

The nonlinear effects based on peat chronology data in paleoclimatic reconstructions

O G Savichev, M V Reshetko and Yu A Moiseeva

Tomsk Polytechnic University, 30 Lenin Avenue, Tomsk, 634050, Russia
E-mail: OSavichev@mail ru, mrechetko@tpu ru, julchiky@mail ru

Abstract The simplified mathematical model of peat deposits growth is suggested based on assuming the swamp is a thermodynamics system. Its validation was performed according to the data of the swamps in Siberia. It is shown that the peat deposits growth is nonlinear related to climate change. Therefore, for the appropriate methods applying in paleoclimatic reconstructions is expedient to establish the optimal values of functioning particular bio- and ecosystem in natural conditions that determine the most probable existence of life forms of biological species.

1. Introduction

Paleoclimatic reconstructions play an important role in the study of regularities and mechanisms of climate and environmental changes and their prediction and development of regional socio-economic programs, before the adoption of global strategies for the development of the various fields of the world economy. The used methods have different disadvantages [1, 2, 3]. As a result, some methods are usually used simultaneously, with used as dendrochronology [4, 5], palynology [6, 7] and algorithms of complex analysis of marshy processes [4, 8] the reference methods (used for "calibration")

Although the above methods have positive features (first of all, the relative simplicity), when applying in paleoclimatic reconstructions, it is necessary to take into account the nonlinear relation of the environment components, and, especially, nonlinear reactions of vegetation to climate change. It is caused by the influence of several factors from astronomy to "atmosphere-ocean" system. Taking this into account, some aspects of the analysis of the relations between climate characteristics and the intensity of growth of peat deposits are described below. In this work the peat chronology is understood as the determination and the restoration of natural events, so it is the same as dendrochronology.

2. Materials and methods

Methods of research consist of construction of a simplified mathematical model of peat accumulation based on assuming that the swamp is a thermodynamic system (arising and existing under excess moisture). Testing this model is carried out according to the published data on the depth of the peat deposit taking from a Siberia bogs [9-14] and on materials of the Roshydromet observation over the temperature of atmospheric surface layers [15-17]. The choice of research objects is due to exceptionally high bogginess of the region, which reaches over 70 % in the number of river catchments [17, 19].



2.1. Subject of research

As the objects of study, we have chosen Vasyugan swamp and a number of swamps in the Salym-Yugansk interfluvium, near the township Igarka, Lake Samotlor, the village Sytomino, the catchment of the rivers Kas and Shuchya. Vasyugan swamp is located in the interfluvium of the Ob and the Irtysh rivers, mainly in the southern taiga subzone and sub taiga and situated in the Tomsk, Omsk and Novosibirsk oblasts [18, 19]. Areas of headwaters of the rivers Shegar, Chaya, Parabel, Vasyugan, Om, Tara are located within Vasyugan swamp. Some researchers also include parts of the catchment of the rivers in Vasyugan swamp, such as the Bolshoi Yugan and the Demyanka (of Khanty-Mansi Autonomous Area and Tyumen oblast). The rivers Om, Tara and Demyanko – the tributaries of the Irtysh River; the Shegarka, Chaya, Parabel, Vasyugan and Bolshoi Yugan rivers – the tributaries of the Ob River. The Kas River is a left tributary of the Yenisei River. Its catchment is located on the eastern border of the West Siberian Plain, in subzone of the southern taiga (the Krasnoyarsk Territory). The swamps on the watershed of the rivers Salym and Bolshoi Yugan, near the village Sytomino and Lake Samotlor are located in the middle taiga subzone in Khanty-Mansi autonomous area. The swamp in the catchment the Shchuchya River (the tributary of the Ob) is located in the southern part of the tundra zone (within the Yamal-Nenets Autonomous district) and the swamp near village Igarka is located in the forest-tundra zone in the watershed the Yenisei River (in the Krasnoyarsk Territory).

3. Results and discussion

Suppose that the condition of the swamp ecosystem can be described by the equation according to the first law of thermodynamics:

$$d\Theta = dU + A, \quad (1)$$

where $d\Theta$ is the thermal energy added to the system; dU is the change of inner energy of the system; A is the work performed by the system

$$m \cdot \phi \cdot k_{sa} \cdot dT_a = k_U \cdot k_{sa} \cdot d(m \cdot T_a) + m \cdot g \cdot \delta \cdot dh_p, \quad (2)$$

$$\delta = \begin{cases} 0, & H - Y - E \leq 0 \\ 1, & H - Y - E > 0 \end{cases}, \quad (3)$$

where m and h_p is the mass and the average vertical size of the system; k_{sa} is the ratio of air temperature T_a and the systems T_s ($T_a = k_{sa} T_s$); H , Y , E is the layers of atmospheric moistening, runoff and evaporation; ϕ is the specific heat of swamp ecosystem (conditional); g is the acceleration of gravity. Assuming that $m = k_{p,1} \cdot h_p^b$ and the average air temperature during the period equals $T = k_{p,2} \cdot (T_0 + T_t)$, then we obtain the following equation at time t :

$$\delta \cdot \int dh_p = \int k_{p,3} dT_a - k_{p,4} \cdot T_a \int \frac{dh_p}{h_p}, \quad (4)$$

$$h_{p,t} = h_{p,0} + k_{p,3} \cdot (T_{a,t} - T_{a,0}) - k_{p,4} \cdot b \cdot k_{p,2} \cdot (T_{a,t} + T_{a,0}) \cdot \ln \left(\frac{h_{p,t}}{h_{p,0}} \right), \quad (5)$$

where $k_{p,1}$, $k_{p,2}$, $k_{p,3}$, $k_{p,4}$ is the empirical coefficients; δ is the average value of the delta-function of water balance in a specified period; $T_{a,t}$ and $T_{a,0}$ are the average annual air temperature at the end and beginning of the period; $h_{p,t}$ and $h_{p,0}$ is the depth of peat deposit at the end and beginning of the period.

The equation (5) takes the form (figure 1) for the West Siberia Plain according to [9-14]:

$$h_{p,t} - 0.10 = (-12.36 \pm 3.44) - (1.81 \pm 0.51) \cdot T_{a,t} - (0.73 \pm 0.16) \cdot T_{a,t} \cdot \ln \left(\frac{h_{p,t}}{0.10} \right) + (5.08 \pm 0.91) \cdot \ln \left(\frac{h_{p,t}}{0.10} \right) \quad (6)$$

the squared correlation relation $R^2=0,74$

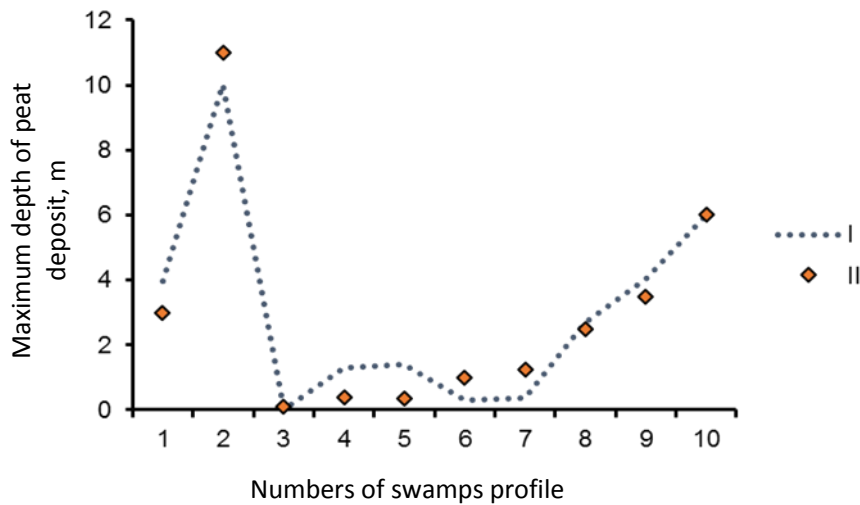


Figure 1. Calculated (I) and measured (II) values of the maximum depth of peat deposits; swamps profile: 1 – the catchment of the Kas River [14]; 2 – Vasyuganskoye swamp, the interfluves of the rivers Parabel, Tara, Om [12]; 3, 6 – the catchment of the Shuchya River; 4, 5, 7 – area of the township Igarka; 8 – Lake Samotlor’s area; 9 – area of the village Sytomino; 10 – the Salym-Yuganskaya interfluve [11]

According to the analysis of the dependence (6) it follows that, firstly, in the taiga zone in Western Siberia the calculated maximum depth of peat deposit is equal to 7.7 m, which is close to the average maximum depth of peat bogs in the region, that corresponds to a period of constant temperature -3°C . Secondly, when the average annual air temperature is over -7°C , the marked growth of peat deposits (over 0.1 m) is observed. The peat deposit is not formed when the air temperatures are about or lower -7°C , but perhaps it is preserved due to peat formation in the previous warmer period. Thirdly, there is a nonlinear dependence between growth of peat deposits and maximum increment air temperature corresponding to not maximum, but optimal one for the given ecosystem (figure 2).

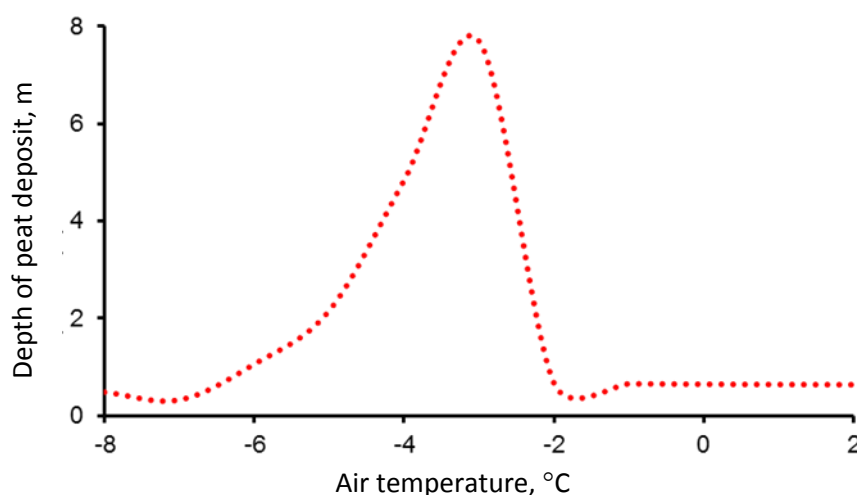


Figure 2. The relation between the temperature of surface layers of the atmospheric air and the depth of peat deposits, calculated according to the equation (6)

Fourth, if we assume minor change in internal energy of the system with changes in its mass, it is possible to simplify the equation (5) to linear relation, which has the following form for the taiga zone of Western Siberia:

$$h_{p-\max,t} = (6.97 \pm 1.42) + (0.87 \pm 0.26) \cdot T_{a,y} \quad (7)$$

where $h_{p-\max,t}$ is the maximum depth of peat deposits; $R^2=0,58$

However, the use of equation (7) is limited by the range of temperatures from -8°C to -2°C , after which the non-linearity of the relation is very difficult to be ignored (figure 3)

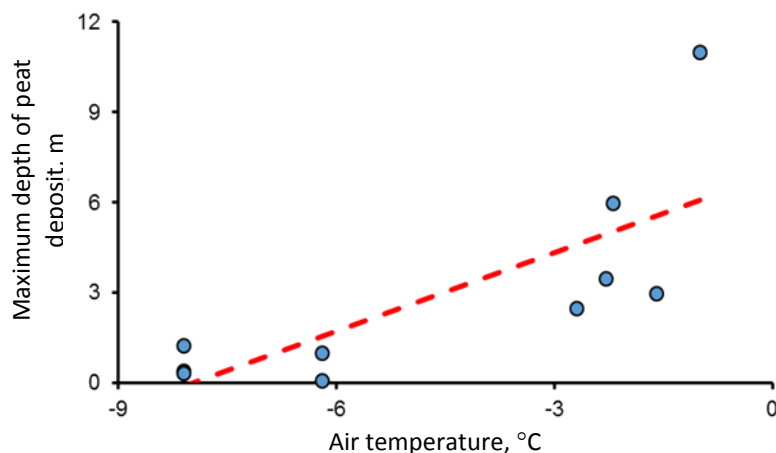


Figure 3. The relation between the temperature of surface layers of the atmospheric air and a maximum depth of peat deposits according to [11, 12, 14]

4. Conclusions

As a result of the study it was shown that peat deposits growth is nonlinear related to climate change. Therefore, for the appropriate methods to be applied in paleoclimatic reconstructions it is expedient to establish the optimal values of functioning particular bio- and ecosystem in natural conditions that determine the most probable existence of life forms of biological species.

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