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The influence of land use change on transport of water and energy in ecosystem and climate change

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Increasing population led to the increasing demand to food, raw materials, water and energy, followed by the increasing intensification of land use, and increasing industrial and agricultural production. This led to fossil fuels combustion and related carbon dioxide emissions, to building of structures impermeable to water as industrial infrastructure, transport facilities and dwelling structures, which basically change land properties, structure of water and energy fluxes of biosphere, and to climate change of the Earth. The aim of this paper is to quantify the influence of modified evaporating surfaces by land use changes on water and energy fluxes in modified ecosystems. The influence of land use changes on energy fluxes in the boundary layer of atmosphere is compared to the influence of carbon dioxide concentration increase. It was demonstrated that the contribution of land use changes can be more significant than the influence of carbon dioxide emissions on atmosphere boundary layer temperature.

KEY WORDS: ecosystem, land use changes, carbon dioxide emission, global warming, climate change

Introduction

Natural reasons of climate change

Climate of the Earth was changed continuously. In the past, the climate changed mostly by natural, or non-anthropogenic reasons. The ice age ended approximately ten thousand years ago; medieval warm period (9–13 century) was followed by the so called „little ice age“ (14–19 century). Those climate changes were relatively slow. It is not known exactly, what was the reason of such changes, but it was a mixture of natural reasons, like Milankovich cycles (Milankovich, 1930), volcanic activity (Kirchner et al., 1999), or collision of the Earth with extraterrestrial body. Actually observed climate changes are predominantly due to human activity, because in the last centuries there were not observed significant changes of solar activity, nor changes of our planetary system orbits. Therefore, actually observed climate changes are mostly due to anthropogenic reasons (Balek, 2006; Nemešová, 2007; Kutílek and Nielsen, 2010; Novák, 2021; Kučera, 2021).

Anthropogenic reasons of climate change

Scientific literature devoted to climate change and their reasons is prioritizing the influence of carbon dioxide concentration increase (and other so called „greenhouse gases“) in an atmosphere and its contribution to the long wave radiation to the boundary layer of atmosphere, which is increasing its temperature. It is understood, that increasing concentration of carbon dioxide in an atmosphere (in year 2021 up to 410 ppm) and backward long wave radiation emitted by carbon dioxide molecules can contribute to the surface temperature increase and to the change of the heat balance structure. But, this phenomenon is only one of many reasons of the Earth surface temperature increasing (Novák, 2021).
To preserve conditions suitable for life on the Earth, it is necessary to eliminate, or mitigate rapid change of climate. The necessary precondition of such activity is identification and quantification of the most important reasons of climate change. Greenhouse effect of an atmosphere due to increasing concentration of the so called „greenhouse“ gases, like carbon dioxide, water vapour and methane, is an important reason of climate change. But, to the climate change are significantly contributing the land - use changes. Mankind, trying to manage suitable conditions to preserve their existence on the Earth, is increasing agricultural and industrial production leading to increasing demand for water, raw materials, food and energy. A result of this activity, is the increase in agricultural land area (mostly arable land), as well as areas covered by dwelling facilities, industrial and transportation infrastructure. Such surfaces are impermeable (to water) surfaces. Precipitation impacting such surfaces are rapidly flowing out, not infiltrating into the soil, and consequently not evapotranspirating and not

consuming latent heat to change the liquid to vapour phase. This is leading to the additional heating of boundary layer of an atmosphere and increasing its temperature. Well known are the so called „heat islands“, as areas of higher air temperatures in and around big cities; the differences between air temperatures in the city and those temperatures above the natural surfaces are some degrees of Celsius.

Increasing population of the Earth

Increasing population itself is not the direct reason of global changes. But pressure on consumption of water, raw materials, food and energy is increasing pressure on land use exploitation efficiency. Such a rapid increase of inhabitants number of the Earth leads to land use changes. People are changing the properties of land and thus changing the structure of water and energy fluxes in the boundary layer of an atmosphere. The question is, how many people could be supplied by the available Earth resources.

In the year 2022 number of people on the Earth reached 8×10^9. It is assumed that in the year 2050 on the Earth will be living 10×10^9, and in the year 2100, we can reach 10.9×10^9 inhabitants (The European state and outlook, 2015). It is assumed that 2000 years ago on the Earth lived about 1.8×10^8 people, in the year 1820, it was 1×10^9 and 110 years later (1930) on the Earth lived 2×10^9 inhabitants. Since then, during the 90 years the gain of population of the Earth was 6×10^9. Approximately, 6×10^9 live in Asia and Africa. Currently, population explosion in Africa is generating gain higher than 3%, i.e. 50 million annually. It is assumed, that in Subsaharan Africa and in some countries of Asia will be living more than 75% inhabitants of the Earth. Subsaharan Africa and some states of Asia (known as developing countries) with low GDP will be faced to the increasing pressure to food production as well as to raw materials and energy. The lack of water, food, arable land and fertilizers as well as lack of resources needed to agriculture intensification in such countries is one of the main reason of massive emigration, mostly to the Europe.

The influence of carbon dioxide concentration on the energy fluxes in the boundary layer of atmosphere

The role of carbon dioxide as a „greenhouse gas“ was early understood, but the problem was to quantify the influence of this phenomenon on long – wave energy fluxes (Novák, 2021). A few years ago, there were published results of long – term measurements to estimate long wave energy fluxes emitting by the molecules of carbon dioxide back to the surface (Feldmann et al., 2015). From results of numerous measurements in Oklahoma and Alaska during the decade 2000–2010 was estimated that the contribution of the long wave energy flux due to increasing carbon dioxide concentration is 0.02 Wm^{-2} per year. Since the beginning of the „industrial revolution“ the contribution of the carbon dioxide on the back flux of long wave radiation was estimated by 1.82 Wm^{-2}. Is this significant value contributing to the climate change? The average income of solar energy by the Earth surface is 350 Wm^{-2}. To find an answer, it is necessary to compare this value to the extra fluxes of energy due to land use change.

Earth surface structure and its properties

The planet Earth surface area is 520×10^6 km^2, dry land surface is less than one third of Earth surface area (149×10^6 km^2). Arable land surface is less than 12% of land, (19.8×10^6 km^2), and represents ecosystem, which is the main source of food for mankind, Interestingly, the area of deserts over the Earth is (19.85×10^6 km^2), which is close to the area of arable land. Even more interesting is that dryland glaciers are covering approximately the same area (15.7×10^6 km^2) as arable land, or deserts. The basic area is covered by forests (60×10^6 km^2), which represents 38% of dryland area (Rejmers, 1985). Tre rest of the land is covered by steppes and savannas, by vegetationless areas in the Arctic, dwelling infrastructure, industrial areas, water bodies and impermeable surfaces, like buildings and communications. To preserve existing ecosystems temperature regime, it is important to use the maximum part of the incoming solar energy, by evapotranspiration. Energy, not used for evapotranspiration is heating boundary layer of an atmosphere, and dryland surface and thus increasing its temperature.

Key role in stabilizing of ecosystem temperature play water surfaces (seas and oceans), because they cover more than 70% of Earths surface, and for evapotranspiration are utilizing about 90% of incoming solar energy. Tropical (rain) forests (RF) have similar consumption structure of solar energy to evapotranspiration, i.e. they can consume up to 90% of incoming solar energy (Shuttleworth, 1988), and therefore is the role of RF in the formation of climate so important. Another important factor is, that continents are mostly located north of equator (Europe, Asia, Africa, and North America) and south of equator (South America, Australia), therefore, water surfaces with the highest income of solar energy and with highest evaporation rates are mostly located between the tropics and thus contributing to decrease air (and water) temperature. If the trend of increasing air temperature will be preserved, it could lead to the glaciers thawing and to increase of the water surfaces area. Hypothetically, from the increased sea surfaces due to thawing, it can be expected evaporation increasing and cooling of an environment. The autoregulation could work and evaporation can decrease. The higher evaporation is, the higher can be cooling effect due to this phenomenon. Properties of water surface are not changing, but land surfaces are changing significantly. Therefore, it is important to quantify land use changes and their influence on climate and its change.

To minimize the temperature of the boundary layer of atmosphere, it is necessary to maximize energy consumption. It means, to create conditions for maximum evapotranspiration. Process of evapotranspiration consumes basic part of solar energy reaching the Earth surface, due to extremely high latent heat of evaporation ($L=2.5\times10^6$ J kg^{-1}). Evapotranspiration from land consumes about 51% of net radiation (energy reaching land surface), evaporation from seas and oceans consumes more than 82% of net radiation reaching the water surface (Budyko, 1974). Results of measurements showed (Shuttleworth, 1988), the ratio of consumed energy by evapotranspiration to the incoming one in rain forests (RF) and in tropical seas approximately equals, is up to 0.9.

An attempt to quantify the influence of land use changes on transport of water and energy

The basic problem to quantify the influence of different surfaces and their changes on transport of water and energy in the soil – plant – atmosphere continuum (SPAC) is lack of information, characterizing different surfaces. Satellite photographies can give detailed information about the objects and their distribution in ecosystem, but to estimate quantitative information about evaporation surfaces and their changes is not easy even by ground measurements. To quantify the influence of land use changes on water and energy fluxes, it is necessary to evaluate their quantitative characteristics, like temperature, albedo, leaf area index (LAI), wind velocity, soil properties and meteorological characteristics of the area. Because such information are not available, scientists are trying to use qualified estimates and use methods of quantifications with minimum input data. In this paper an attempt is made to evaluate the influence of land surface and their changes on energy fluxes in the boundary layer of an atmosphere and compare those changes with known changes of energy fluxes by emissions of carbon dioxide.
The most important water and energy fluxes change in the boundary layer of an atmosphere are changes of surfaces in subtropical and tropical areas, because sums of precipitations as well as solar radiation are maximum here, and can significantly modify water and energy fluxes of the Earth. Therefore, to quantify the influence of changed evaporation surfaces on energy fluxes, effort will be focused on decreasing area of rain forests (RF), progressive desertification in sub Sahara region (SH) and on the increasing area of impermeable surfaces (IA, buildings, communications), which are products of mankind.

Decreasing area of rain forests

The area of rain forests (RF) of the Earth is estimated as 15×10^6 km^2, it covers approximately one tenth of dryland area. During the last 21 years, the area of RF was decreased by clearing approximately about 2.6×10^6 km^2 (Global Forest Rev., 2021). Realistic average annual clearing area of RF is 100,000 km^2. Annual evapotranspiration total of RF was estimated by 2700 mm (90% of total annual precipitations). It is assumed, that clearing will decrease evapotranspiration approximately to one half, i.e. to ΔE = 1350 mm per year. Incoming solar radiation, not consumed by evapotranspiration (and therefore „saved“) and heating the environment is $L\times\Delta E = 4.81\times10^9$ J m^2 year^{-1}, (latent heat of water evaporation is $L= 2.5\times10^6$ J kg^{-1}). The average heat flux due to unused energy for evapotranspiration per year (R_s) can be calculated by dividing $L\times\Delta E$ by number of seconds per year ($t = 3.153\times10^7$s); then, $R_s = 1.070\times10^2$ Wm^{-2}, or $R_s = 107$ Wm^{-2}. If this „saved“ energy flux will be regularly distributed across the Earth surface (assuming the homogeneous distribution due to global circulation), then $R_g = 0.0206$ Wm^{-2}. This value (R_g) is the average flux of energy not consumed by evapotranspiration, but heating the environment as a result of clearing of 100,000 km^2 rain forests annually.
The change of land properties, due to RF area decrease is influencing climate globally, but the main effect can be observed locally, i.e. on the area where RF was cleared. The surface soil layer properties change will lead to the surface temperature increase as a result of different plant canopies and other surface, increasing albedo and decreasing of surface roughness. It was estimated decrease of precipitation during the vegetation period by 16–24% depending on properties of changed evaporation surface (pastures, soy). The process of soil devastation, mainly due to cattle breeding is accelerating too (Sampaio, et al., 2007, Kenderessy, 2022).

Desertification of sub Sahara region

The increasing area of Earth´s deserts is reality. Results of measurements showed that the south boundary of Sahara desert moved southwards about 250 kilometers during the last 100 years and desert area increased by 1.62×10^6 km^2. At Sahara desert there were found old anchors (Balek, 2006), so the desert did not always cover this area, but the process of desertification was lasting hundreds of years. It is known from history, that north Africa was important source of food for Roman Empire.
The aim of this chapter is to evaluate the Sahara desert area increasing and its influence on energy fluxes in this area and its contribution to climate change. One hundred years ago, the desert area was smaller at about 1.62×10^6 km^2, and this area was covered by savanna. According to Palmer et. al., (2015), the average annual evapotranspiration total of savanna is $E_s = 379$ mm year^{-1}. After savanna desertification, it is assumed the decrease of average annual evapotranspiration approximately to one half, i.e. $E_d = 200$ mm year^{-1}. Corresponding energy flux decrease needed for evapotranspiration is $R_d = 5.2\times10^8$ J m^{-2} year^{-1} and the average flux of energy not used as latent heat of evaporation (which can heat boundary layer of an atmosphere) of deserted area was calculated by dividing R_d by number of seconds per year (t); resulting value is $R = 16.5$ Wm^{-1}. Sum of energy not consumed by evapotranspiration (because evapotranspiration was decreased by desertification of savanna) is 26.73×10^6 MW. It was calculated by multiplication of energy flux R by the area of „desertificated“ savanna. Assuming homogeneous distribution of the energy, „saved“ by lower evapotranspiration, the resulting value of energy flux is $R_g = 5.24\times10^{-2}$ Wm^{-2}.

Impermeable surfaces

Impermeable surfaces, are covering the surface of dryland with an increasing speed. Their properties are quite different than permeable (to water) or covered by vegetation. Precipitation falling on the impermeable surfaces basically outflows, only small part of it covers impermeable surfaces by thin layer of water, which evaporates quickly. It means, that basic part of energy reaching such impermeable surface is not used as latent heat of evaporation, but will be heating impermeable surface and adjoining layer of atmosphere. Impermeable surfaces (roofs, asphalt) are usually dark with low albedo, which means high ratio of solar energy absorption (Brutsaert, 1982; Novák, 2012).

To make it more difficult, there are not known shares of impermeable surfaces on total dryland area of the Earth and their shares in particular continent. According to serious estimates based on satellite information, in industrial states of Europe, the share of impermeable surfaces area on total surfaces area is about 5 percent. The same situation can be observed even in Slovakia. According to data of UN up to 0.6 of Earth´s area is disturbed by mankind activity. There are not known quantitative data, therefore it is difficult to use them to calculate its influence on climate change. Globally, it can be assumed the impermeable surfaces (A_i) share is about one percent of dryland area (A_s); ($A_i = 0.01\ A_s$). Using this assumption, we shall try to quantify the influence of impermeable surfaces on energy (and water) flux in ecosystem.

Dryland surface area is $A_s = 149{\times}10^6$ km^2; one percent of it is $A_i = 0.01A_s = 1.49{\times}10^6$ km^2, or $1.49{\times}10^{12}$ m^2. To calculate the influence of one percent impermeable surface of the Earth on evaporation change, the average annual evapotranspiration total from the dryland surface should be known. According to Babkin (1984), average dryland evapotranspiration total per year is 71,000 km^3, or $E_s = 7.1{\times}10^{13}$ m^3. The average evapotranspiration total per year and unit surface area can be evaluated by dividing it by dryland area, so E_s = 475 mm year^{-1}; (E_s = 475 kg m^{-2} year^{-1}). Assuming decrease of evaporation from the impermeable surfaces in comparison to the permeable one to one half, (expressed by water layer height) E_s = 240 mm year^{-1}, or in weight units (E_s = 240 kg m^{-2} year^{-1}), then, the total decrease of evaporation from impermeable layers is $\Delta E_s = 3.57{\times}10^{14}$ kg year^{-1}.

The average energy flux not used by evapotranspiration ΔR_{se} is calculated by multiplication of „saved“ annual sum of evapotranspiration (ΔE_s) by latent heat of evaporation (L), and by its dividing by number of seconds per year (t). Then $\Delta R_{se} = (\Delta E_s \times L) / t$, and $\Delta R_{se} = 2.94{\times}10^{13}$ W.

The maximum additional energy flux „saved“ by decreasing evapotranspiration from impermeable surfaces which can heat boundary layer of an atmosphere corresponds to the situation when it is heating the area of impermeable surfaces only. This is maximum contribution to the boundary layer temperature increase. This energy flux ΔR_{si} can be calculated by dividing ΔR_{se} by impermeable surface area $A_i = 0.01A_s$, $\Delta R_{si} = \Delta R_{se} / \mathrm{A_i}$ = 19.73 W m^{-2}.

The average „saved“ energy flux (or energy not used for evapotranspiration) divided by the Earth surface area (A_g), is $\Delta R_{si} / A_g$ = 0.0565 W m^{-2}. The realistic value of additional energy which can contribute to the heating of the boundary layer of an atmosphere ΔR could vary within the range 0.0565 W m^{-2} $\leq \Delta R \leq$ 19.73 W m^{-2}.

Comparison of the land use changes and carbon dioxide on energy fluxes in SPAC

In the previous part of this study, an attempt was made to quantify the influence of land use changes (represented by different surfaces) on energy fluxes in the boundary layer of an atmosphere. Analysis was concentrated on such types of land use changes, which are significantly modifying the energy fluxes of the Earth globally and contributing to climate change. The most important changes of the surface types are rain forests (RF) areas clearing, areas impermeable (for water) surfaces, like buildings and communications (IS) and desertificated areas in sub Sahara region (SH). Interesting is, that those three types of surfaces are approximately equal, and their total area is $4.26{\times}10^6$ km^2. Their ratio to the dryland of the Earth is relatively small (0.0285), but their changes can significantly contribute to climate changes. The above mentioned selection is not complete, the aim of this selection is to demonstrate the influence of land use changes (artificial or natural) on evapotranspiration and transport of water and energy in ecosystems. We would like to demonstrate the influence of land use changes on energy fluxes as comparable (or even more important) to the role of greenhouse gases.

Discussion

Due to land use changes, land surface properties are changing too. Changes of albedo of the modified surfaces, aerodynamic roughness, leaf area index, soil properties, meteorological characteristics of boundary layer of an atmosphere reflect land use change, and is followed by modified fluxes of water and energy in the soil – plant – atmosphere system. Characteristic feature of land use changes is the decrease of area covered by canopies (plants) and increase of bare areas, like desertificated areas, impermeable areas for water and cleared areas.

From the above described results of analysis it follows that long-wave energy fluxes in the boundary layer of an atmosphere to the land surface are of the same order as those due to the increased concentration of carbon dioxide, emitted by fossil fuel burning. Table 1 presents the value of long wave energy contribution due to increased concentration of carbon dioxide to the Earth surface R = 1.82 W m^{-2} (Feldmann et al., 2015). The influence of three types of „modified“ land surfaces (RF, IS, SH), on increase of long –wave radiation fluxes to the surface was estimated as R = 5.76 W m^{-2}. The ratio of energy fluxes to the surface due to increased carbon dioxide concentration R = 1.82 W m^{-2} and due to land use change R = 5.76 W m^{-2} is 0.31. It means, that the contribution of the effect of carbon dioxide concentration on the long wave radiation to the lad surface is less than one third of the effect of land use changes analysed according to used scenario. Analysed land use changes represent only part of reality, because

Table 1. **The contribution of land use changes and increasing concentration of carbon dioxide in an atmosphere on increasing of long – wave energy fluxes (*R*) heating boundary layer of an atmosphere and upper layer of the Earth.**

	RF	IS	SH	CD
	R [W m^{-2}]			
1	107	19.73	16.5	–
2	0.0718	0.197	0.175	–
3	0.0206	0.0565	0.0524	0.02
4	0.2620	2.82	2.62	1.82
5		5.64		1.82
6		7.46		

RF – the influence of rain forest area decrease to energy fluxes change, IS – the influence of increased impermeable surfaces area to energy fluxes change, SH – the influence of increased area of Sahara desert and decrease of savanna area to energy fluxes change. CD – the influence of the increase of carbon dioxide concentration in an atmosphere on long –wave energy fluxes.
1. Increased energy flux (W m^{-2}) due to change of area RF, IS, SH and by carbon dioxide concentration increase CD. 2. Increased energy flux recalculated to the dryland area. 3. Energy flux recalculated to the Earth surface. 4. Contribution of different surfaces to the energy fluxes to the Earth during the past one hundred years (IS, SH), and by 21 years (RF). Calculation of cumulative energy fluxes was assumed to increase linearly (starting from zero value), up to actual energy fluxes. Contribution of CD to the energy fluxes was calculated since the industrial revolution start (Feldmann et al., 2015). 5. Total of energy fluxes (long wave radiation) to the soil surface from three sources (RF, IS, SH), and contribution of increased concentration of carbon dioxide (CD). 6. Total of energy fluxes (long wave radiation) to the soil surface from four sources (RF, IS, SH, CD).

detailed information about actual changes of land use are not known.

Contribution of identified land use changes to long wave radiation in soil surface direction was estimated as R = 7.56 W m^{-2} (Table 1). Is it a lot or is it a negligible value? It is difficult to give the definite answer. The average income of solar radiation to the Earth surface is 350 W m^{-2}, but the surface of Slovakia is reaching an average flux of energy 125 W m^{-2} (Chrgijan, 1978). From analysis it follows, that the changes of surface properties, and following energy fluxes changes are felt mostly locally. Contributions of the energy fluxes as a result of land use changes are integrating, as it can be seen in the Table 1, line 4.

The area of seas and oceans is covering more than two thirds of the Earth surface, they are basic stabilizing element of our planet climate. Water bodies are absorbing part of additional heat, thus integrating heat fluxes produced by the discussed land use changes (RF, IS, SH), and partially absorbing high energy fluxes from the areas where consumption of energy by evapotranspiration was decreased. It seems realistic, to explain majority of climate change by land use changes with significant contribution of carbon dioxide concentration increase.

Conclusions

Current land use changes, and resulting evapotranspiration rates decrease means less energy consumption and additional long – wave energy fluxes, comparable, or higher than energy fluxes due to carbon dioxide concentration increased by emissions. Both are contributing to the increase of the temperature of the boundary layer of atmosphere. Reasons of estimated increased long – wave energy fluxes in boundary layer of atmosphere and air temperature increasing can be of various origin. But the contribution of rain forests (RF) clearing, sub Sahara region desertification (SH) and increasing ratio of impermeable surfaces (IS) are dominant. The average rate of additional fluxes of long – wave radiation due to estimated land use changes is 5.64 W m^{-2}, during the last century. It is significantly higher, than flux estimated due to concentration of carbon dioxide increasing – 1.82 W m^{-2} – since the beginning of the industrial revolution. Our results are based on available data of land use changes and they illustrate how those processes participate in redistribution of energy in an atmosphere. It was shown land – use changes can increase water and energy fluxes even more than increasing concentration of carbon dioxide in an atmosphere.

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References

Brutsaert, W. (1982): Evaporation into the atmosphere. Doortrecht, D. Riedel Publ. Comp.
Babkin, V. I. (1984): Evaporation from water surface. Leningrad, Gidrometeoizdat, pp. 72. (In Russian)
Balek, J. (2006): Hydrological consequences of global changes. J. Hydrol. Hydromech.v. 54, 4, 357–370.

Budyko, M. I. (1974): Climate and life. Leningrad, Gidrometeoizdat. (In Russian)
The European state and outlook (2015): Asessment of global megatrends, EEA, Copenhagen. Denmark.
Feldman, D. R., Collins, W. D., Gero, P. J., Torn, M. S., Mlawer, E. J., Shippert, T. J. (2015): Observational determination of surface radiative forcing by CO_2 from 2000–2010. Nature. 519, 339–343.
Global Forest Rev. (2021): https://research.wri.org/gfr/global-forest-review
Chrgijan, A. Ch. (1978): Physics od atmosphere I., II. Gidrometeoizdat, Leningrad. (In Russian)
Kenderessy, P. (2022): Land use change and the role of forests in current climate change. In: Zmena klímy I. Bratislava, Slovenská akadémia vied, 69–81. (In Slovak)
Kirchner, I. G., Stenchikov, H. F., Graf, A. A, Robock, J. A. (1999): Climate model simulation of winter warming and summer cooling following the 1991 Mount Pinatubo volcanic erruption. J. Geophys. Res.,104, 19,039- 19,055.
Kučera, A. (2021): Global climate change and Solar activity. Is Sun the reason of climate change? In: Zmena klímy I. Bratislava, Slovenská akadémia vied, 46–53. (In Slovak)
Kutílek, M., Nielsen, D. R. (2010): Facts about global warming. Catena, Reiskirchen, pp. 227.
Milankovich, M. (1930): Matematische Klimalehre und Astronomische Theorie der Klimaschwankungen. Handbuch der Klimatologie, Band 1. Teil A. Gebrűder Bornträger, Berlin.
Nemešová, I. (2007): Climate change as a part of global change. Meteorol. Zprávy, 60, 1–6. (In Czech)
Novák, V. (2012): Evapotranspiration in the Soil – Plant – Atmosphere System. Springer Science + Business Media, Dordrecht, 253 p.
Novák, V. (2021): Ecosystems and global changes. Acta Horticult. Regiotext. Spec. issue, 70–79.
Palmer, A., Wiedeman, C., Finca, A., Hanam, N., Everson, C., Ellery, W. (2015): Modeling annual evapotranspiration in a semiarid African savanna: Functional convergence theory, MODIS LAI and the Penman-Monteith equation. African J. Range Forage Sci. v.32, p.23.
Rejmers, N. F. (1985): The vocabulary of nature: Biosfphere. Horizont, Praha, 176 p. (In Czech)
Shuttleworth, W. J. (1988): Evaporation from the Amazonian rainforest. Proc. Roy. Soc., London, B233, 321–346.
Sampaio, G., Nobre, C., Costa, M. H., Satyamury, P., Soares-Filho, B. S., Cardoso, M. (2007): Regional climate change over eastern Amazonia caused by pasture and soybean cropland expansion. Geophys. Res. Letters, v.34, 17.

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