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PREDICTION OF FOREST VEGETATION SHIFT DUE TO DIFFERENT CLIMATE-CHANGE SCENARIOS IN SLOVENIA

PROGNOZA PROMJENA ŠUMSKE VEGETACIJE ZBOG RAZLIČITIH SCENARIJA KLIMATSKIH PROMJENA U SLOVENIJI

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ABSTRACT: By using an empirical GIS model, the potential spatial changes of forest vegetation driven by expected climate change have been analysed. Based on the three different scenarios predicting climate warming in Slovenia (the mean, pessimistic and optimistic scenarios), the simulation showed that the share of vegetation types will be altered under the impacts of climate change, and the shift of vegetation belts upwards might be expected.

By the year 2100, the share of mesic beech forests is likely to decrease. From ecological, – nature-conservation – and forest-management points of view, the predicted decrease of the share of Dinaric fir-beech forests is especially important. The model predicts an increase of the share of thermophilous forests from the present 14% to a range between 50% (according to the optimistic scenario) and 87% (according to the pessimistic scenario). A significant part of the coniferous forest with Picea abies *and* Abies alba *predominating might be converted to deciduous forests.*

Key words: climate change, forest vegetation, model, simulation, climate scenarios

INTRODUCTION – Uvod

The results of climate research suggest that the risks caused by weather extremes may increase considerably in future (IPCC 2001, 2007). Warmer, drier conditions will lead to more frequent and prolonged droughts, as well as to a longer fire season and increased fire risk, particularly in the Mediterranean region (IPCC 2007).

Beniston et al. (2007) estimated that countries in central Europe would experience the same number of hot days as currently occur in southern Europe, and that in the Mediterranean droughts would start earlier in the year and last longer. The regions most affected could be the southern Iberian Peninsula, the Alps, the eastern Adriatic coast, and southern Greece. The regions most prone to an increase in drought risk are the Mediterranean and some parts of central and eastern Europe (IPCC 2007). The Mediterranean and even much of eastern Europe may experience an increase in dry periods by the late 21st century (Polemio and Casarano, 2004), and the longest yearly dry period could increase by as much as 50%, especially over France and central Europe (Good et al. 2006).

Forest ecosystems in Europe are very likely to be strongly influenced by climate change and other global changes (Shaver et al. 2000, Blennow and Sallnäs 2002, Askeev et al. 2005, Kellomäki and Leinonen 2005, Maracchi et al. 2005, IPCC 2007). Forest area is expected to expand in the north (White et al. 2000, Kljuev 2001, MNRRF 2003, Shiyatov et al. 2005), but contract in the south (Metzger et al. 2004, IPCC 2007). Native conifers are likely to be replaced by deciduous trees in western and central Europe (Maracchi et al. 2005, Koca et al. 2006). The distribution of a number of main tree species might decrease in the Mediterranean (Schröter et al. 2005).

At higher elevations in the Alps, net primary productivity (NPP) is likely to increase throughout the

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century. However, by the end of the century (2071 to 2100) in continental central and southern Europe, NPP of conifers is likely to decrease due to water limitations (Lasch et al. 2002, Lexer et al. 2002, Martínez-Vilalta and Pińol 2002, Freeman et al. 2005, Körner et al. 2005) and higher temperatures (Pretzch and Dursky 2002). Negative impacts of drought on deciduous forests are also possible (Broadmeadow et al. 2005).

Abiotic hazards for forests are likely to increase, although expected impacts are regionally specific and will be substantially dependent on the forest management system used (Kellomäki and Leinonen 2005). Fire danger, length of the fire season, and fire frequency and severity are expected to increase in the Mediterranean (Santos et al. 2002, Pausas 2004, Pereira et al. 2005, Moriondo et al. 2006), and lead to the increased dominance of shrubs over trees (Mouillot et al. 2002). Although to a lesser degree, the danger of fire is also likely to increase in central, eastern and northern Europe (Goldammer et al. 2005, Kellomäki et al. 2005, Moriondo et al. 2006).

Slovenia, situated on the transition between the Mediterranean and central Europe, between the mountain region of the Alps and the Dinaric range, is the under influence of the Mediterranean and of the continental climate of the mountainous ranges and of the Pannonia basin (Wraber 1969). The evidence on climate change can also be found in datasets of air temperature and precipitation amounts (Bergant 2007).

The aim of this study is to simulate the future forest vegetation in Slovenia driven by expected climate change. Taking into consideration different climate-change scenarios for this region, changes of forest vegetation will be predicted.

MATERIAL AND METHODS – Materijali i metode

Forest vegetation in Slovenia – *Šumska vegetacija u Sloveniji*

Diverse vegetation patterns have been recognised in Slovenian forests: in periodically flooded lowlands, in narrow strips along the rivers and brooks, forests of willows (*Salix* sp.), alders (*Alnus glutinosa* (L.) Gaertn., *Alnus incana* (L.) Moench), ashes (*Fraxinus excelsior* L., *Fraxinus oxycarpa* Willd.), and common oak (*Quercus robur* L.) grow. In the hilly areas above the floodplains, where for the most part the forests have now been converted to farmland, is the region of mixed forests of sessile oak (*Quercus petraea* (Matt.) Liebl.) and hornbeam (*Carpinus betulus* L.). In the mountainous areas, these change gradually into forests with predominantly beech (*Fagus sylvatica* L.) trees. The beech forests with mixtures of different broadleaves and conifers cover the major part of the forested area of the country, and the Dinaric forest of common beech and silver fir (*Abies alba* Miller) is one of the most extensive forest communities in the country. In the Alpine region, together with Norway spruce (*Picea abies* (L.) Karst.), and European larch (*Larix decidua* Mill.), more or less pure beech forests reach up to the belt of the dwarf mountain pine (*Pinus mugo* Turra) in the Dinaric range.

On extremely warm, steeper sites all over the country, mainly on limestone and dolomite terrain, forests and woodland of different thermophile tree species (e.g. *Ostrya carpinifolia* Scop., *Fraxinus ornus* L. *Quercus pubescens* Willd.) extend.

In its natural range, spruce grows more abundantly only in the Alpine area, on the high plateaus of the Julian Alps, and in the Kamnik-Savinja Alps and Karavanke Mountains. To a small extent, natural spruce forests grow in cold valleys and sinkholes in the Dinaric region. However, they also grow on Pohorje Mountain, where they are, for the most part, not native, and throughout the country in which they have been disseminated, mainly by man, for their useful wood. In these areas, the spruce is much more sensitive to the rigours of the weather and to the more widespread bark beetles.

Beside woodlands of dwarf mountain pine in the high-alpine zone, the pine forests are composed of Scots pine (*Pinus sylvestris* L.) and of Austrian pine (*Pinus nigra* Arnold). The Scots pine can be found throughout the interior of the country on the poorest soils, and Austrian pine forests grow on some of the steeper slopes of the continental part and extend over the larger part of south-western Slovenia, in the Karst region. Centuries ago, the deciduous forests of this region were degraded by logging, burning and pasturing. Intensive reforestation and afforestation of the Karst region with Austrian pine started in the middle of the 19th century.

This study is focused on the potential forest vegetation, based on the forest-plant community system by Košir et al. (1974, 2003), described on 74,123 forest compartments – the lowest level of the hierarchical forest-management system – which are sized from 10 to 30 hectares. Based on the similarity of site characteristics with a special emphasis on climatic factors and according to criteria of hierarchical classifications of habitat types (Devillers and Devillers-Teschuren 1996, Jogan et al. 2004), the potential-forest-community types have been agregated together in 13 group or so-called vegetation types (Table 1, Figure 1).

Table 1. Forest vegetation types (groups of similar forest communities) and forecast forest areas for the year 2100 based on different scenarios

Tablica 1. Tipovi šumske vegetacije (grupe sličnih šumskih zajednica) i prognozirane površine šuma u 2100 godini na temelju različitih scenarija

Veg. type	Description of vegetation type	Actual forests in year 2000		Forecasted forest areas (in %) in year 2100		
		Area (ha)	Share (%)	Mean scenario	Optimistic scenario	Pessimistic scenario
1	Acidophilic *Fagus sylvatica* forests	168.591	14.2	0.7	5.0	0.0
2	Acidophilic *Pinus sylvestris* forests	56.045	4.7	0.0	2.5	0.0
3	Submontane *Fagus sylvatica* forests	154.624	13.0	0.1	4.0	0.0
4	Montane *Fagus sylvatica* forests	113.116	9.5	4.3	6.4	1.4
5	(Alti-)montane *Fagus sylvatica* forest in (Pre-)Alpine region	103.438	8.7	0.2	3.2	0.0
6	(Alti-)montane *Fagus sylvatica* forest in (Pre-)Dinaric region	133.599	11.2	0.4	7.4	0.0
7	Thermophile *Fagus sylvatica* forests	78.109	6.6	4.8	11.7	1.3
8	Collinar forests of *Quercus petraea* and *Carpinus betulus*	101.964	8.6	18.6	17.8	11.8
9	Lowland forests of *Salix* species, *Alnus glutinosa* and *Quercus robur*	34.521	2.9	0.0	0.1	0.0
10	Thermophile forests of *Ostrya carpinifolia*, *Quercus* species, *Pinus sylvestris* and *P. nigra*	91.244	7.7	70.8	38.7	85.5
11	*Abies alba* forests	77.707	6.5	0.0	1.4	0.0
12	*Picea abies* forests	43.453	3.7	0.0	1.7	0.0
13	*Pinus mugo* woodlands	34.117	2.9	0.0	0.1	0.0
SUM		1.190.528	100.0	100.0	100.0	100.0

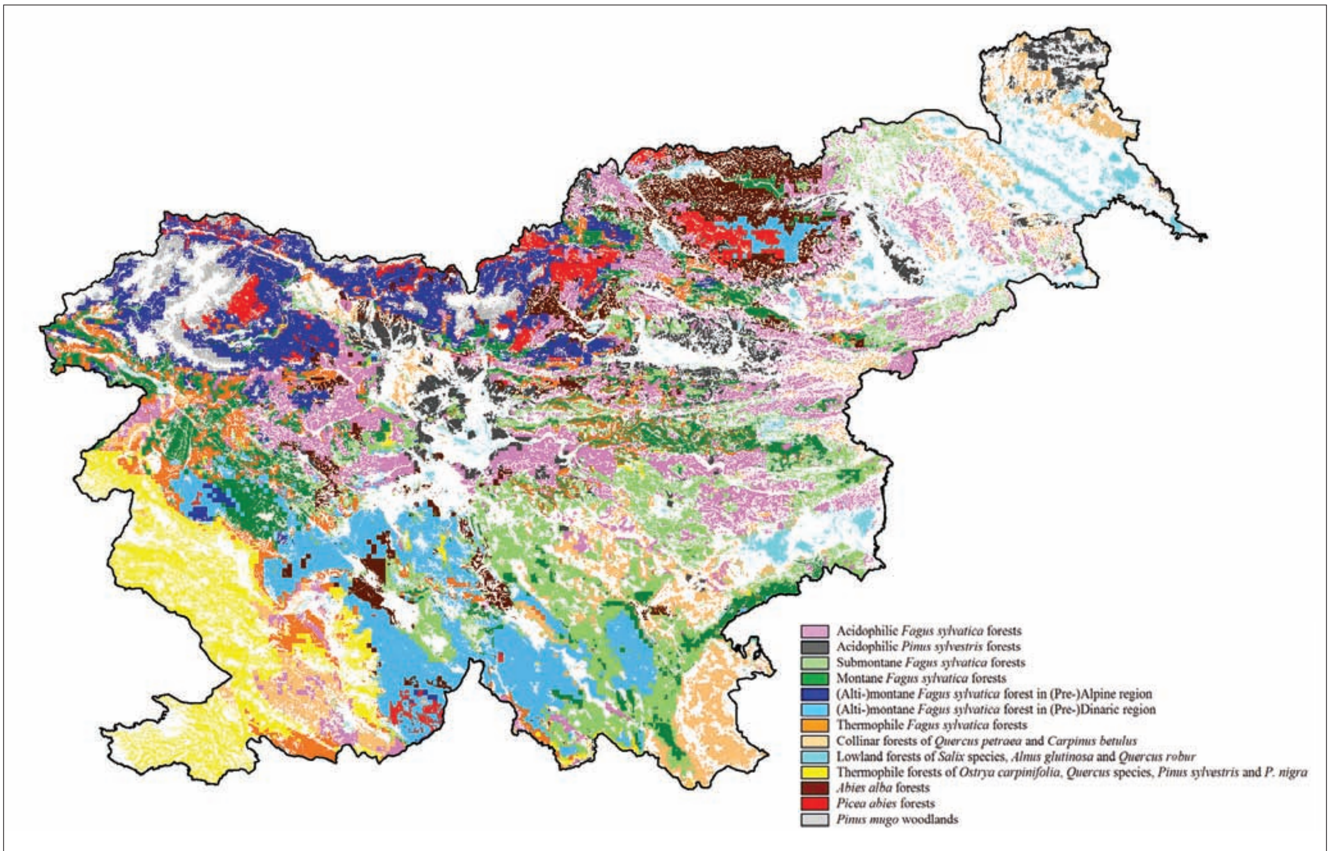


Figure 1 Model of the present forest vegetation state in Slovenia.

Slika 1. Model stanja sadašnje šumske vegetacije u Sloveniji.

Climate change scenarios – *Scenariji klimatskih promjena*

For simulation of future vegetation states, the existing climate-change predictions for Slovenia have been used (Bergant 2007, Kutnar et al. 2009). To estimate the future temperature and precipitation conditions in different regions of Slovenia by the end of the 21st century, empirical downscaling was used to project the results of General Circulation Model (GCMs) simulations with four different models (CSIRO/Mk2, UKMO/HadCM3, DOE-NCAR/PCM in MPI-DMI/ECHAM4-OPYC3) to five selected locations in Slovenia (Ljubljana, Novo Mesto, Murska Sobota, Rateče-Planica in Bilje) (Bergant 2007). A combination of empirical orthogonal function analysis together with a partial least squares regression was used to develop empirical models based on local observations and NCEP/NCAR reanalysis in the large scale. As GCM simulations are commonly based on a limited number of emission scenarios, in this case SRES A2 and B2, local projections were additionally scaled to other marker SRES scenarios (A1Fl, A1T, A1B). The results of projections indicate the strongest warming in summer (3.5 °C to 8 °C) followed by winter (3.5 °C to 7 °C), spring (2.5 °C to 6 °C), and autumn (2.5 °C to 4 °C) (Bergant 2007). No significant change in precipitation amounts is expected in spring and autumn, while in summer a decrease in precipitation (-20%) and in winter an increase (+30%) is expected.

For the simulation of changes of potential forest vegetation, the existing climate-change predictions for Slovenia (Bergant 2007) have been used to create three different scenarios.

Spatial model – *Prostorni model*

Within the present forest area, a model was constructed, linking the vegetation type to the climate factors, the relief and the soil at the spatial level of 100×100 m quadrants, in order to provide the model-based predictions of potential vegetation distribution in case of climate warming. The relationship was gleaned with the data mining tool SEE5 (www.rulequest.com) from the empirical data (training dataset). The training data consisted of equal numbers of randomly sampled records for each vegetation type. Each record consisted of the current vegetation type at a particular 100×100 m quadrant, followed by the corresponding climate data (average monthly and yearly temperature, precipitation and evapotranspiration values for the 1970–2000 period), relief data (elevation, terrain slope, terrain exposition), and soil data (FAO soil type). The model constructed with SEE5 took the form of a decision tree. The accuracy of the model was estimated to be 71% (at the level of 13 vegetation types) with 10-fold cross-validation on training data. The cross-validation returns similar accuracy values as the validation using an independent control sample. Using the model and the existing predictions of the likely future climate (Bergant 2007), we predicted the shift of the forest vegetation in Slovenia for the years 2040, 2070 and 2100 under three climatic scenarios: the mean scenario (median predicted temperature T, median predicted precipitation R, median predicted evapotranspiration E), the pessimistic scenario (max T, min R, max E), and the optimistic scenario (min T, max R, min E). For comparisons of the predicted values to the present values, we used the potential present values, i.e. modelled present values, and not the real present values. Therefore, the differences between the present and the predicted values were less influenced by the errors of the model. Since the empirical model is only valid within the present forest area, it cannot predict change of the forest area due to climate warming. Therefore, our predictions of vegetation change were only made within the present confines of the forests.

RESULTS – Rezultati

Taking into consideration the future climate changes (defined by three different climate scenarios**:** the mean scenario, the pessimistic scenario and the optimistic scenario), the simulation of the future potential forest vegetation showed significant changes of vegetation-type shares in Slovenia. By using all three climate scenarios in an empirical GIS model, the simulations showed the alteration of spatial pattern of 13 vegetation types (groups of similar forest communities) under impacts of climate vary considerably (Figure 2).

The mesic forest vegetation may be adversely affected by such changing environmental conditions. The decrease of the share of currently prevailing beech vegetation types, e.g. groups of Acidophilic *Fagus sylvatica* forests (14.2%), of Submontane *Fagus sylvatica* forests (13.0%), and (Alti-) montane *Fagus sylvatica* forest in (Pre-)Dinaric region (11.2%), could be expected (Table 1). By the year 2100, the share of Acidophilic *Fagus sylvatica* forests might be decreased to range between 0.0% (pessimistic scenario) and 5.0% (optimistic scenario); and the share of Submontane *Fagus sylvatica* forests might be contracted to range between 0.0% and 4.0% (Table 1). The constant decreasing of (Alti-)montane *Fagus sylvatica* forest in the (Pre-)Dinaric region, among which Dinaric fir-beech forests (*Abieti-Fagetum dinaricum*, sin. *Omphalodo-Fagetum*) prevail, has been forecast (Graph 1).

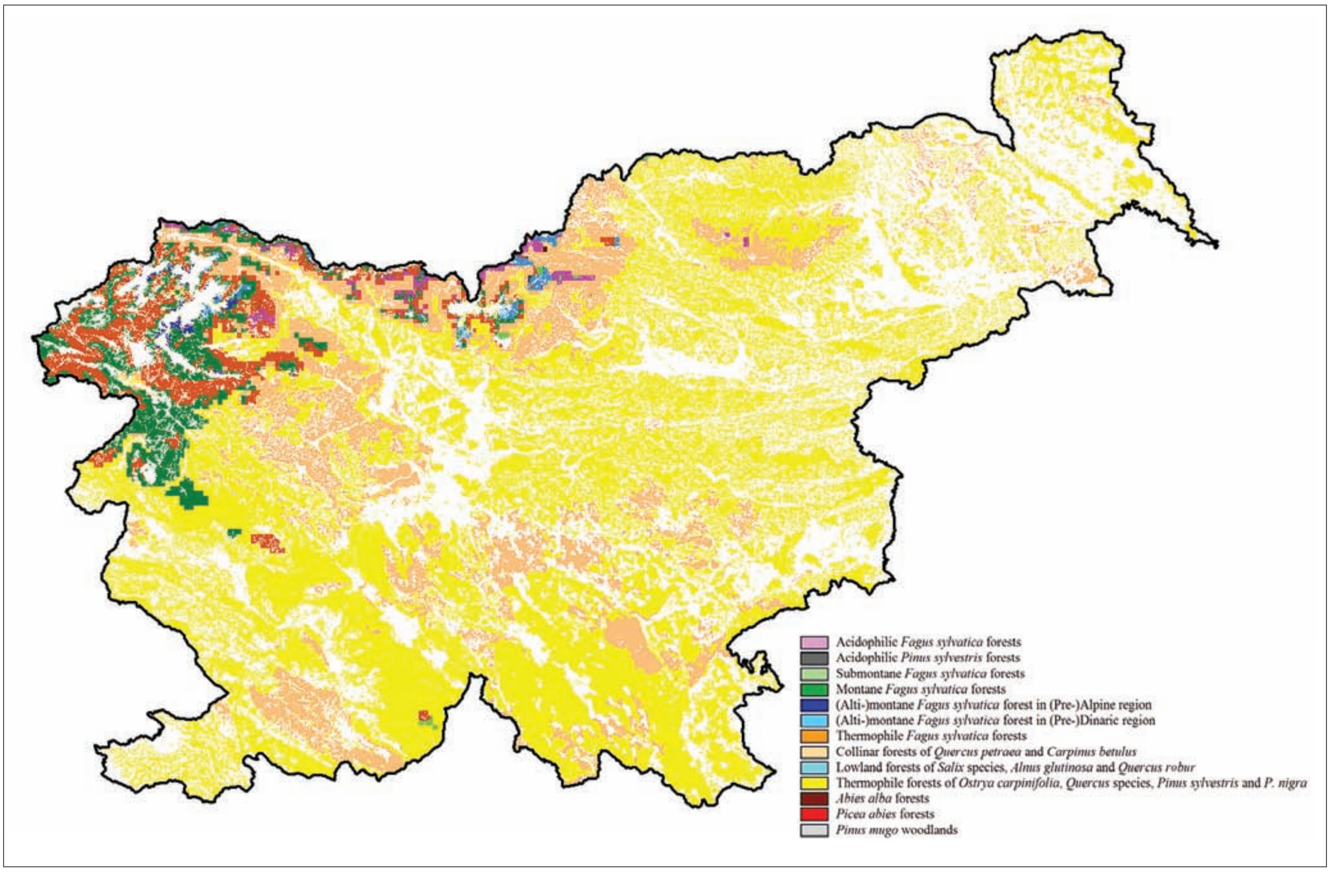
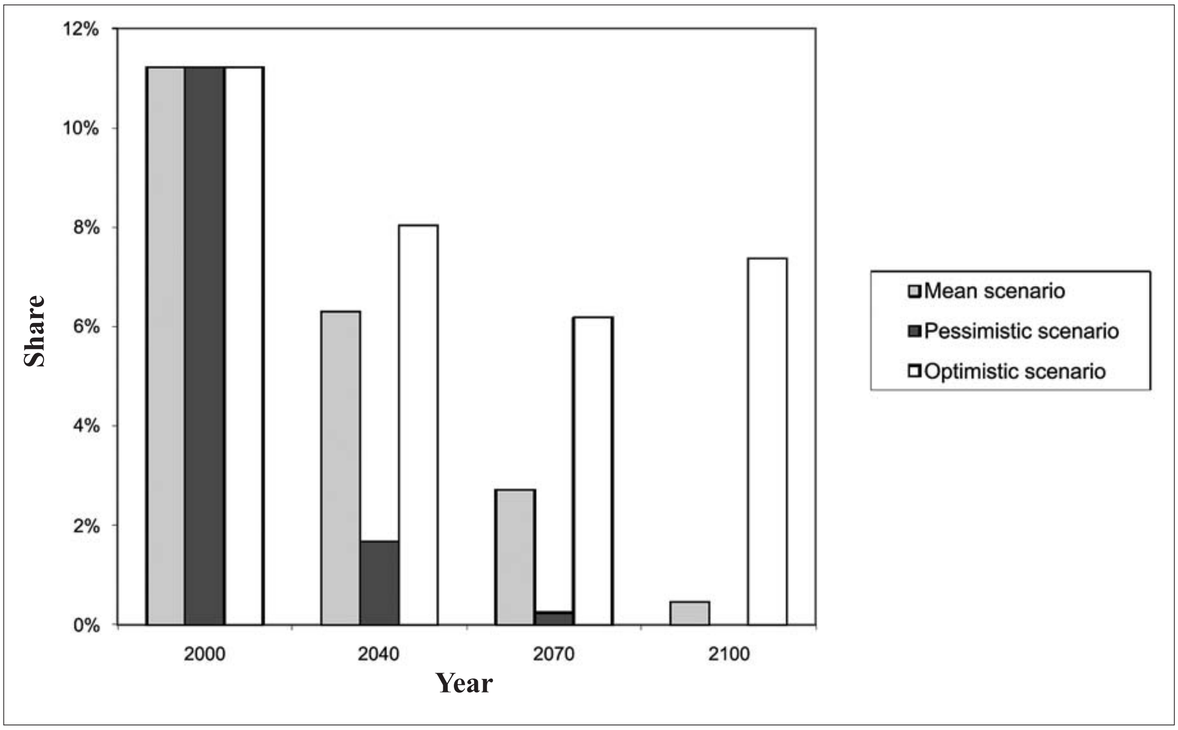


Figure 2 Forecast of forest-vegetation distribution in the year 2100 according to the mean climate scenario. The white color denotes currently non-forested areas, since the model only predicts vegetation changes within the forest areas.

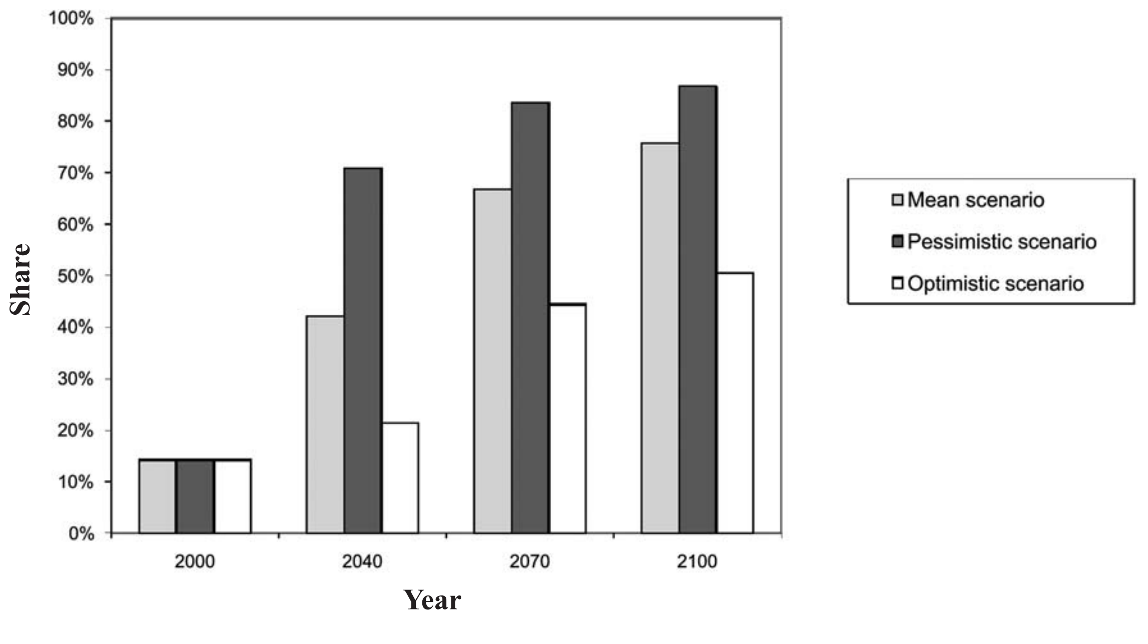
Slika 2. Prognoza raširenosti šumske vegetacije u 2100 godini prema srednjem klimatskom scenariju. Bijela boja označava područiju bez šuma. Model prognozira promjene vegetacije samo unutar šumskog područja.



Graph 1 Forecast share of (Alti-)montane Fagus sylvatica forest in (Pre-)Dinaric region based on different scenarios for three periods

Grafikon 1. Prognozirani udio (Alti-)montanskih šuma bukve u (Pre-)dinarskoj regiji na temelju različitih scenarija za tri razdoblja

On the contrary, the warmer climate predicted by all three future scenarios will favour drought-tolerant forest species and vegetation types. It could be expected that different thermophile forests, which are partly dominated by beech trees, but mostly by different drought-tolerant tree species, like Ostrya *carpinifolia* Scop., *Fraxinus ornus* L., *Sorbus aria* (L.) Cr., *Quercus pubescens* Willd., *Q. cerris* L., *Q. ilex* L. and *Q. petraea* (Matt.) Liebl., and also *Pinus sylvestris* L. and *P. nigra* Arnold, will expand over a larger area of the country. Even different Mediterranean evergreen forests and maquis shrublands of the order *Quercetalia ilicis*, with dominant *Quercus ilex* L., *Q. coccifera* L., *Pinus halepensis* Mill. or *Carpinus orientalis* Mill., similar to current vegetation of the Croatian coastal area (Trinajstić 2008) could possibly be distributed over extreme warm sites in Slovenia. By the end of century, the share of such thermophile vegetation might be enlarged from 14.2% to range between 50.4% (optimistic scenario) to 86.8% (pessimistic scenario) (Graph 2).

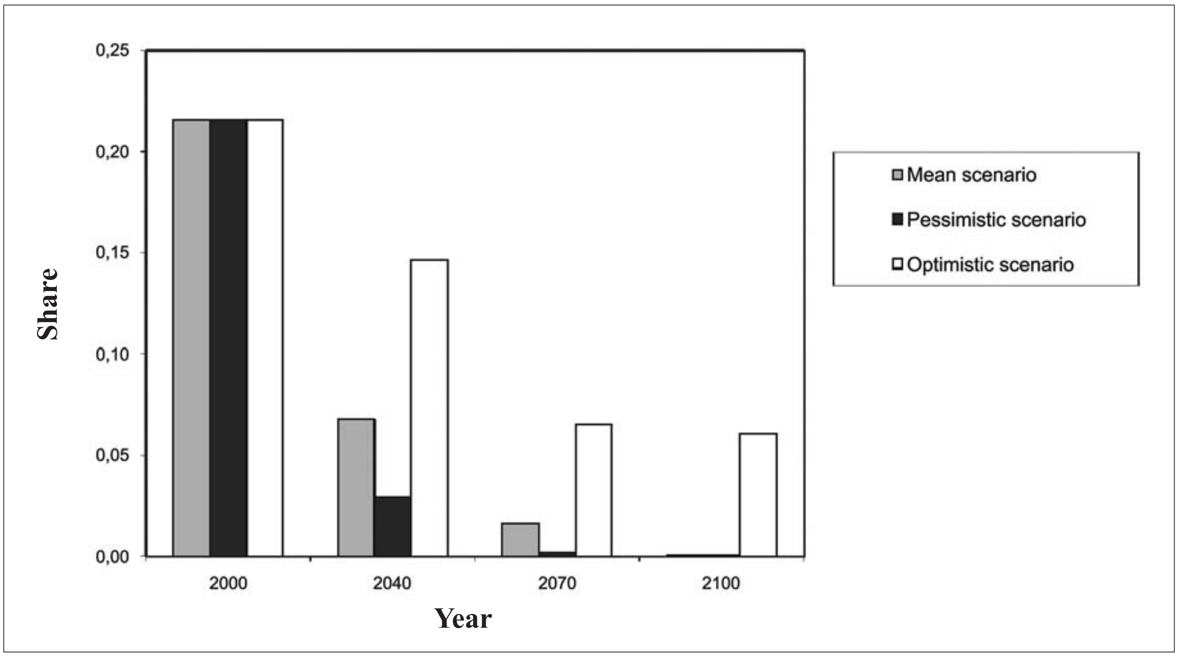


Graph 2 Forecast share of different thermophile forests (vegetation types of Group 7 and Group 10 are aggregated) based on different scenarios for three periods

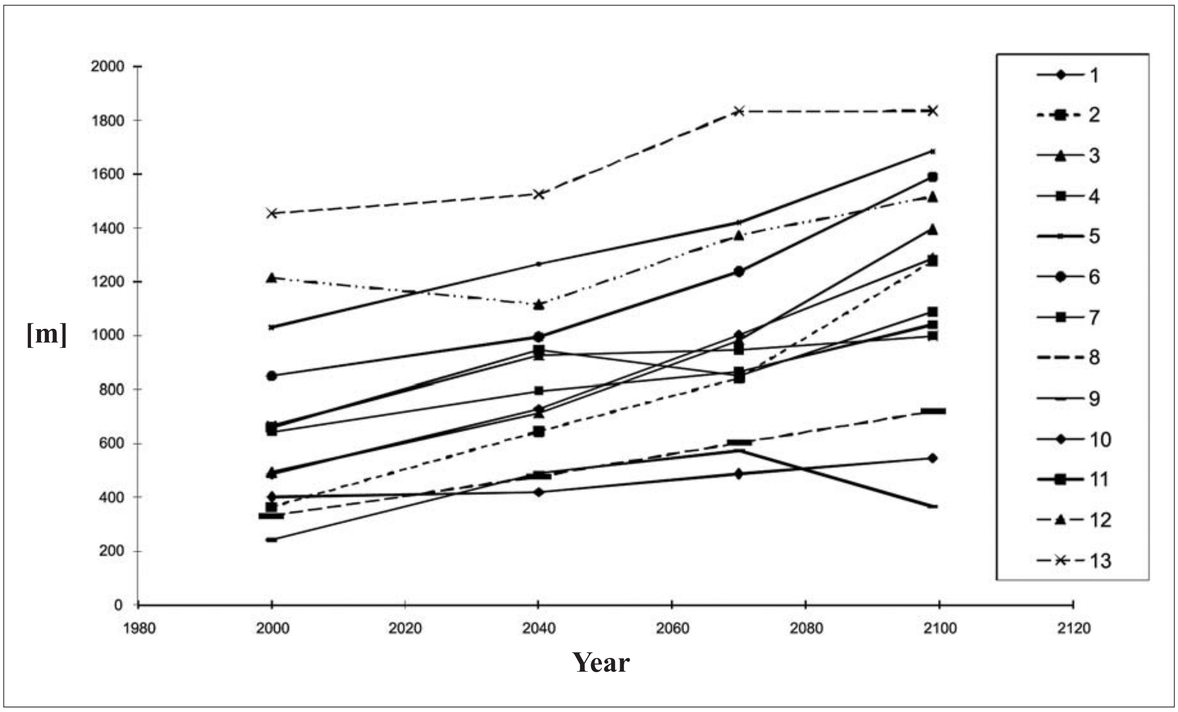
Grafikon 2. Prognozirani udio različitih termofilnih šuma (vegetacija skupina 7 i 10 zajedno) na temelju različitih scenarija za tri razdoblja

Beside this, the Collinar forests of *Quercus petraea* and *Carpinus betulus*, admixed with various tree species, like *Prunus avium* L., *Acer campestre* L., *A. pseudoplatanus* L., *Tilia cordata* Mill., *Fraxinus excelsior* L., *Abies alba* Miller, *Picea abies* (L.) Karsten, growing from plains to hilly areas, from the Sub-Mediterranean to Pre-Pannonian regions, covering 8.6% of total forest cover, will be spread over larger area. By the year 2100, the forecast share of these forests might be between 11.8% (pessimistic scenario) and 17.8% (optimistic scenario). However, even more xerothermic vegetation with dominant oak species (e.g. *Quercus cerris* L., *Quercus frainetto* Ten.) might also be expected after such significant warming.

The more commercially interesting coniferous species, like *Picea abies* and *Abies alba* are present in diverse forest types, and they have significant shares of the total growing stock (*Picea abies*: 32%, *Abies alba*: 8%; Lesnik and Matijašić 2006). However, taking into account potential sites of coniferous dominant vegetation types (including vegetation types 2, 11, 12, 13) the share of these forests is less than 18% of the total (Table 1). Based on different climate scenarios forecasting the lower ratio between share of coniferous and broadleaves dominant vegetation types (Graph 3), the negative impacts of climate warming and water limitations on the coniferous forests of more humid and colder site conditions were estimated.



Graph 3 Forecast ratio between share of coniferous dominant vegetation types (2, 11, 12, 13) and broadleaf dominant vegetation types (1, 3, 4, 5, 6, 7, 8, 9, 10) based on different scenarios for three periods
Grafikon 3. Prognozirani omjer između staništa vegetacijskih skupina sa dominantnom crnogoricom (2, 11, 12, 13) i vegetacijskih skupina sa dominantnom bjelogoricom (1, 3, 4, 5, 6, 7, 8, 9, 10), na temelju različitih scenarija za tri razdoblja



Graph 4 Predicted mean elevation height of vegetation, based on mean scenario (numbers correspond to Table 1)
Grafikon 4. Predviđena srednja nadmorska visina vegetacije na temelju srednjeg scenarija (brojevi odgovaraju tablici 1)

The simulation showed that under warmer conditions the shift of vegetation belts upwards could be expected (Graph 4). It means that *Fagus*-dominated communities in the colline-submontane belt might eventually be replaced by oak-hornbeam communities, and the shift of tree-line to higher elevation is predicted. A shift upward of mean average of *Pinus mugo* woodlands by almost 400 metres by the year 2070 has been simulated with the GIS model.

DISCUSSION – Rasprava

Simulations of the future climate with general circulation models (GCMs) indicate an even more intensive climate change than that detected in the last decades of the 20th century (Bergant 2007). Most of the current climate projections for central Europe predict increased temperatures that are expected to cause an increase in the frequency and duration of intense summer droughts (e.g. IPCC 2001, 2007). Based on the three different climate scenarios, the simulations showed that the spatial pattern of forest vegetation types in Slovenia will be altered, and the vegetation type of major part of forest sites might be changed in the following decades under the impacts of climate change. Under warmer and wetter conditions, the vegetation shift might not be as drastic as under warmer and drier conditions.

Nowadays, the most abundant and dominant tree species of the potential natural vegetation of central Europe is European beech (*Fagus sylvatica*) (Ellenberg 1996); it is one of the ecologically and economically most important forest tree species presently supported by forest management in this area (Geßler et al. 2006). Beech forests of different types are prevailing in Slovenia too, occurring on calcareous as well as on silicate and mixed bedrock, on very different soil types, from hills (150 metres a.s.l.) to the subalpine belt (1650 metres a.s.l.) (Lesnik and Matijašić 2006, Dakskobler 2008). In Slovenia, approximately 63% of all forests currently grow on the beech, fir-beech and beech-oak potential sites; a reduction of beech sites is predicted to range between 7% (pessimistic scenario) and 42% (optimistic scenario) by the year 2070 (Kutnar et al. 2009). The beech forests are likely to be threatened, owing to beech sensitivity towards low water availability (Ellenberg 1996) and longer drought periods (Fotelli et al. 2002); the physiological performance, growth and competitive ability of European beech may be adversely affected by such changing climate conditions (Peuke et al. 2002, Geßler et al. 2006). In Slovenia, the situation may be aggravated by the fact that the area of distribution of beech forests includes many sites with shallow limestone- and dolomite-derived soils of low water storage capacity.

By the end of century, the distribution range of fir is likely to change (Anić et al. 2009), and a decrease of the area of Dinaric fir-beech forests (*Omphalodo-Fagetum*) has been forecast in preliminary studies (Kutnar and Kobler 2007, Kutnar et al. 2009). According to the most pessimistic hot-and-dry scenario and assuming that the actual ecological niche of this vegetation type would not be changed in the future, this forest type might disappear completely from territory of Slovenia by the end of the 21st century. It seems that Dinaric fir-beech forests might be the most threatened forest community in Slovenia.

Dinaric fir-beech forest is one of the most extensive forest communities in Slovenia (Dakskobler 2008), covering the Dinaric Mountain area, extended along the Adriatic coast over the Balkan Peninsula. In Slovenia, the Dinaric mountain chain reaches the south-eastern Alps; in term of diversity, the vegetation on the border zones of different ecological influences is especially interesting. Beside their significant forest-management role, the Dinaric fir-beech forests are among the most important timber productive forests; their ecological and nature-conservation aspects are also significant. In area of these forests, the central part of habitat of three large European beasts of prey, the brown bear (*Ursus arctos* L.), lynx (*Lynx lynx* L.), and wolf (*Canis lupus* L.), and of many other species (Kutnar et al. 2002, Ódor and Van Doort 2002) that are of special interest (e.g. Habitat Directive 1992), and the major part of these forests has been designated as part of the Natura 2000 network (Skoberne 2004). Thus, the loss of habitat of Dinaric fir-beech forests is likely to mean the potential extinction of many key species. Climate change has already caused numerous shifts in species abundance and distribution within the last 50 years (Parmesan and Yohe 2003) and it is presumed to be a major cause of species extinction in near future (Thomas et al. 2004).

The share of different thermophile forests, which are less economically interesting and more fire-prone, will increase significantly, replacing the currently predominant mesic forests. The extension of thermophile forests all over the country would have very dramatic consequences and would affect forest-management, forest policy, and forest protection activities. The shift from dominant semi-natural mesic forests, mainly belonging to order of *Fagetalia sylvaticae*, to low density forests or woodlands, potentially belonging to orders of *Quercetalia pubescentis*, *Erico-Pinetalia* or even to Mediterranean evergreen forests and maquis shrublands of order *Quercetalia ilicis*, is likely to happen by the end of the 21st century. The production of high-quality wood is one of the main objectives of forest management at present, but forests provide a wide range of other benefits. The future forest roles might be critically affected by redistribution and changed proportions among the forest types.

Different types of thermophile forests of the sub-Mediterranean region of Slovenia have recently been damaged by forest fires (Mavsar et al. 2005, Jakša 2006). Driven by the warmer conditions and drought, similar as in the Mediterranean (Santos et al. 2002, Pausas 2004, Pereira et al. 2005, Moriondo et al. 2006), forest fire frequency and severity are very likely to increase in the future.

In Slovenia, the coniferous forests might be affected by warmer climate (Ogris and Jurc 2010). As in western and central Europe (Kienast et al. 1998, Maracchi et al. 2005, Koca et al. 2006), a significant share of potential coniferous vegetation might be replaced by forests mainly dominated by deciduous trees. Native coniferous forests characterised by humid site conditions and relatively lower average temperatures might even disappear according to the most pessimistic scenario, which predicts a rapid increase of temperature and a decrease of precipitation.

A shift upward of the treeline by several hundred metres caused by climate change could be expected (Badeck et al. 2001, Grace et al. 2002); there is some evidence that this process has already begun in some regions (Mindas et al. 2000, Kullman 2002, Peńuelas and Boada 2003, Camarero and Gutiérrez 2004, Shiyatov et al. 2005). In harsh conditions in Slovenia, where continuous forests are no longer able to exist, the *Pinus mugo* woodlands are spread in the subalpine zone, while the scrubland scattered trees of *Larix decidua*, *Picea abies*, *Sorbus aucuparia* L. subsp. *glabrata* (Wimm. & Grab.) Hayek., *Fagus sylvatica* L. and some other more rare species form the upper treeline in this region. The shift upward of *Pinus mugo* woodlands was simulated with the GIS model, and the change of treeline together with the effect of abandonment of traditional alpine pastures is predicted as in other European mountain areas (Guisan and Theurillat 2001, Grace et al. 2002, Dirnböck et al. 2003, Dullinger et al. 2004). For this reason, the composition and structure of alpine and nival communities are very likely to change, and threatening of nival flora is predicted (Guisan and Theurillat 2000, Gottfried et al. 2002, Walther 2004).

Although, many research findings support the clear impact of climate change to forests vegetation (e.g. IPCC 2007), there is no doubt that the results of present climate projections reflect some degrees of uncertainty (see, e.g. Rial et al. 2004, Von Storch et al. 2004) that are due to the incomplete understanding of the climate as a system and its complex interactions with the biosphere and oceans. Beside the relatively uncertain climate-change model, a potentially changed ecological niche of existing forest vegetation types under changed climate or even the ecological niche of future forest vegetation types with other dominant tree species have not been considered. Moreover, the secondary effects of climate change (e.g. higher frequency of forest fires, land use change, and especially effects of tree diseases and harmful pests and their new appearances (Jurc and Ogris 2006, Jurc et al. 2006, Ogris et al. 2006, 2008, Piškur et al. 2011)) have not been foreseen in the model.

On particular sites in the centre of the current area of distribution of beech in central Europe, beech may lose its dominance and growing potential as compared to drought or flood-tolerant species (Geßler et al. 2006). Since similar impacts are also likely to occur in the studied area, forest policy and management need to take such risk into consideration. Species-rich forests with a high resilience potential will reduce the risk for forestry related to the prognosticated climate development in this region.

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SAŽETAK: Rezultati istraživanja promjene klime pokazuju da bi rizici uzrokovani ekstremnim vremenskim pojavama mogli značajno porasti u budućnosti (IPCC 2001, 2007). Topliji i sušniji uvjeti pridonijet će češćim i dužim sušama, posebice u području Sredozemlja (IPCC 2007). Vrlo je vjerojatno da će na šumske ekosustave značajno utjecati klimatske promjene i druge globalne promjene (Shaver et al. 2000, Blennow and Sallnäs 2002, Askeev et al. 2005, Kellomäki and Leinonen 2005, Maracchi et al. 2005, IPCC 2007).

U ovom su istraživanju analizirane moguće promjene šumske vegetacije u Sloveniji zbog globalnih klimatskih promjena.

Potencijalne promjene vegetacije u prostoru simulirali smo pomoću empirijskog GIS modela, koji prognozira prostornu raspodjelu šumske vegetacije u odnosu na klimatske i druge ekološke čimbenike. Ovaj prostorni model – osim gore spomenutih – ne uzima u obzir druge važne čimbenike, koji značajno doprinose distribuciji šumske vegetacije, kao što su: sukcesije i proširivanje šuma, antropogeni čimbenici te utjecaj sekundarnih čimbenika (bolesti šumskog drveća, zoo-komponenta šuma, požari). Prognozirajući budući sastav šumske vegetacije, koristili smo postojeća očekivanja klimatskih promjena za Sloveniju te predvidjeli tri različita scenarija: srednji scenarij, pesimistički scenarij i optimistički scenarij (Bergant 2007, Kutnar et al. 2009).

Na temelju tri različita klimatska scenarija (svi tri predviđaju zagrijavanje klime), simulacije pokazuju da će se prostorni raspored i udio trinaest vrsta šumske vegetacije (skupina sličnih šumskih zajednica) mijenjati pod utjecajima promjene klime (tablica 1). Zbog toga možemo očekivati pomicanje vegetacijskih pojaseva prema gore (grafikon 4).

*Postoji velika vjerojatnost da će se u Sloveniji do kraja 21. stoljeća bitno sniziti udio šuma bukve (Fagus sylvatica) –ponajprije na uštrb širenja različitih termofilnih šuma (vrsta) (tablica 1, slika 1 i 2); od današnjih 14.2 % površina acidofilnih šuma bukve (Fagus sylvatica) do površine između 0.0 % (pesimistički scenariji) i 5.0 % (optimistički scenariji); pretplaninske (Submontanske) šume bukve (Fagus sylvatica) (13,0 %) od 0.0 % do 4.0 %. Predviđa se postepeno smanjenje (Alti-)montanskih šuma bukve u (Pre-)dinarskoj regiji (11,2 %) među kojima dominiraju dinarske šume bukve i obične jele (*Abieti-Fagetum dinaricum*, sin.* Omphalodo-Fagetum*) (grafikon 1).*

*Prema pesimističkom scenariju i uz pretpostavku da se ekološka niša dinarskih šuma bukve i obične jele neće promijeniti u bliskoj budućnosti, ovaj tip šuma mogao bi – na području Slovenije – u potpunosti nestati do kraja 21. stoljeća. Dinarske šume bukve i obične jele spadaju među najvažnije šume za proizvodnju drveta, a značajna je i njihova ekološka uloga te uloga na području zaštite prirode. Na području ovih šuma nalazi se središnji dio staništa triju velikih zvijeri europske važnosti – smeđi medvjed (*Ursus arctos *L.), ris (*Lynx lynx *L.), i vuk (*Canis lupus *L.), te mnogo drugih organizama od posebne važnosti po Direktivi o staništima (1992). Veći dio tih šuma uključen je u ekološku mrežu Natura 2000 (Skoberne 2004). Zato je vjerojatno, da bi gubitak staništa* *dinarskih šuma bukve i obične jele istovremeno označio i izumiranje određenih ključnih vrsta.*

Opisani model predviđa povećanje udjela termofilnih šuma, gdje djelomično prevlađuje bukva, uz mnoštvo vrsta drveća, koja su izrazito otporna na sušu, kao Ostrya carpinifolia*,* Fraxinus ornus*,* Sorbus aria*,* Quercus pubescens*,* Q. cerris*,* Q. ilex *i* Q. petraea*, te* Pinus sylvestris *i* P. nigra*, sa dosadašnjih 14 % – od cjelokupne površine šuma u Sloveniji – na razinu od 50 % (prema optimističkom scenariju) do čak 87 % (prema pesimističkom scenariju) (grafikon 2).*

Do kraja dvadeset i prvog stoljeća, dominantne polu-prirodne šume mezičnih staništa, koje uglavnom pripadaju redu Fagetalia sylvaticae*, bit će vjerojatno zamijenjene rijetkim šumama i šumarcima reda* Quercetalia pubescentis*,* Erico-Pinetalia *ili čak sredozemnim zimzelenim šumama i makijama reda* Quercetalia ilicis*.*

*Prema prognozi modela, značajan dio crnogorice, u kojima dominiraju smreka (*Picea abies*) i jela (*Abies alba*), mogao bi se u postupnosti pretvoriti u listopadne šume (bjelogoricu) (grafikon 3). Čak štoviše, prirodne šume crnogorice, koje su obilježene vlažnim staništima te relativno nižim prosječnim temperaturama, mogle bi u potpunosti nestati, uzevši u obzir najpesimističniji scenarij, koji predviđa brzi porast temperature te pad količina padavina.*

Ključne riječi: klimatska promjena, šumska vegetacija, model, simulacija, klimatski scenariji