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Impact of Documented Land Use Changes on the Surface Albedo and Evapotranspiration in a Plain Watershed

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Abstract. Agricultural land use series are investigated in a plain catchment area of the Tisza River, almost identically represented by six administrative counties. Each county, commonly covering 34,000 km^2, is characterised by high percentage (70-80 %) of managed vegetation. Effects of area coverage variations between the different plants are computed for the period 1951-1993 by applying results of a literature-based syntheses, specified for Hungary. The latter studies estimate surface-albedo values and proportion between real and potential evapotranspiration for the great majority of the plants grown in the region. Potential evapotranspiration and relative soil moisture content are estimated from the monthly meteorological series of temperature, precipitation and atmospheric water vapour pressure. Product of these plant-specific characteristics and the relative area coverage yield in monthly series of surface albedo and real evapotranspiration. Furthermore, these values are related to the energy balance of the surface-atmosphere system by using a radiative-convective model adjusted for the given location. Two questions are investigated:

i) Are there monotonous trends in the given terms of the energy and water budget ?
ii) Are these changes comparable to the effects caused by other external forcings ?

Our computations give positive answer to both questions.

1. Introduction

It is certified by measurements that greenhouse effect is strengthening more and more all over the world. Intensity of the greenhouse effect is determined by virtual decrease of the outgoing long-wave radiation leaving the Earth's atmosphere. (This decrease is virtual, since it is compensated by the increase of the temperature.)

Since the 19th century, the atmospheric CO_2 has been responsible for 1.5 Wm^{-2} primary radiation change, methane for 0.55 Wm^{-2}, N_2O for 0.2 Wm^{-2} and CFC gases, together for 0.3 Wm^{-2}, respectively *(IPCC, 1996)*. Consequently, total radiation growth is 2.55 Wm^{-2} which, as medium estimation, is equivalent to 1.5 °C global temperature increase. However, recently it is shown only about 0.7 °C warming. The difference is explained by the decrease of ozone in the stratosphere (-0.2 Wm^{-2}) and the opposite effect caused by tropospheric aerosols (-1 – -2 Wm^{-2}); furthermore, by the important fact that only 47-83 % of the equilibrium warming occurs synchronously with concentrations *(IPCC, 1996, Table 6.3)*, because of enormous heat capacity of the oceans

Sunshine radiation absorbed by the Earth-atmosphere system is about 240 Wm^{-2}. The greenhouse effect is expected to add about 6 Wm^{-2} by the middle of the 21st century (*IPCC, 1996)*. Consequently, recent and future climate change forcing considerations are based on calculations originating from 1 % change of the energy balance. This is a very little number compared either to measuring accuracy of most environmental physical parameters, or to relative error of model calculations. Hence, it is worth studying various external factors and feedback mechanisms which, in addition to greenhouse gases and aerosols, might influence climate. This idea is manifested in recent publications *(CLIVAR, 1998)*.

One set of the possible feedbacks can be focused by vegetation. Role of plant cover has already been mentioned in the literature since the 1970's, when two possible ways of surface modification, namely overgrazing in the subtropics and devas-tation of rain forests were counted to be potential causes of the global climate change *(Charney et al., 1977; Sagan et al, 1979)*. Both changes express their effect on climate through the light-reflecting capacity of the surface, i.e. its *albedo*.

The Sahel problem occurs in more recent *models (Xue and Shukla, 1993)* and possibility of vegetation feedbacks on paleoclimatic events are also considered *(de Noblet et al, 1996; Texier et al., 1997)*. Physical submodel of mosaic *vegetation (Claussen, 1994)* are incorporated in some GCMs and there are small scale 1 D modelling efforts *(Clark et al., 1995)*, too. Besides physical effects on albedo, evaporation and surface roughness, chemical interactions are also under study *(Foley et al., 1996)*.

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A likely biological feedback was found in two steps for Hungary. *Mika (1988)* established statistically that during the last 100 years, the 0.5 K hemispheric warming had been accompanied with 0.5-0.8 K temperature increase, 7-14 percent decrease of precipitation, 20 percent increase of sunshine duration in the summer half-year. These changes correspond to ca. 60 % increase in frequency of dry months (i.e. soil moisture content < 30 % of field capacity) and to 8-10 % increase of global radiation at the surface.

In relation to these local changes, three possible feedback mechanisms, connected to surface albedo modifications, were quantified. These are the longer vegetation period, the less precipitation and the adequate alterations in the managed vegetation, all induce increase of the surface albedo. Characteristic albedo values are taken from an independent climatological synthesis of local albedo measurements *(Dávid, 1985)*. In a study *(Mika et al., 1992)*, the sum of these feedbacks was assessed to be -0.7 Wm^{-2} presuming changes in vegetation cover due to regional consequences of 0.5 K global warming in Hungary. This value is comparable to the radiative forcing of 100 ppm CO_2 increase.

The *present study* is aimed to analyse the effects of registrated changes in the managed vegetation on evapotranspiration and surface albedo. *Sect. 2* describes the methods of computation for evapotranspiration, surface albedo and short-wave radiation balance of the earth-atmosphere system perturbed by changes of vegetation. *Sect. 3* introduces the investigated region in East-Hungary and the experienced changes of vegetation during the 1951-1993 period. *Sect. 4* presents the results of computed changes in the physical parameters described in Sect. 2, also those in comparison with changes hypothetically caused by other factors. Limitations of these computations, in respect to general comparison of these regional processes to the regional effects of the global ones, are discussed in *Sect. 5.*

2. Estimation of evapotranspiration and albedo

2.1 Evapotranspiration

Evapotranspiration of natural surfaces can not be measured directly; it should be assessed by calculation, first step of which is to determine the potential evapotranspiration, ET_p:. This is the maximum evapotranspiration limited only by the actual meteorological conditions. In certain circumstances, ET_p equals to evaporation of the free water surface.

In natural circumstances evapotranspiration is influenced also by available water capacity of the soil and by transpiration capacity of plants. In our computations, the former effect is expressed by the *relative soil moisture, w,* which is the ratio of actual soil moisture content and field capacity, i.e. the water of the upper soil layers, available for plants.

Transpiration by plants is determined by the growing season and individual state of plants, which is considered by the *biological constant, B,* which is generally less than 1.

Table 1. shows monthly values of the biological constant for some frequent agricultural plants *(Antal, 1968).*

Table 1. Monthly average values of the *B* biological constant for the most frequent agricultural plants in Hungary (after *Antal, 1968*)

	April	May	June	July	Aug.	Sept.	Oct.
maize	0.00	0.06	0.31	0.89	0.69	0.17	0
potato	0.02	0.17	0.74	0.90	0.48	0.08	0
sugar beet	0.03	0.16	0.61	0.94	0.59	0.24	0.06
alfalfa	0.32	0.60	0.74	0.86	0.80	0.65	0.33
red clover	0.48	0.67	0.87	0.83	0.88	0.65	0.29
wheat	0.38	0.87	0.92	0.28			
barley	0.31	0.62	0.93	0.50			
oat	0.04	0.38	0.86	0.47			
pea	0.10	0.54	0.48				

These factors of evapotranspiration, from a plant-covered surface, *ET,* are connected by the formula *(Antal, 1968)*:

$$ET = \frac{w+B}{1+B} \cdot w \cdot ET_p \ , \qquad (1)$$

where w is the relative soil moisture, B the biological constant and ET_p: the potential evapotranspiration (mm).

Actually our calculations of evapotranspiration are performed by using five-days averages, applying biological constants determined by *Posza and Stollár (1983)* in a way similar to that followed by *Antal (1968)*. The *B* plant constants were evaluated for 19 species by field experiments performed at the Agrometeorological Observatories since the late sixties in Hungary, by using Thornthwaite type compensation lysimeter *(Posza and Stollár, 1983)*.

For w the soil moisture data of *Dunkel (1994)* are used, which are based on monthly surface water balance computations, considering actual precipitation, temperature and vapour pressure. For the calculation of potential evaporation, the empirical regression determined by Antal (1968):

$$ET_p\text{:} = a \cdot [e_s(1-r)]^b \cdot (1 + A \cdot t)^c \qquad (2)$$

was used, where a, b c and A are empirical constants, e_s saturation water vapour pressure, r relative humidity, t mean air temperature.

In the followings, sums of evapotranspiration are calculated from long-term of climatic averages of ET_p and w in order to isolate effects of land-use changes on evapotranspiration. Historical variations of these values, driven by the meteorological anomalies, are introduced only for comparison in Sect. 4.1.

2.2 Surface albedo

Surface albedo is influenced by the type and state of soils, species of plant cover and its growing phase. In the course of preparing albedo-maps of Hungary, *Dávid (1985)* synthesised surface albedo values of special literature, established according to plants and growing phases. Territory of Hungary can be divided to some plant-specific regions, according to the temporal differences of growing phases. Dávid established climatologically specific surface albedos for these regions and groups of plants in ten days' resolution. Average monthly surface albedo of plants, most frequently raised in Hungary, are listed in *Table 2.*

Table 2. Average surface albedo of some plants (after Dávid, 1985)

Region	Surface albedo, %						
	Apr.	May	June	July	Aug.	Sept.	Oct.
				wheat			
1.	18	20	33	23	21		
2.	18	20	21	23	21		
				barley			
1.	17	20	21	23	21		
2.	17	19	21	23	21		
				rye			
1.	18	20	21	23	20		
2.	18	19	21	23	20		
				maize			
1.		15	18	23	23	24	25
2.		15	17	20	23	23	25
				alfalfa			
1. & 2.	23	20	23	22	23	23	19
				potato			
1.	15	19	24	20	18	19	
2.	15	18	22	23	19	19	
				sugar beet			
1.	14	15	19	19	21	22	22
2.		14	18	19	20	22	22
				lawn (meadow, pasture lands)			
1. & 2.	17	19	20	20	19	20	19
				forests (in leaf and conifers)			
1. & 2.				14			

In Table 2., Region 1 indicates southern part of East-Hungary, while Region 2 relates to its northern part, differing in average thermal and hydrological characteristics.

2.3 Radiation balance of the earth-atmosphere system

Change of energy balance, caused by the land use, was determined not only at the surface but to the surface-atmosphere system, as well. This makes possible to compare energy changes due to surface modification with primary energetic effects of CO_2-concentration or aerosols, estimation of which is more reliable at the top of the atmosphere.

For this aim, results of a former calculation *(Mika et al., 1993),* made by the help of a radiative-convective model *(Práger and Kovács, 1988),* adapted from the Main Geophysical Observatory, St. Petersburg *(Karol and Frolkis, 1984),* was used, by freezing its convective adjustment and other feedback mechanisms to simulate the primary changes in the radiative heating. The model is a horizontally averaged one with 16 levels of computation from 1000 hPa at the surface to 0.64 hPa at about 60 km from the surface. Step between the levels is 100 hPa in the troposphere.

Broadband approximation, based on empirical transmission functions, is applied for 24 and 17 spectral intervals in the short- and long-wave parts of the spectrum, respectively. Long-wave transmission functions are adapted from *Rozanov et al. (1981).* The δ-Eddington method is used for parallel calculations of absorption and scattering. Optical thickness is calculated by the Curtis-Godson approximation.

Internal parameters and astronomical conditions of the model are set for Budapest (47° 26' N 19° 17' E). Cloud amount of the different layers are taken from *Warren et al. (1985),* after normalising to local climatology. Low- and medium-level clouds are considered as blackbodies for long-wave radiation. High-level cloudiness is simulated by 0.5 emissivity coefficient. Aerosol optical profile is adapted from *WMO (1983)* considering "continental background" aerosol.

By this model we determined how surface albedo changes affect the short-wave energy balance, of the surface-atmosphere system, R_s. Connection of this term and system albedo, α_s is:

$$\Delta R_s = -G_0 \cdot \Delta\alpha_s , \tag{3}$$

where G_0 is sunshine radiation at the top of the atmosphere.

Dependence of the system albedo on α surface albedo is, with high accuracy, linear *(Mika et al., 1992)* from which:

$$\Delta\alpha_s = k \cdot \Delta\alpha . \tag{4}$$

Unit change of surface albedo involves k = 0.40 - 0.45 change of system albedo in the examined seven months. Damped changes appearing at the outer boundary of the atmosphere can mainly be explained by the existence of cloudiness and limited transparency of the atmosphere. The higher coefficients characterise the summer period, when cloudiness is less and the optical length is shorter.

3. Land use in the East-Hungarian region

3.1 The selected region

The region, selected for the investigation, is the Hungarian plain-water catchment area of the Tisza River *(Fig. 1),* for which there was previously made a regional energy- and water balance model, as well *(Mika et al., 1991; 1998).*

In the followings, this region will be represented by six administrative counties, called Borsod-Abaúj-Zemplén, Szabolcs-Szatmár-Bereg, Hajdú-Bihar, Jász-Nagykun-Szolnok, Békés and Csongrád, considering the fact that land use data are officially published county by county.

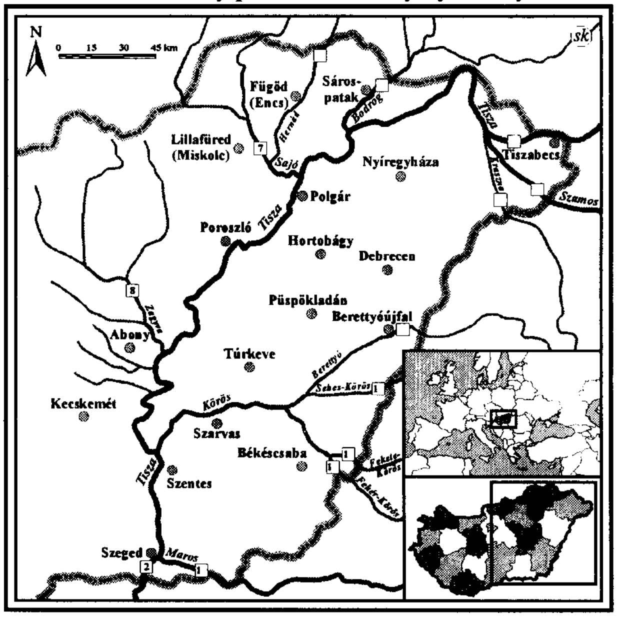

Fig. 1. The Tisza River sub-catchment in East-Hungary and the administrative counties, six of which approximately cover this region (34,000 sq. km)

Natural vegetation of the Hungarian Plain represents the westernmost extension of this forest-steppe zone in Europe. In the forest-steppe vegetation of the country, the forest cover decreases with increasing aridity from north-west to south-east *(Kovács-Láng et al., 2000)*. This large landscape has always been characterised by high proportionality of managed vegetation. Recently, 74 % of the total administrative area (34,000 km^2) is cultivated. Hence, the investigated region is likely vulnerable to climate variations and, also, to non-climatic conditions of plant management.

3.2 Land use series

In this chapter it is briefly shown, how sown area of the different plants developed in six examined counties according to the data in the annual reference books of the *Central Statistical Office (1951-1993)*, and from *Historical Statistical Contributions (1971-79)*. The relative share of various plants was determined for the period 1951-1993.

Total share of agricultural plants, considered, is the least in Hajdú-Bihar county (0.71) and the highest is in Csongrád and Jász-Nagykun-Szolnok counties (0.80). Altogether 74 % of the total 34,000 km^2 belong to the area of examination.

The plants are also arranged into five groups, for easier interpretation, but original plants are used in the computations:
- *cereals* - wheat, rye, barley and rice;
- *fodder-plants* - maize, alfalfa, red clover, maize for silage, oat and cattle-turnip;
- *food and industrial plants* - sugar beet, tobacco, sunflower, potato and fibre hemp;
- *vineyard and fruits*;
- and *other*: forest and lawn.

Area of agricultural land use shows clear, decreasing trend in the examined region *(Fig. 2)*. In computation of area average evapotranspiration and albedo, however, variations of the total sown area are not considered, since the area-weighted sums will be normalised by this area, i.e. by the sum of the weights. On the other hand, possible variations at the set-aside areas are not included into our estimations.

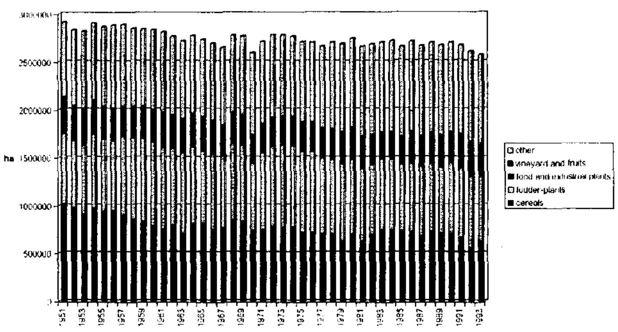

Fig. 2. Total sown area of the plant groups in the examined six counties 1951-1993. (in hectares, 1 ha = 0.01 sq. km)

4. Results and comparisons

4.1 Evapotranspiration

Change of land use between 1951 and 1993 increased evapotranspiration clearly *(Fig. 3.)*. Linear trend of the change was 0.18 mmyr^{-1}, which means an average increase of 8 mm, considering the total examined period (43 years). The connection is very close with 0.81 correlation coefficient. However, the mentioned average increase of 8 mm does not mean dramatic change, since average evapotranspiration of the examined 7 months (April-October) is about 280 mm; that is to say, relative change is only 3 %.

On the basis of the above-mentioned formula, total fluctuation of evapotranspiration influenced by fluctuations of meteorological conditions was counted for the examined period between 1951 and 1993 *(Fig. 4.)*. It could be seen, that inter-annual fluctuation of the total evapotranspiration exceeded effect of land use by one order of magnitude. At the same time, there were no any one-way trends observed in the total evapotranspiration data sets.

Summarising our results on evapotranspiration, it can be said that change of land use caused clear but little changes in the East-Hungarian region.

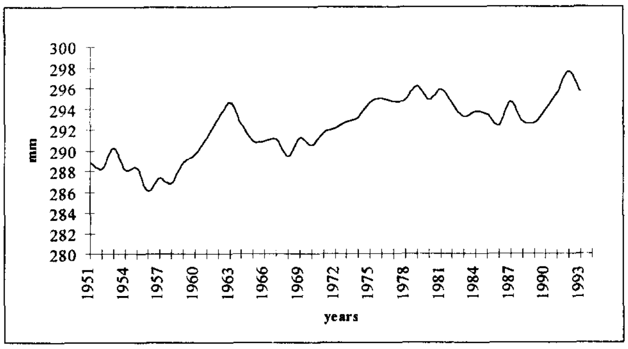

Fig. 3. Effect of changes in land use to evapotranspiration (mm / 7 months).

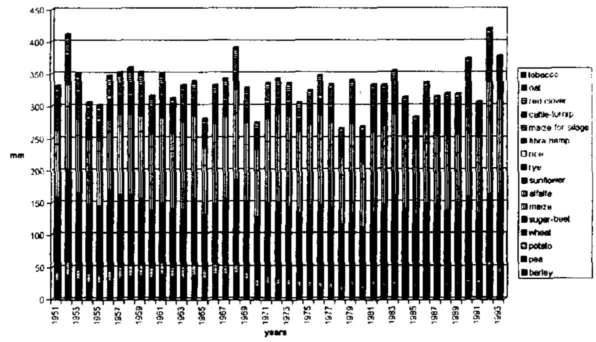

Fig. 4. Estimated evapotranspiration due to simultaneous fluctuation of meteorological factors and land use variations in average of the cultivated area.

4.2 Surface albedo

Surface albedos multiplied with the yearly sown areas of each plant, give time series of albedo changes caused by changes in land use *(Fig. 5.)*. The total average surface albedos of the six counties show decreasing tendency in each month from April till July, separately. In other words, share of relatively darker plant stocks increased with larger green mass, giving thicker cover. The situation in August is the same, whereas no clear change can be established in the two following months. Probably, this is in connection with the fact that plants, however they are present in September-October in the major part of the territory, have no longer developed; and, because of this, they differ little from each other.

As it is assumed from the monthly decrease of albedos, regional averages of the surface energy balance increased steadily in the examined term. Trend of the change was +0.014 $Wm^{-2}yr^{-1}$; that is to say, 0.6 Wm^{-2} as a total during the examined 43 years period. The linear trend fits fairly tightly to the data set, since value of the correlation coefficient is 0.98.

4.3 System albedo in comparison with other effects

If monthly values of the system albedo are multiplied by astronomically maximum sunshine radiation, coming to the outer boundary of the atmosphere, then short wave energy balance of the surface-atmosphere system is received.

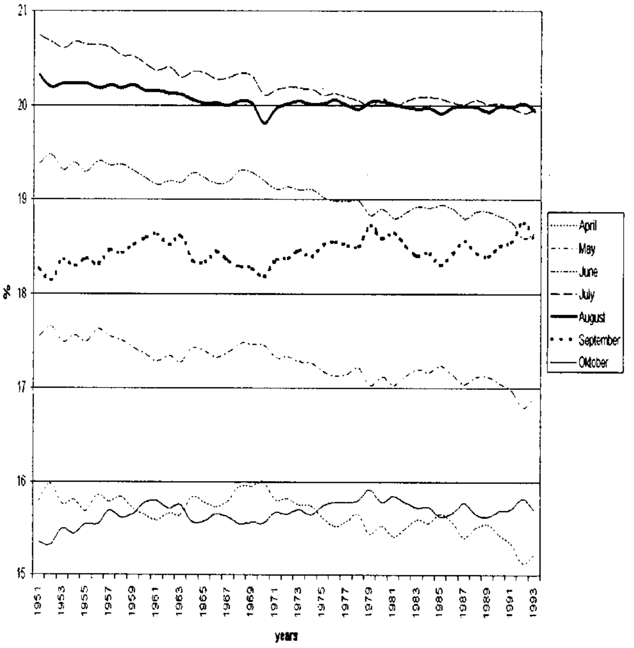

Fig. 5. Effect of changes in land use to surface albedo from April to October in 1951-1993.

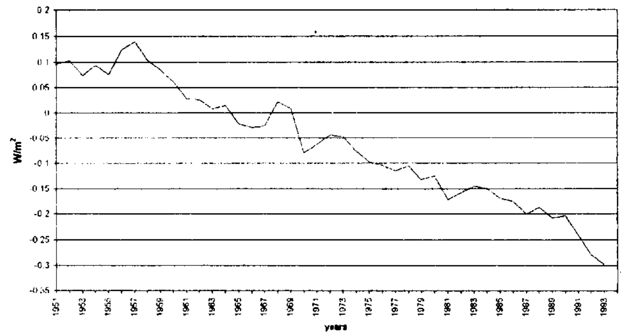

Fig. 6. Effect of changes in land use to short wave energy reflected by the surface-atmosphere system in the average of the six examined counties and the seven months, compared to the average of the period 1951-1980.

Energy surplus which remains in the system, because of the decrease of radiation energy reflected by the surface-atmosphere system *(Fig. 6.)*, is +0.009 $Wm^{-2}yr^{-1}$; namely, 0.4 Wm^{-2} as a total, during the examined 43 years.

In order to demonstrate the importance of this value, it should be noted that global atmospheric CO_2-concentration has only shown 1.5 Wm^{-2} virtual increase per year since the industrial revolution. If the effect of concentration changes (from 310 to 357 ppm) is calculated by using the simplified zero-dimensional global model, parameterised from the experiments of recent *(IPCC, 1996; p. 298, Table 6.3)* GCMs *(Mika, 1998)* a far less change is received: +0.9 Wm^{-2}.

Change of albedo becomes more important, if it is considered that the same change of CO_2-concentration, in relation to the average global long wave energy balance per year, has somewhat less effect in the summer in Hungary.

The ratio, established by using the above radiative-convective model, is about 77 %; namely, the effect of change in CO_2-concentration in Hungary during the examined 43 years period was only + 0.7 Wm^{-2}. Consequently, changes of land use between 1951 and 1993 caused more than half as much change in the energy balance of the surface-atmosphere system, than those of CO_2-concentration.

It is worth to calculate, how much is the effect of the 8 mm increase of evapotranspiration to heat release from the surface. Considering the fact, that evapotranspiration of 1 kg water needs 2,470 J energy, and the total 214 days of the examined seven months correspond to 18,489,600 seconds, this 8 mm evapotranspiration surplus deprives exactly 1 Wm^{-2} energy of the energy balance of the surface. This value is of similar magnitude with that of change of CO_2-concentration, detected during the examined 43 years period. Nevertheless, energy surplus used to evapotranspiration expresses only a minor contribution to modification of temperature at the different altitudes.

5. Discussion

The above-mentioned calculations determined effect of changes in land use to evapotranspiration and albedo. These computations mixed fairly exact, in situ data on land use with generalised average physical parameters on albedo and biological constant of vegetation.

This might arise the question whether or not the latter errors of estimation can influence the final conclusions, based on small differences of albedo and evapotranspiration. Although, it is rather difficult to quantify this effect, one may note that all annual values came from weighted averages of 20-25 different plants and, also, that the parallel response of vegetation is plausible: the more heat income is compensated by enhanced evapotranspiration.

These effects of land use were compared to the components of the energy and water balance. According to these comparisons, it could be established that, for the region of East-Hungary (34,000 km^2), changes due to land use were of the same magnitude with those of energy and water balance occurred in relation to the global climate change.

However, the question: whether or not changes in land use could produce that of regional climate (temperature, precipitation, etc.) with similar magnitude, could not be answered. To this, temporal change of land use should be known for a much larger region, as climate of Hungary is function of the energy- and water balance of a far larger area (this connection is less tight if the territory increases).

That is to say, heat- and water balance strongly depend on horizontal transport of temperature and water vapour. Intensity of this procedure is, at first approach, directed by horizontal (spatial) differences of these two elements (temperature and water vapour). For this reason, if temporal change of the balances can be detected only at us, and not in the neighbouring regions, then this change is spread by the horizontal exchange on a well larger area.

In other words, the above result according to which changes of land use in East-Hungary in the last decades increased surface energy balance considerably but decreased water supply can be utilised if, together with similar examinations of the neighbouring countries, it might be built in a regional climate model.

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