



# **Use of spatial analogy in analysis and valuation of climate scenarios**

PhD theses

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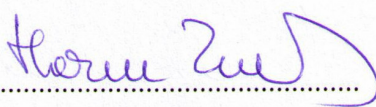

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## Introductions and aims

Custom run of our weather in a specific place and time -what can be defined by the averages of climatic parameters- we can call the climate of that area. The climate of a specific area significantly define the ecology, potential vegetation, flora and fauna, soil type and it's quality of that called area. Also define (with the previous ones) the human activity. The adaptation technics to climate of the society can define the human activities on a called area. The human activities depends from the actual climate, but the climate sensitivity is different by type-to-type. The most sensitive areas are the followings:

1. agriculture,
2. silviculture,
3. water management,
4. enviroment conservation,
5. human- animalhealth.

These climate sensitive areas also define the area's land use types, which influences the natural and social activities. Of course there are some other factor, the geographic and social custom which also can influence the land use. It's clear that the changes of the climate of a specific area can change the ecological, social and natural processes, hence the magnitude of that research of that area is needed. Optimalization of human activiteis and encroachment to the adaptation of the human-influenced ecosystems to climate change is today is an unsolvable problem.

Behind the question of climate change, across the human carbon emission, in cause an effect there are ecological questions, because to influence the climate change, we can only reduce our carbon emission or control ecological processes.

It is interesting that we are know a lot about the effect of the climate change we can read many of the publications, we working in huge projects, but we only know a few things about these ecological processes.

From the IPCC reports, the scope of the EU7 projects and the VAHAVA project we can see, that we should hastily and accurately answer the following questions:

1. By the most approved climate scenarios what kind of consequences are waited about the the change of natural vegetation, agriculture and land use?
2. What kind of consequences are waited about the biodiversity change?
3. What is the infulence of the landuse change to the biodiversity?
4. Behind these questions, what are the considerations about the adaptation?

The effect of changing climate on bigger regions and complex processes can be characterized by the spatial analogy. With the spatial analogy we can search for regions which present climate is similar to our study area's in the future. With this method it is possible to analyze the future image of our study area by the most possible climate scenario, and to utilize their adaptation strategies. There are three main direction to utilize the method of spatial analogy.

1. By the GIS representing the different climate scenarios can be visualizing, compareing and grouping. And showing the amplitude of the changes by different scenarios
2. By collecting all of data about the crops, land use natural vegetation from the analogue regions we can build a possible picture of our study area. With that we can make hypotheses to build adaptation strategies.
3. The other way is also important, we can define analogue regions which climate in the future will be similar to our in the present. From that we can get information about where we can sell our knowledge about vegetation, cropping systems adaptation technics etc. (for example where open new markets for our product technologies, where needed our expert knowledge)

It's more important to know, that the analogue regions are analogue only by the used parameters. By the changing in weather system the daily temperature and precipitation will change, but the length of the daytime the radiations won't change. Important to define, that with the spatial analogy we didn't count with the changing of the CO<sub>2</sub> level, because we are comparing present climates. The social questions can be also problem, because of the traditions used crops, agricultural systems and financial conditions

The defined the research topics are the followings:

1. Synthesis of the national and international literature about the spatial analogy methods and the effect of climate change.
2. To develop the methodology of spatial analogy.
3. Characterizing the analogue regions by the most used climate scenarios. And visualize them by GIS.
4. The define the regions which climate will be similar to ours and also visualizing them.
5. To collect and compare all data (crops, land use, natural vegetation) of analogue regions and our study area.

## **Materials and methods**

### *Basic climatic data*

By the recommendation of World Meteorological Organization (WMO) for the base period we chose the time table from 1961 to 1990. The monthly temperature and precipitation data comes from the OMSZ for Debrecen, and for whole Europe it comes from the CRU TYN CL 2.0 database, which has a 10 minutes spatial resolution.

### *Climatic scenarios*

The scenario is a script, which is showing a possible image of our climate in the future. Not a forecasting, only the picture of the future. The differences between the scenarios can be seen in the differences of climate scenarios. For the future climate we analyze the following models and databases

UK Met Office (UKMO) Hadley Centre' climate database:

- TYN SC 1.0
- UKTR (1992):

Geophysical Fluid Dynamics Laboratory's (USA) climate database:

- GFDL2534 (1991)
- GFDL5564 (1991).

From the TYN SC 1.0 database we used three timetable the 2011-2040, 2041-2070 and the 2071-2100 30 years averages.

### *Statistical data of European regions*

In 1970 the EUROSTAT was building the NUTS system, to make easier the datacollections from regions. That system has 3 levels, from the country level to county level by the size and the population of the regions. From the EUROSTAT database we collect the averages of the 1997-2006 time table for the land use and the crops. For the natural vegetation we used the CORINE 2000 database.

1. Land use data (1000 ha)  
(agricultural area, cropfield, forest, pasture, olive field, orchard, vineyard)
2. Field of different crops (1000 ha) and the yield (t/ha)

(wheat, maize, sunflower, rye, rape, sugarbeet, potato, cotton, flax, rice, soya, pulse, tobacco, olive, orchards, grape)

## Methodology of spatial analogy

The scope of the method, is to find the analogue regins. The analogue regions are which climate is most similar to our study area's in the future, or the opposite way, which regins future climate will be similar to our' in the present.

### *Climex method*

With the CLIMEX method, we can compare to climatic datasets, and the method is the following::

$$T_{dj} = \frac{1}{12} \cdot \sum_{i=1}^{12} |TEMP_{ji} - T_i|$$

$$P_{dj} = \frac{1}{12} \cdot \sum_{i=1}^{12} \frac{|PREC_{ji} - P_i|}{1 + a \cdot (PREC_{ji} + P_i)}$$

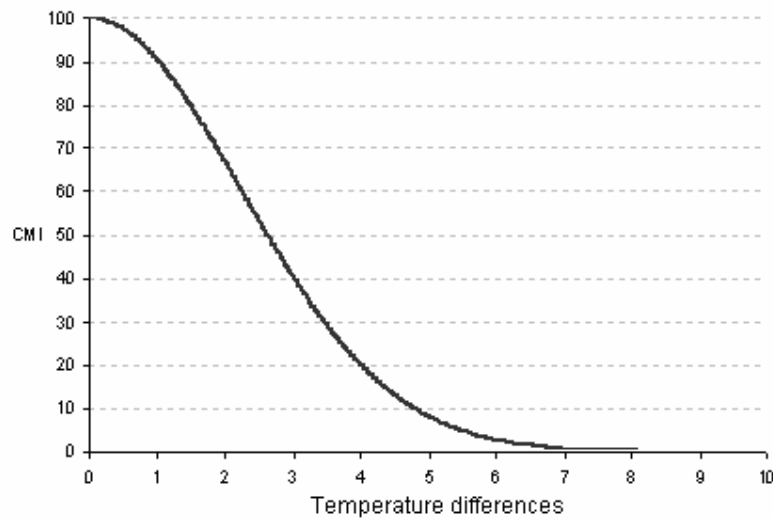
$$I_{Tj} = e^{-\lambda \cdot k_T \cdot T_{dj}}$$

$$I_{Pj} = e^{-(1-\lambda) \cdot k_P \cdot P_{dj}}$$

$$CMI_j = I_{Tj} \cdot I_{Pj}$$

Ahol

- $j$ : number of the gridpoint ( $j=1-31143$ )
- $i$ : number of the month ( $i=1-12$ )
- $TEMP_{ji}$ : the temperature of the grid  $j$  in the month  $i$
- $T_i$ : the temperature of the scenario in month  $i$
- $PREC_{ji}$ : the precipitation of the grid  $j$  in the month  $i$
- $P_i$ : the precipitation of the scenario in month  $i$
- $T_{dj}$ : the absolute differences of temperature
- $P_{dj}$ : the differences of temperature
- $a$ : we can count only the differences of precipitation, because the differences for small precipitation is more important than for the high ones. Fort he calculation we used  $a=0,05$
- $I_{Tj}$ : the similarity of the grid  $j$  by the temperature to the scenario (value: 0-1, if the temperature is the same, than  $I_{Tj}=1$ )
- $I_{Pj}$ : the similarity of the grid  $j$  by the precipitation to the scenario (value: 0-1, if the precipitation is the same, than  $I_{Pj}=1$ )
- $k_T$ : can be set by the user, if  $k_T=0,1$  than for 1°C differences the similarity is  $I_{Tj}=90\%$ , az to define the analogue regions, we used teh value (Figure 1)
- $k_P$ : can be set by the user, we choose the  $k_P=0,1$
- $CMI_j$ : „Composite Match Index”, the similarity between the gridpoint and the scenario, for the exact similarity the value is  $CMI=1$



**Figure 1.** Value of CMI for temperature

The user can set the similarity indicies, from which value he or she can call the regions analogue. We choose the similarity for 90% because for that value the temperature differences is 1 °C.

## Results

### *Development of Climex method*

With the Climex method we can only use the temperature and the precipitation in same weight. To calculate the similarity for only for the temperature or for the precipitation we should have alter the calculation of CMI. We started to use a new  $\lambda$  parameter to weightening the temperature and the precipitation. If we choose the  $\lambda=1$  we get the similarity only by the temperature if we choose  $\lambda=0$  than only for the precipitation. For different  $\lambda$  we can set the weight of the parameters as which is more important to us. It is asked to collect the experts knowledge to choose the right  $\lambda$ , because in the different phenophases the crops need from the one than the other parameter, and this is also can changed to month to month. We collect some recommendation for different crops in Table 1.

Because that the calculations can be make very fast and easy, we recommend the calculate for more  $\lambda$  value. From previous research we can say, that for different  $\lambda$  we kept different regions, but some of the had the same for only the temperature and for the precipitation, but there was some, which had high similarity by the temperature and low for the precipitation vice versa. Because there wasn't big differences between the regions for different  $\lambda$  we recommend to use the  $\lambda=0,5$  value with the same weight for the temperature and precipitation.

**Table 1.** Set of  $\lambda$  parameter for different crops

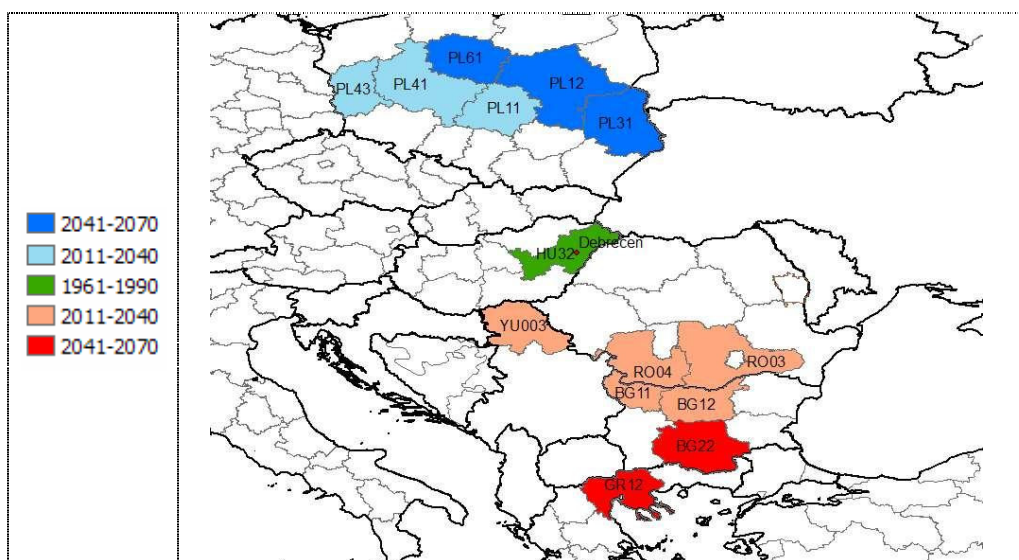
Crops	$\lambda$				
	1	0,75	0,5	0,25	0
Winter wheat	X	X	X		
Autumn barley		X	X		
Spring barley	X	X	X		
Rye		X	X	X	
Maize	X	X	X		
Sugar beet		X	X	X	
Sunflower	X	X	X		
Potato	X	X	X		

Alfalfa	X	X	X		
Grape		X	X	X	
Pea	X	X	X		
Tomato		X	X		
Apple, pear, plum, strawberry, raspberry			X	X	X
Cherry, sour cherry, peach	X	X	X		
Irrigated cultivars	X	X			
High valued cultivars	X	X			

Our study area was Debrecen's region. From the results we can say that the analogue regions for the timetable 2011–2040 is to south, for 2041-2070 the shifting is more but the similarity is also high. For the end of the century 2071-2100 we didn't find analogue region. Analogue region for that timetable are in North-Africa. We only work on the 2011-2040 and the 2041-2070 timetable because for that period have high similarity regions in Europe.

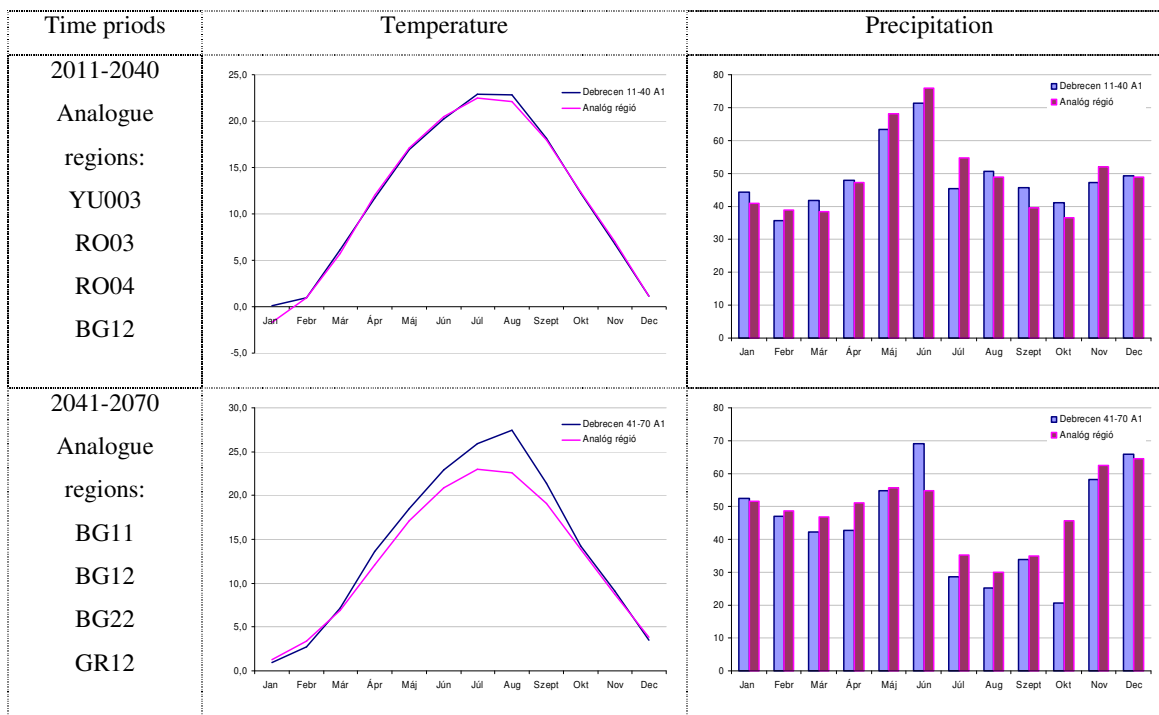
### *Define analogue regions*

We characterizing analogue regions, for which NUTS2 regions are the analogues for Debrecen. (Figure 2.) and needed to define the opposite analogue regions, which climate in the future is similar to ours in the present. We also used the climex method, but we used the scenarios as a base period (for 2011-2040 and 2041-2070) with the  $\lambda=0,5$  value.



**Figure 2.** Analogue NUTS2 regions

To see that the analogue region has the same climate as for the scenario for Debrecen, we should have analyzed the climate of the regions. (Figure 3.) From the diagrams we can see, that for 2011-2040 the temperature and the precipitation are very similar, small differences can be seen for the 2041-2070 period in the summer temperature and in the precipitation in June and October.



**Figure 3.** *Climate of analogue regions*

We can state that the changing climate in time shows more shifting to the south in analogue regions. For the next decades this shifting is about 250-450kms, for the middle of the century is 450-650 kms. To the south direction for the analogue region of Debrecen and to the north in the opposite way.

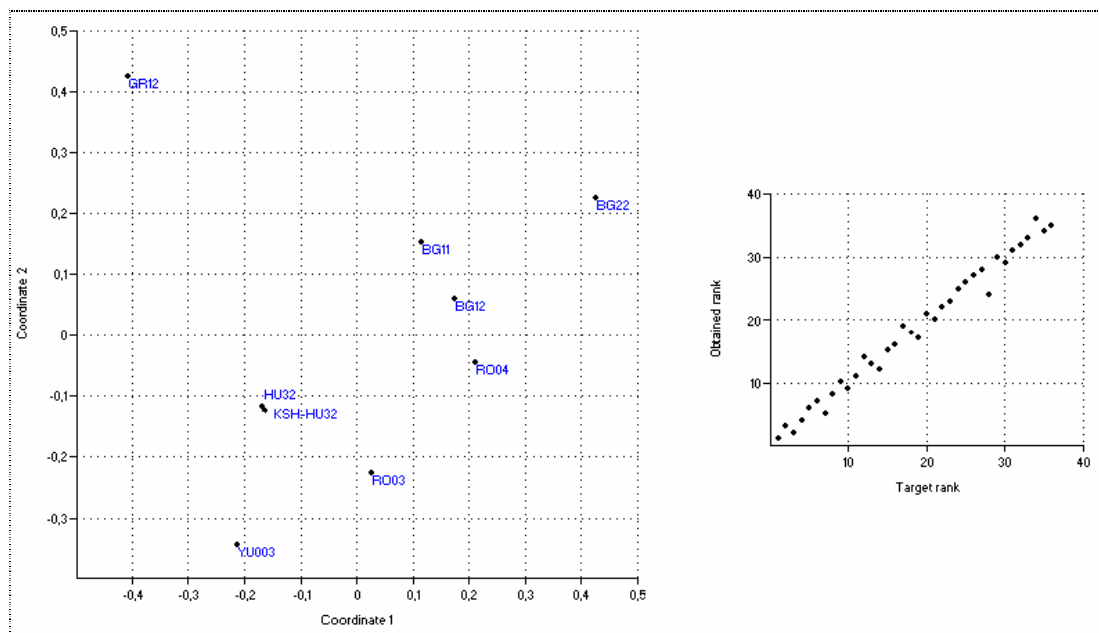
We compare these analogue region by the data of EUROSTAT and by the natural vegetation data from the CORINE database.

Debrecen's analogue regions are for the next decades are in Vojvodina, South Romania and North-Bulgaria, for the middle of the century are in middle Bulgaria and North Greece. For the opposite way the analogue regions are in Poland.

#### *Characterization of the land use data of analogue regions*

We analyze the analogue regions by the relative area of landuse types with the Non Metric Distance Scaling based on euclidean method. (Figure 4.). We can say that Hungary is in the middle of the regions by the similarity patterns, so the possible changes are not leads to the same directions. It can be seen that the closest regions are the RO03 and the YU003, and in farthest time the analogue regions are far away. In the directions we can see some orientations of the regions, they are lead one-to-one by geographic locations. Close are the YU and the RO regins further the BG and the GR.





**Figure 4.** *Similarity of analogue regions by land use*

The cause behind this similarity is the arable land usage, because the ratio of this land use type is higher in YU003 and RO03 and in BG and GR are lower than in Hungary. The ratio of forests are different because geographic conditions, it seen from the ratio of flat plains in the regions. About the usage of arable lands we can get more later.

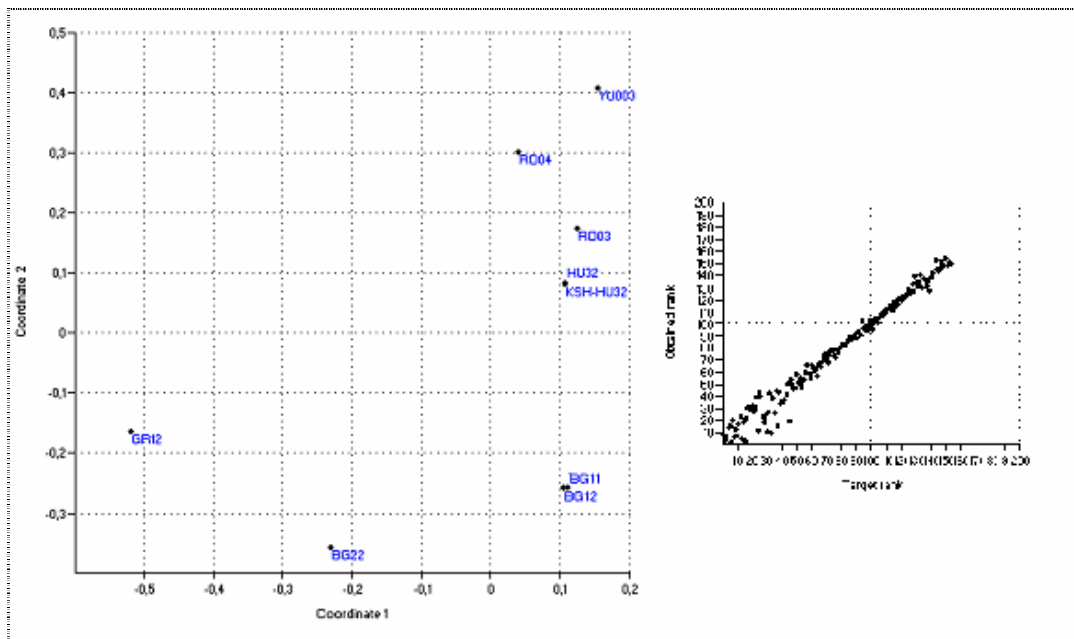
It is more important to declare, that in the analogue regions the ratio of pasture is higher than in Hungary, and the forest use is significant. Increasing the ratio of these extensive land use type should be followed in Hungary, because the save of natural vegetations and natural resources. Interesting to see the ratio of the vineyards, with a small changes in climate we shift in to the good climatic conditions for grape, with more shifting we decreased to the present level.

Diversity of natural and humaninfluenced vegetation is very important in adaptation strategies for the changing climate. The more diverse vegetation is decreasing the risk of climate change, and lead to higher diversity in natural vegetation, which is general environmental question. This is interesting that the decreasing the financial risk and the save of the environment facet o same deriction.

In 2011-2040 the diversity of the analogue regions by land use are lower than in Hungary and higher in 2041-2070. Behind the lower diversity not the number of assortments stand but the equable distribution of the same assortments.

#### *Analysis of cropfields of analogue regions*

The ratio of cropfields to the arable land also was analyze by NMDS based on euclidean method (Figure 5.). This analysis is good for deeper understand the differences in land use types. The result of NMDS shows that the regions are distincting and leading to one row. Can be seen that Hungary also in the middle of the RO and YU regions and BG GR regions.



**Figure 5. Similarity of cropfields**

From the relative values seems that the YU003 and RO03 regions are the closest ones the BG and GR regions are far and different. From topographic conditions the souther regions the BG is closer than the GR. The closest regions are in the other directions than the farthest ones, but all regions are on one line. Behind the differences and the similarity stands the use of maizefield. Can be seen the cornbelt, because the climatic conditions of the southern regions are better than in Hungary, for the farthest regions are worse. Same by the wheat in the Duna basin, the ratio of that wheat is higher than in Hungary also by the sunflower. But behind the differences in the ratio of sunflower stands some social behavior, in the south they prefer the olive oil instead of sunfloweroil.

A smaller climate change leads to the shift into the cornbelt to the YU and RO03 region with higher ratio of maize, higher changes will an over shifting on the cornbelt leads to lower ration.

By the analyzing of the relative data the basic similarity can be defined.

1. The ratio of the maize is increasing for the next decades and decreasing for the middle of the century, as the move into the cornbelt and after overshifting.
2. The ratio of wheat increasing.
3. The barley is opposite to the maize, first decreasing after increasing.
4. The use of rice is important only at the southern regions if we have enough water. This will be a main question in the southern regions.
5. Potato needs lower temperature, so as we waited the ratio is lower in the south regions.
6. The use of sunflower is decreasing only in GR regions, this because the social behaviour, they using the olive oil instead of sunfloweroil.

As at the landuse the calculating of the diversity also needs at the ratio of cropfields. At the ratio of cropfield we can say the same as at the diversity of landuse. The diversity is higher than in the Debrecen region, which leads to decreasing the risk of climate change. This is only truth by the diversity of the dominant crops. The diversity is lower when we enter the cornbelt and higher when we left it.

Interesting if we check the yield of the crops in the analogue regions. The yield as usual opposite than the ratio of the crops. The maize have smaller yield in the cornbelt, than outside of that. The yield of wheat and the sunflower is also lower to the south.

This causes trace back to three reasons.

- Where the climatic conditions are better the farmers try to use these crops on worthier soil conditions, what leads to lower yield.
- As the maize and the wheat are very important foodcrops so if the yields are lower they use them on bigger fields.
- When the climatic conditions are better, financially it is better to save money on the agricultural techniques instead of higher yield.

#### *Analysis of Polish analogue regions by land use and cropfields*

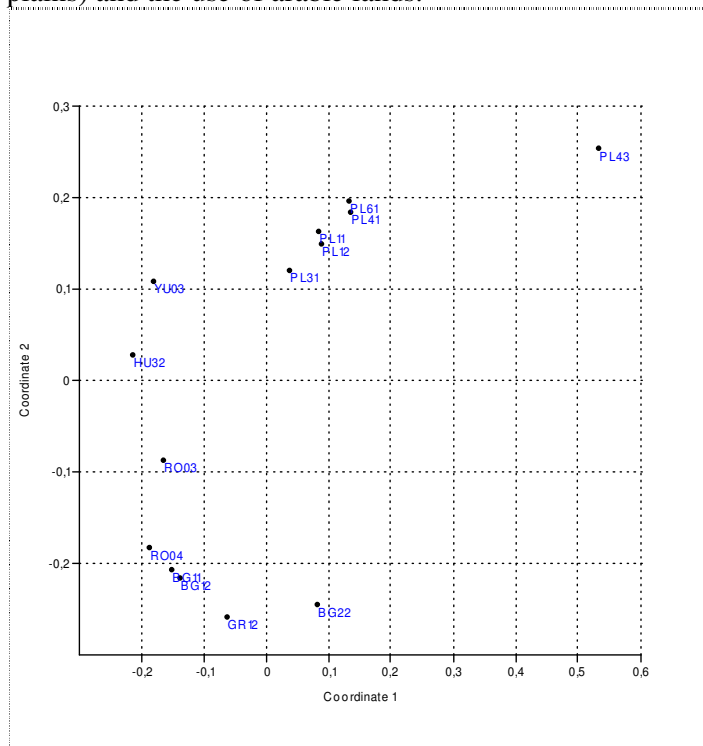
As in the previous research, we make the same analysis for the Polish regions. About the land use we used also the NMDS, we find that the regions are in the same directions as far as they are in time. So the seen differences as the south regions can't be found but the ratio of the forest is much more higher than Hungary.

For further analysis we calculate the diversity of the land use types and the ratio of the cropfields. We can see differences from the side of environment only in the use of forest.

By the crops, as at the land use, all Polish regions are in one direction. The main differences are in the use of maize and the sunflower; their ratios are lower than in Hungary. Correspondingly the ratio of rye, barley and potato are much higher. With the climate change, the ratios of maize and sunflower can be much higher. For the yield data we can say the same as in the previous, the lower ratio leads to higher yield in every crop. This was previously discussed.

#### *Analysis of analogue regions by natural vegetation*

With the use of the NMDS (Figure 6.), it can be seen that as we waited the geographically close regions are close by the vegetation. On the y-axis we can see the south-north directions. At the Polish regions the coniferous woods in the south regions, the deciduous wood and the sclerophil vegetation is the dominant, the Hungarian and Serbian regions are transitional. In these regions the ratio of the natural vegetation is the smallest, this because of the geographical condition (they are flat plains) and the use of arable lands.



**Figure 6.** Similarity of analogue regions by natural vegetation

In the similarity pattern we also can see the differences of the vegetation types as we waited. But we can consider, that the feasible area of the natural vegetation always bigger than the real area because the human activities. There are some differences in the regions about the forest type, but the greek regions differ more by floristic and phisiognomical consition.

We can find more information if we using the EEA classification, by the ecological and biogeographical regions. The ecological flavour of the hungarian region is as an island- as the Carpathian basin- stand in Europe's map. Our status is differ to the others. Because of that, a small changing in climate will change radically the natural system. This call the attention to more on environment, safe of biodiversity and build adaptration strategies.

It can bee state the our natural resources are in only small places, they will suffer from a climate change.

## Theses

1. We developed the new method by generalizing the climex method with a new  $\lambda$  parameter. We this new method we can weight the temperature and the precipitation, so the method can be cropspecific. We also developed a new method, with that we can search for regions which climate in the future will be similar to ours in the present.
2. We state, that the analogue regions to debreceni n the next decades will be 250-450 kms south to Hungary, for the middle of the century this shifting is 450-650 kms. This regiond are in Serbia, South-Romania, North-Bulgaria (YU003, RO03, RO04, BG11, BG12). For 2041–2070 period the analogue regions are in Middle-Bulgaria and Greece (BG22, GR12). For the 2071–2100 period there are no analogue regions in Europe, only in North-Africa.
3. We state that the north analogue regions are in Poland. For the 2011–2040 period the regions are the PL11, PL41, PL43, for the 2041–2070 period are the PL61, PL12, PL31 regions. The analogue regions are differ to the different scenarios and for different periods. Fort he closest peroods the scenarios are mostly shows the same regions, the differences between them are more significant in later periods.
4. From the land use of different analogues regions we can say that the forest and the paisture is more important. The diversity of the regions are the same or higher than in Hungary. The ratio of maize and wheat is higher than in Hungary in 2011-2040, and lower in 2041-2070. We can say that the yields are higher in the lower used crops. The comparison of analogue regions are good only for state general statements, for further analisys we need more resarch. We can't eliminate the social behaviour of the analogue regions because they determine the landus e and the cropuse.
5. Analysing the natural vegetation, we can say, that coverages of the natural vegetation is higher in the analogue regions than in Hungary. To the north the coniferous woods to the south is the dfeciduous woods are the dominant. Only in the greek regions the schlerophill vegetation is teh dominant. The biogeographical zonality shows that Hungary in a worth position, because all the other region are in a different biogeographical zone, so for a small changes we ru out of our region.

## Discussion

We developed a new method for spatial analogy with generalizing it with a  $\lambda$  parameter, with that we can weight the temperature and the precipitation. With different weight we get different areas, they not differ very much, but we can get areas which are similar by the temperature and not by the precipitation and vice versa. To find the analogue regions we should use the limiting parameters and their weights, but we should say that there are some climatic and not climatic parameter which won't change (radiation, daytime, geographic, soil types etc.) To weight the parameters we need some recommendation from experts.

We start the new face of analogy, we can search for regions which climate will be similar to our study area in the present. With this method we can characterize regions where we can sell our knowledge, where needed our experts.

For further research we can develop the method, by using more parameter minimum maximum temperature cloud coverage and some non climatic parameter as soil types or soil conditions. If we using more parameters the analogue regions are restricted.

Higher diversity of a regions leads to less risk in climate change and less financial risk, so different climatic condition, different crops and agricultural techniques has a potential to adapt to changing climate or extreme weather events. It is needed to keep the diversity on high level.

To develop adaptation techniques we should learn from our neighbourhood, analyse the land use and cropping techniques.

For the next decades we should change some of our crops and try to use more diverse land use (new forests, better water management, emission reduction). For the middle of the century we should change drastically, we should change the crop patterns, we should use new techniques, active environment conservation. After 2071 we can't say anything the changes more drastically and extreme, build adaptation strategies for that period is impossible.

The results of this research are usable in agriculture, spatial planning, environment and conservation, and open a new window to analyse the effect of climate change

The conclusion about agriculture leads to find adaptation strategies, opening the land use possibilities, which can support mitigation. The adaptation means to change crop patterns support systems crops or crop species and decreasing the ratio of intensive agricultural fields. All of the results shows that we need to change our behaviour about environment and conservation. Instead of conserving the environment we should help to keep the biodiversity on higher level. For this we should reduce the carbon emission and with active help on the natural processes. But it is very hard to import these techniques because the ecology of Hungary differ more from the analogue regions. In our case we should open new emergency ways to our vegetation and develop the eco-engineering systems, mostly to Poland. This has to job, to help to introduce new ecosystems, and to help to adapt to older ones. The aim is to reduce the harmful effects and help to settle new species, but it's not enough. With the spatial analogy we can look for the possible new coming species which are adapted to their climate, possibly they can move northward. The other job is to conserve the species how can't adapt to changing climate, we should look for areas which climate will be same as ours now (these regions are in Poland). Also needed -because the previous- to cooperate within the national environmental protection agencies, to help to open the emergency ways.

It has also financial questions about the conservation and environment protection, but the involved sectors are sometimes on the opposite site. To solve these problem the ecological economy can help to determine the changes in monetary ways. The most important research was by Constanza in 1997, how to calculate the value of the biosphere and biosphere services. It impressed other scientist to develop the method and other to criticise. The others are afraid of the the biosphere can be bought. But that's not true. We used the price as a general unit and we use it to compare different habitats by their services. This comparison can be a base of a new agricultural support system which is using climatic environmental protection aspects and control the economy. As at the emission markets we can develop new methods in adaptation and mitigation to climate

change. With that we can support environment protection projects, decrease the ratio of the intensive agricultural fields or ecofriendly agriculture. The exact cost-benefit analysis of the environment protection part of the national adaptation strategy can't be imagine. But without that it's weak.

For all of the previous questions and to solve these problems or just help to solve them the method of spatial analogy can be an excellent solution.

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