edition March, 2012

Understanding greenhouse gas sources, emissions, measurements, and management is essential for capture, utilization, reduction, and storage of greenhouse gas, which plays a crucial role in issues such as global warming and climate change. Taking advantage of the authors' experience in greenhouse gases, this book discusses an overview of recently developed techniques, methods, and strategies: - A comprehensive source investigation of greenhouse gases that are emitted from hydrocarbon reservoirs, vehicle transportation, agricultural landscapes, farms, non-cattle confined buildings, and so on. - Recently developed detection and measurement techniques and methods such as photoacoustic spectroscopy, landfill-based carbon dioxide and methane measurement, and miniaturized mass spectrometer.