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Land surface model within climate model ECSib*

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Vegetation is important for many ecological studies because it determines the rate of CO_2 during photosynthesis as well as for hydrologic and atmospheric studies as it effects on the latent heat flux. The most detailed parameterizations of vegetation are often found in the land surface models jointly used with atmospheric models [1, 2]. This may be summarized as follows: the effects of leaf area on the absorption of solar radiation at the surface; sensible heat flux and latent heat flux; biochemical fluxes; and the soil heat fluxes, which are important due to the effects of soil temperature on biochemical fluxes; the surface energy budget and soil hydrology. The land surface model considered in this paper is an extension of the earlier developed model [3] and is based on the works by P.J. Sellers, et al. [3] and G.B. Bonan [1, 2, 4–6]. *A substantial part of this model is based on the NCAR reports* [2]. The proposed version of the land surface model takes into account rather completely the physical factors to assess the interaction of the atmosphere with the surface and the possibility of including it to the general circulation model ECSib [7].

1. Atmosphere general circulation model ECSib

The atmospheric model ECSib has been developed from the ECMWF model (therefore the first part of its name is EC) and the dynamical package and some physical subroutines developed at the ICM&MG SB RAS (the former Computing Center) [8].

There are 15 levels in the vertical which are defined on σ – surfaces in the troposphere and the low stratosphere. The dynamic terms and physical processes are calculated on the Arakawa C-grid which yields $5° \times 4°$ horizontal resolution. The spatial–finite difference scheme gives the second order approximation and exhibits the potential enstrophy conservation law at the eddy advection by the horizontal velocity (in the barotropic atmosphere (A. Arakawa and M. Lamb, 1981)). A special choice approximation of the hydrostatic equation allows us to construct a vertical scheme conserving an angular momentum.

The basis of integration algorithms construction is a semi-implicit scheme with respect to the linear part of the dynamic operator, an explicit scheme

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with respect to "slow" physical processes and an implicit scheme with respect to "fast" physical processes (e. g. the vertical diffusion).

The physical parameterizations are the following:

A nonlinear fourth-order horizontal diffusion operator applied to velocities and temperature.

Processes of the planetary boundary layer. Calculation of surface fluxes is based on the Monin–Obukhov similarity theory, where wind and temperature profiles depend on the external parameters and on surface moment and heat fluxes, the equation used in the model for the moment, sensible heat and moisture fluxes are different for a stably and an unstably stratificated surface layer.

Cumulus convection. The deep moisture convection parameterization scheme is based on Kuo's method (H. Kuo, 1974).

Scheme for stratiform clouds. In the non-convective cloudiness parameterization scheme the condensation process occurs when specific humidity attains the saturation value, but the liquid water does not fall in the precipitation form until one of the two conditions is fulfilled.

The first condition is *a fairly cold cloud top* ($T_c = 261.1$); the second condition – a fairly thick cloud ($q_{lc} = 0.0002\,\mathrm{m}$).

Surface processes. A thin soil layer is singled out with a certain heat capacity which exchanges heat and moisture with the atmosphere and deep soil.

Wave drag scheme. This scheme evaluates the tendencies due to gravity wave drag following the work by M. Miller and T. Palmer (1987). The wave drag modifies the horizontal components of the momentum equations and thermodynamics equation by means of dissipation.

Radiation scheme. This scheme evaluetes the radiative fluxes following the work by J.-F. Geleyn and A. Hollingworth (1979). The solution to the radiative transfer equation involves integration over the angles, the vertical coordinate and some intervals of the spectrum. First we make computation without any gaseous absorption, the resultant flux representing either a parallel flux or the upward or the downward diffuse flux. After that, we add each gas (CO_2, H_2O, O_3), with a small absorption coefficient and, finally, we compute the real flux. We use the interactive scheme of radiation with three-layer clouds and the convective tower, predicted from relative humidity. Clouds have the fixed optical properties (J. Slingo, 1987).

2. Land surface model for general circulation model ECSib

On the basis of the experience gained from the work with the climatic model ECSib [8] and the desire to investigate the interaction of processes in the

VC and atmosphere, there arised a necessity to formulate a more complete surface model in the climatic model ECSib for carrying out the experiments on the interaction of the climate dynamics of the atmosphere and ecosystem dynamics of the land surface.

1. Atmosphere boundary conditions for land surface model. The following atmosphere variables are used as upper boundary condition in the land surface model:

$z_{\rm bot}$ is a height of the lower sigma level ECSib model;

$T_{\rm bot}$ is a temperature at $z_{\rm bot}$;

$U_{\rm bot}$ is a zonal wind at $z_{\rm bot}$;

$V_{\rm bot}$ is a meridional wind at $z_{\rm bot}$;

$P_{\rm bot}$ is a pressure at $z_{\rm bot}$;

$Q_{\rm bot}$ is a specific humidity at $z_{\rm bot}$;

$P_{\rm surf}$ is surface pressure;

$p_{\rm conv}$ is convective precipitation;

$p_{\rm larg}$ is large-scale precipitation;

and incident direct solar, diffuse solar, and longwave radiation.

2. Momentum, sensible and latent heat fluxes. Fluxes of zonal τ_x and meridional momentum τ_y, sensible heat H (W/m^2), water vapour E (kg/m^{2}s), latent heat λE between an atmosphere on some reference level $z_{\rm atm}$ (with the zonal wind $u_{\rm atm}$, the meridional wind $v_{\rm atm}$ m/s, the potential temperature $\theta_{\rm atm}$ (K) and the specific humidity $q_{\rm atm}$) and the surface (with parameters $u_{\rm s}$, $v_{\rm s}$, $\theta_{\rm s}$, $Q_{\rm s}$) are set by the formulas

$$\tau_x = -\rho_{\rm atm}\frac{(u_{\rm atm} - u_{\rm s})}{r_{\rm am}}, \qquad \tau_y = -\rho_{\rm atm}\frac{(v_{\rm atm} - v_{\rm s})}{r_{\rm am}},$$

$$H = -\rho_{\rm atm}C_{\rm p}\frac{(\theta_{\rm atm} - \theta_{\rm s})}{r_{\rm ah}}, \qquad E = -\rho_{\rm atm}\frac{(q_{\rm atm} - q_{\rm s})}{r_{\rm ah}}.$$

These formulas are obtained from the Monin–Obukhov theory for the layer of constant fluxes. In this case it is assumed that $u_{\rm s}$, $v_{\rm s}$ are equal to zero at the height $z_{0m} + d$ (a sink for the moment), therefore $r_{\rm am}$ c/m is the aerodynamic resistance between the atmosphere at the height $z_{\rm atm}$ and the surface at the height $z_{0m} + d$. Similarly, $\theta_{\rm s}$ and $q_{\rm s}$ are determined at the heights $z_{0h} + d$ and $z_{0w} + d$ (a drain for heat and water vapour). Hence, $r_{\rm ah}$ and $r_{\rm aw}$ are the aerodynamic resistance to sensible heat and water vapour transfer between the atmosphere at the level $z_{\rm atm}$ and by the surface at the heights z_{0h} and z_{0w} respectively.

3. Sensible and latent heat fluxes on the bare surface. The surface is considered to be non-vegetated if the sum of $L+S$ leaf and stem indexes is equal to zero. In this case, the surface temperature T_s is also the temperature of the ground. Hence, the sensible and latent heat fluxes are set by the following formulas:

$$H = -\rho_{\text{atm}} C_{\text{p}} \frac{(\theta_{\text{atm}} - T_{\text{g}})}{r_{\text{Ah}}},$$
$$\lambda E = -\frac{\rho_{\text{atm}} C_{\text{p}}}{\gamma} \frac{(e_{\text{atm}} - e_*(T_{\text{g}}))}{(r_{\text{aw}} + r_{\text{srf}})},$$

where $q \approx 0.622e/P$, $\gamma = C_{\text{p}} P_{\text{atm}}/0.622\lambda$, E_{atm} is pressure of the water vapour at the height z_{atm} and $e_*(T_{\text{g}})$ is pressure of the saturation water vapour in the atmosphere with ground temperature T_{g}, r_{srf} is resistance at the surface to the vapour transfer between the ground with pressure of the saturation vapour $e_*(T_{\text{g}})$ and the level of sink for the water vapour with the vapour pressure e_{s}. The equation for latent heat flux is similar to the equation for H. Accumulation of water is also obtained under assumption that vapour in the layer is absent. Therefore

$$-\frac{\rho_{\text{atm}} C_{\text{p}}}{\gamma} \frac{(e_{\text{atm}} - e_{\text{s}})}{r_{\text{aw}}} = -\frac{\rho_{\text{atm}} C_{\text{p}}}{\gamma} \frac{(e_{\text{s}} - e_*(T_{\text{g}}))}{r_{\text{srf}}},$$
$$E_{\text{s}} = \left[\frac{e_{\text{atm}}}{r_{\text{aw}}} + \frac{e_*(T_{\text{g}})}{r_{\text{srf}}}\right] \Big/ \left[\frac{1}{r_{\text{aw}}} + \frac{1}{r_{\text{srf}}}\right],$$

and the surface resistance r_{srf} increasing when the ground becomes drier is a linear combination of the resistance to the part of the ground covered with snow f_{snow} and the resistance of the ground $1 - f_{\text{snow}}$:

$$r_{\text{srf}} = 150 f_{\text{snow}} + (1 - f_{\text{snow}}) \frac{r_{\text{Aw}}(1 - \beta_{\text{e}})}{\beta_{\text{e}}}.$$

Here β_{e} is a dimensionless parameter varying from unit (when the ground is wet) up to zero (with dry ground).

For calculation of parameters r_{0m}, r_{ah}, r_{aw}, the roughness parameters z_{0m}, z_{0h}, z_{0w} are respectively used, where $z_{0m} = Z_{0\text{soil}}(1 - f_{\text{snow}}) + z_{0\text{snow}}$ f_{snow}, $Z_{0h} = z_{0w} = z_{0m} \exp(\ln(z_{0m}/z_{0h})/(ku_*))$. The parameter $z_{0\text{soil}}$ is equal to 0.05 m for the ground, ice and, humidified surfaces to 0.001 m for unfrozen lakes and to 0.04 m for the frozen lakes $Z_{0\text{snow}} = 0.04\,\text{m}$.

4. Sensible and latent heat flux on the surface, covered with vegetation. In this case, the fluxes H and λE are divided into flows inside vegetation and flows from the ground, depending on the vegetation temperature T_{v} and the ground T_{g} (in addition to the temperature surfaces T_{s}) and the vapour pressure e_{s}. The sensible heat flux H between the surface $Z_{0h} + d$ and the atmosphere at the height z_{atm} is divided into two parts:

$$H = -\rho_{\mathrm{atm}} C_{\mathrm{p}} \frac{(\theta_{\mathrm{atm}} - T_{\mathrm{s}})}{r_{\mathrm{ah}}} = H_{\mathrm{v}} + H_{\mathrm{g}},$$

$$H_{\mathrm{v}} = -\rho_{\mathrm{atm}} C_{\mathrm{p}} \frac{(T_{\mathrm{s}} - T_{\mathrm{V}}) 2(L+S)}{r_{\mathrm{b}}}, \qquad H_{\mathrm{g}} = -\rho_{\mathrm{atm}} C_{\mathrm{p}} \frac{(T_{\mathrm{s}} - T_{\mathrm{G}})}{r'_{\mathrm{ah}}}.$$

Here L and S are leaf and stem indexes, r_{b} is average resistance in the boundary layer of foliage, and r'_{ah} is the aerodynamic resistance between the ground z'_{0h} and $Z_{0h} + d$. Let us introduce the conductivity

$$C^h_{\mathrm{a}} = \frac{1}{r_{\mathrm{a}}}, \qquad C^h_{\mathrm{v}} = \frac{2(L+S)}{r_{\mathrm{b}}}, \qquad C^h_{\mathrm{g}} = \frac{1}{r'_{\mathrm{ah}}}.$$

Then

$$T_{\mathrm{s}} = \frac{c^h_{\mathrm{a}} \theta_{\mathrm{atm}} + c^h_{\mathrm{v}} T_{\mathrm{v}} + C^h_{\mathrm{g}} T_{\mathrm{g}}}{c^h_{\mathrm{a}} + c^h_{\mathrm{v}} + c^h_{\mathrm{g}}}.$$

By substituting this formula in the expression for H_{v}, we obtain

$$H_{\mathrm{v}} = -\rho_{\mathrm{atm}} C_{\mathrm{p}} \frac{[c^h_{\mathrm{a}} \theta_{\mathrm{atm}} + C^h_{\mathrm{g}} T_{\mathrm{g}} - (c^h_{\mathrm{g}} + c^h_{\mathrm{a}}) T_{\mathrm{V}}] c^h_{\mathrm{v}}}{c^h_{\mathrm{a}} + c^h_{\mathrm{v}} + c^h_{\mathrm{g}}}.$$

Neglecting the accumulation vapour in the air of the crown it is possible to express the latent heat flux λE between the surface at the height $z_{0w} + d$ and the atmosphere at the level z_{atm} by the formula

$$\lambda E = -\frac{\rho_{\mathrm{atm}} C_{\mathrm{p}}}{\gamma} \frac{(e_{\mathrm{atm}} - e_{\mathrm{s}})}{r_{\mathrm{aw}}} = \lambda E_{\mathrm{v}} + \lambda E_{\mathrm{g}}.$$

The latent heat flux for the vegetative cover will be expressed by the formula (similar to the sensible heat):

$$\begin{aligned}\lambda E_{\mathrm{v}} = & -\frac{\rho_{\mathrm{atm}} C_{\mathrm{p}}}{\gamma} (e_{\mathrm{S}} - e_*(T_{\mathrm{v}})) \times \\ & \left[f_{\mathrm{wet}} \left(\frac{L+S}{r_{\mathrm{b}}} \right) + (1 - f_{\mathrm{wet}}) \left(\frac{L^{\mathrm{sun}}}{r_{\mathrm{b}} + r^{\mathrm{sun}}_{\mathrm{s}}} + \frac{L^{\mathrm{shad}}}{r_{\mathrm{b}} + r^{\mathrm{shad}}_{\mathrm{s}}} \right) \right],\end{aligned}$$

where L^{sun}, L^{shad} are the indexes of foliage, on which the beams of the sun fall, and the foliage which takes place in the shadow; $r^{\mathrm{sun}}_{\mathrm{s}}$, $r^{\mathrm{shad}}_{\mathrm{s}}$ are appropriate stomatal resistances. The expression in the square brackets represents evaporation of the intercepted water from the humidified part of the crown of plants f_{wet}, transpiration from the sunlit leaves and transpiration from the shaded leaves. The latent heat from the ground is expressed by the analogous formula

$$\lambda E_{\rm g} = -\frac{\rho_{\rm atm} C_{\rm p}}{\gamma} \frac{(e_{\rm s} - e_*(T_{\rm g}))}{r'_{\rm aw} + r_{\rm srf}},$$

where $e_*(T_{\rm g})$ is the pressure of saturation water vapour with the temperature $T_{\rm g}$, $r'_{\rm aw}$ is the aerodynamic resistance between the ground (z'_{0w}) and the level $d + z_{0w}$. As well as $T_{\rm s}$, $e_{\rm s}$ is defined by the formula

$$E_{\rm s} = \frac{c_{\rm a}^w e_{\rm atm} + (c_{\rm e}^w + c_{\rm T}^w) e_*(T_{\rm v}) + c_{\rm g}^w e_*(T_{\rm g})}{c_{\rm a}^w + (C_{\rm e}^w + c_{\rm t}^w) + c_{\rm g}^w}.$$

Substituting the expression for $e_{\rm s}$ in $\lambda E_{\rm v}$, we obtain the formula for the latent heat flux from the part of the surface, covered with vegetation. Similarly, there is an expression for $\lambda E_{\rm g}$.

The parameters z_{0m} and d which are used for calculation of $r_{\rm am}$, $r_{\rm ah}$ and $r_{\rm aw}$, vary depending on leaf and stem indexes and the height of the crown. In Table 1, for different types of vegetation the values of z_{0m}, d (see [5]) are given.

Table 1. Vegetation dependent aerodynamic parameters [4]

Plant type	z_{0m}, m	d, m
Needleleaf evergreen tree	0.94	11.4
Needleleaf deciduous tree	0.77	9.4
Broadleaf deciduous tree	1.10	13.4
Deciduous shrub	0.06	0.34
Arctic deciduous shrub	0.06	0.34
Arctic grass	0.06	0.34

The values used are such that $z_{0h} = z_{0w} = z_{0m}$. The aerodynamic resistance inside the crown of plants for the sensible and the latent heat fluxes are equal, respectively to $r'_{\rm ah}$ and $r'_{\rm aw}$.

5. Temperature of the vegetative cover and ground surface. Temperature of the ground on the land surface is determined from the thermal balance equation

$$S_{\rm g}^{\downarrow} + L^{\uparrow}(T_{\rm g}) + H(T_{\rm g}) + \lambda E(T_{\rm g}) + G(T_{\rm g}) + M = 0,$$

where $S_{\rm g}^{\downarrow}$ is the solar radiation flux at the Earth's surface; $L^{\uparrow}(T_{\rm g})$, $H(T_{\rm g})$ and $\lambda E(T_{\rm g})$ are the flows determined by properties of a surface; $G(T_{\rm G})$ is the heat flux in the ground:

$$G = \frac{2k_1}{\Delta z_1}(T_{\rm g} - T_1),$$

where K_1 is thermal conductivity, Δz_1 is thickness of a layer, T_1 is temperature of the first layer of the ground (lake or snow), M is a heat flux connected with melting of snow.

In the case of a surface covered with vegetation, the flows $L^{\uparrow}(T_g)$, $H(T_g)$ and $\lambda E(T_g)$ consist of two parts: flows from a vegetative cover and flows from the ground. Therefore, $L^{\uparrow} = L_v^{\uparrow} + L_g^{\uparrow}$, $H = H_v + H_g$, $\lambda E = \lambda E_v + \lambda E_g$. These fluxes depend on the vegetative cover temperature T_v and the ground temperature T_g, determined, from the the thermal balance equations

$$S_v^{\downarrow} + L_v^{\uparrow}(T_g, T_v) + H_v(T_g, T_v) + \lambda E_v(T_g, T_v) = 0,$$
$$S_g^{\downarrow} + L_g^{\uparrow}(T_g, T_v) + H_g(T_g, T_v) + \lambda E_g(T_g, T_v) + G(T_g) + M = 0.$$

Here $S_v^{\downarrow}$ and $S_g^{\downarrow}$ are the solar radiation absorbed by a vegetative cover and the ground.

After calculation of the ground temperature it is determined, whether there are thawing snows. The snow thaws when $T_g \geq T_{fr}$. In this case we assume $T_g = T_{fr}$, and with this temperature we recalculate flows $L^{\uparrow}(T_g)$, $H(T_g)$ and $\lambda E(T_g)$. If the disbalance of energy is positive (i. e., the heat flux is directed into the snow or the ground), snow melts and the relation

$$M = S_g^{\downarrow} - L_g^{\uparrow} - H_g - \lambda E_g \leq \frac{W_{snow} h_{ice}}{\Delta t},$$

holds, where W_{snow} is the weight of snow, h_{ice} is the specific heat of fusion, Δt is a time step.

6. Temperature of the soil. Using the one-dimensional energy equation (the law of conservation of the thermal energy), determine the distribution of temperature in a six-meter layer of the ground:

$$\rho c \frac{\partial T}{\partial t} = -\frac{\partial F_z}{\partial z},$$

where ρc is the volumetric soil heat capacity ($Jm^{-3}K^{-1}$), $F_z = -k\frac{\partial T}{\partial z}$ is a heat flux at the depth Z. This equation is numerically solved to calculate the soil temperature for a six-layer soil in the absence of a heat flux at the bottom and the appropriate value of the flux at the top.

The thermal flux F_i from i-th to $(i+1)$-th layer is calculated by the formula

$$F_i = -\frac{T_i - T_{i+1}}{\frac{\Delta z_i}{2k_i} + \frac{\Delta z_{i+1}}{2k_{i+1}}}.$$

7. Temperature of a lake. Temperature of a lake is calculated from the one-dimensional model of thermal stratification of a lake [6]:

$$\frac{\partial T}{\partial t} = \frac{\partial F_z}{\partial z} + \frac{1}{c_w}\frac{\partial \phi}{\partial z},$$

where $F_z = (k_m + k_e)\frac{\partial T}{\partial z}$ is a heat flux connected with molecular and eddy diffusion, ϕ is a flux of the solar radiation at the depth z.

As well as in the ground, temperature in a lake is numerically determined from the given equations at six levels as for a deep lake (a depth of 50 m, with the layers $\delta z_i = 1, 2, 4, 8, 15$ and 20 m), and for a shallow lake (a depth of 10 m), with the layers $\delta z_i = 0.5, 1, 1.5, 2, 2.5$ and 3 m). For a shallow lake the eddy diffusion coefficient $k_e = 0$. The heat flux on the bottom border should be equal to the flux of energy F_0 which is set equal to zero, and on the surface it equals

$$F_0 = \beta S_g^{\downarrow} - (L_g^{\uparrow} + H_g + \lambda E_g + M).$$

The depth of a lake is assumed necessarily constant everywhere.

8. Hydrology. The hydrological model of the surface parameterized processes of the interception through all by a vegetative cover, accumulation and melting of snow, the surface drain of water, subsurface drainage, redistribution of moisture in the ground.

The fluxes are considered positive, if they are directed to the atmosphere. The system of water balance equations is of the form:

$$\Delta W_{\text{canop}} + \Delta W_{\text{snow}} + \sum \Delta\theta_i \Delta z_i = (q_{\text{prl}} + q_{\text{prc}} - E_{\text{v}} - E_{\text{g}} - q_{\text{runoff}} - Q_{\text{drai}})\,\Delta t,$$

where Δt is a time step, Q_{prl} is the large-scale precipitation, Q_{prc} is convective precipitation, E_{v} is transpiration in a vegetative cover, E_{g} is evaporation from the ground, Q_{runoff} is the surface runoff, Q_{drai} is the subsurface drainage, ΔW_{canop} is accumulation of moisture in a vegetative layer, ΔW_{snow} is accumulation of moisture in a snow cover, $\sum \Delta\theta_i \Delta z_i$ is the volumetric contents of water in the ground.

This equation is valid for the non-irrigate soil.

9. CO_2 fluxes on the surface. The model of exchange of CO_2 between the surface covered with vegetation and the atmosphere has been developed on the basis of [2], [4–6]. The model reproduces the natural cycle of CO_2 in the atmosphere and in the surface bioses. The basic processes of this cycle are photosynthesis, when CO_2 is fixed in plants from the atmosphere and respiration, when CO_2 is lost. The general equation describing the process of exchange, has the form

$$6CO_2 + 6H_2O + h\nu \underset{\text{respir.}}{\overset{\text{photosyn.}}{\rightleftarrows}} 6C_6H_{12}O_6 + 6O_2.$$

The photosynthesis is closely connected with stomatal resistance and is consequently an essential part of the energy exchange on the surface. The leaf stomatal resistance for photosynthesis and for parameterization of the latent heat flux (J.L. Dorman, P.J. Sellers, 1989) is calculated by the formula

$$\frac{1}{r_s} = m\frac{A}{c_s}\frac{e_s}{e_i}P_{atm} + b,$$

where m is an empirical parameter, A is the leaf photosynthesis rate, C_s is concentration on the surface of a leaf, E_s is pressure vapour on the surface of a leaf, E_i is pressure of the saturation vapour inside a leaf with the temperature of VC, P_{atm} is atmospheric pressure, B is the minimal stomatal conductivity with $A = 0$.

The photosynthesis rate is influenced by a light exposure, concentration of CO_2 and the availability of moisture. The leaf photosynthesis rate is determined from the ratio

$$A = \min(w_c, w_j, w_e),$$

assuming $A = 0$ when $T_v \le T_{min}$.

Photosynthesis in plants of the type C_3 is based on the model by Farquhar et al. (1980) and Collatz et al. (1991), and for plants of the type C_4 based on models by Collatz et al. (1992) and Dougherty et al. (1994).

The parameters w_c, w_j, w_e are determined from the formulas of the photosynthesis model by Farquhar et al. (1980) and Collatz et al. (1992).

10. Respiration processes. The losses of CO_2 during respiration of plants break up into two phases: losses at the phase of growth of breath independent of temperature and losses at the phase of balance dependent on temperature. The total breath at the phase of balance R_m (μ mol CO_2 $m^{-2}s^{-1}$) from foliage, stems and roots is expressed by formula [2]

$$R_m = [LR_{f25}f(N)\beta + V_b^s R_{s25} + V_b^r R_{r25}]\, a_{rm}^{(T_v-25)/10},$$

where L is the leaf area index (m^2m^{-2}), R_{f25} is the foliage respiration at the temperature of 25°C, V_b^s kg/m^2) is the stem bioweight, R_{s25} is the stem respiration at 25°C, V_b^r is the root bioweight, R_{r25} is the root respiration at 25°C, T_v is the temperature of a vegetative cover, a_{rm} is a parameter of sensitivity to the temperature. Parameters of sensitivity concerning the contents of nitrogen $F(N)$ and the waters β in foliage are used during the foliage respiration, as they participate in the definition of V_{max}, and R_{f25} proportional to V_{max} (G.D. Farquhar, S. von Caemmerer, L.A. Berry, 1980,

[2]). The growth respiration R_g (μ mol CO_2 $m^2 s^{-1}$) is proportional to photosynthesis [6]:

$$R_g = 0.25(A^{sun}L^{sun} + A^{sha}L^{sha}),$$

where A^{sun}, A^{sha} are photosynthesis in the sunlit and the shaded leaves respectively, L^{sun}, L^{sha} are appropriate leaf indexes. The pure primary product ΔM (μ g/m^2) is expressed by the formula

$$\Delta M = \gamma \left(A^{sun}L^{sun} + A^{sha}L^{sha} - R_m - R_g\right) \Delta t,$$

where $\gamma = 28.5$ μ g is the amount of dry bioweight per μ mol CO_2.

In Table 2, the values of parameters for respiration at the equilibrium phase are presented.

Table 2. Respiration parameters, μ mol $CO_2\, m^{-2}s^{-1}$

Plant type	R_{f25}	R_{s25}	R_{r25}
Needleleaf evergreen tree	0.50	0.94	0.36
Needleleaf deciduous tree	0.50	0.14	0.05
Broadleaf deciduous tree	0.50	0.02	0.01
Deciduous shrub	0.26	0.00	0.00
Arctic deciduous shrub	0.50	1.02	2.11
Arctic grass	0.50	1.02	2.11

11. Numerical results. The current state of the atmosphere (monthly mean parameters simulated by the ECSib model which is forced by the climatology of the annual cycle of SST) is used to force the surface model. The required surface data for each land grid cell derived from Olson et al. (1983), the soil colors were taken from Dickinson et al. (1993), sand, silt and clay data were derived from Webb et al. (1993), the inland water data were derived from Cogley (1991) and overlayed onto the NCAR CCM (128×64) grid (file **fsurdat**). This dataset was used to carry out experiments, where the model was run in the uncoupled mode. Figures 1–9 illustrate the results of the integration of the land surface model.

Conclusion

An important feature of the given model of the surface is the description of biophysical process in addition to common physical processes (consideration of physiology of plants), biochemical (photosynthesis, respiration of plants and manufacture of primary production) processes on the surface. This feature of the model brings it closer to the ecological models of the surface and allows us to carry out the joint modeling of dynamics of climate and ecosystem.

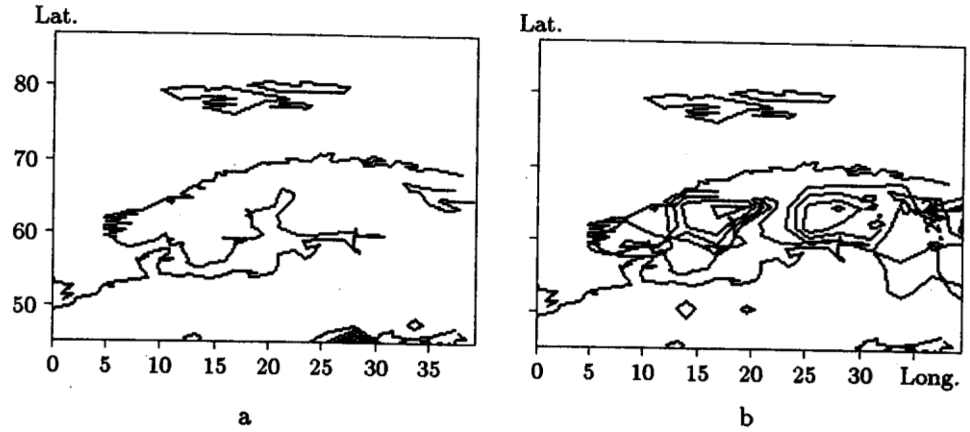

Figure 1. a) Net CO_2 flux; b) photosyn. flux CO_2, April

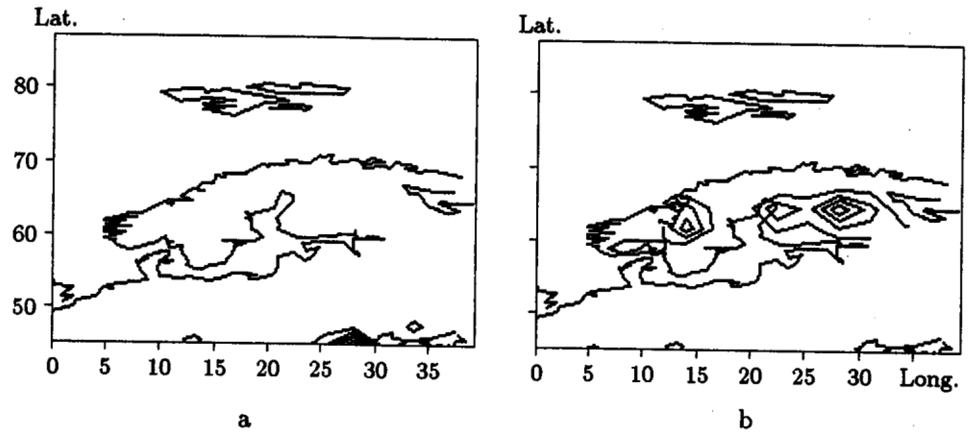

Figure 2. a) Microbial respiration flux CO_2; b) roots, stem and leaves respiration flux CO_2, April

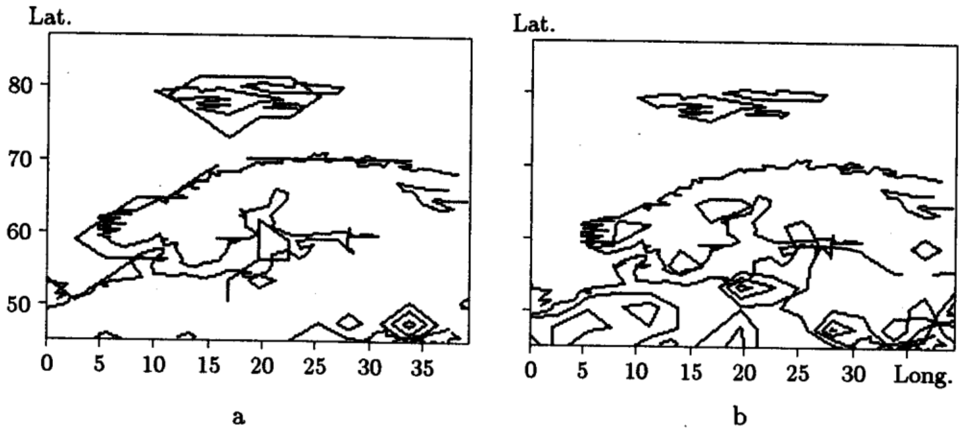

Figure 3. a) sensible heat flux; b) latent heat flux, April

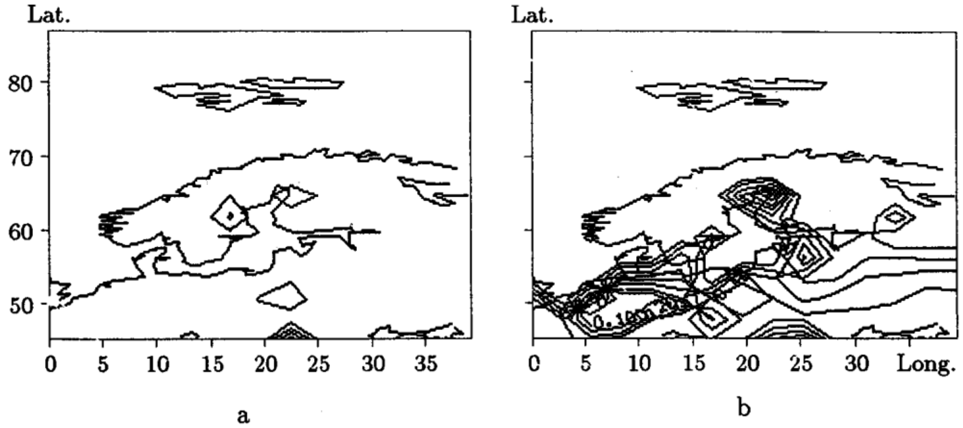

Figure 4. a) Net CO_2 flux; b) photosyn. flux CO_2, June

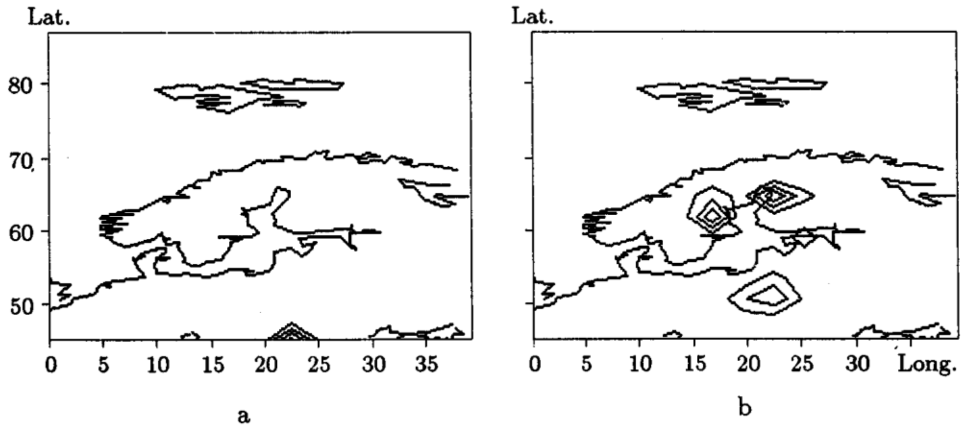

Figure 5. a) Microbial respiration flux CO_2; b) roots, stem and leaves respiration flux CO_2, June

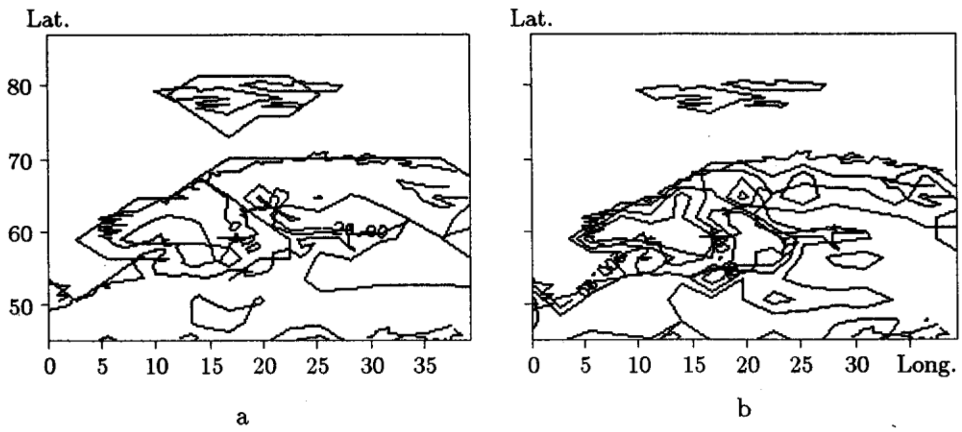

Figure 6. a) sensible heat flux; b) latent heat flux, June

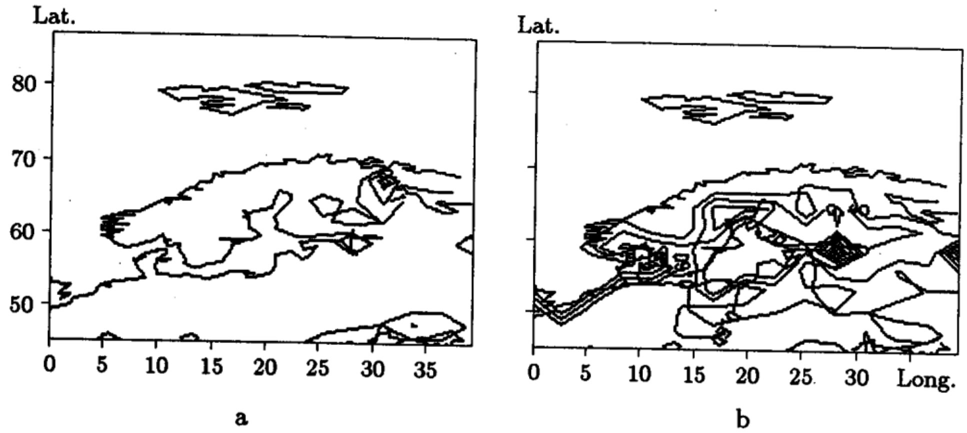

Figure 7. a) Net CO2 flux; b) photosyn. flux CO_2, August

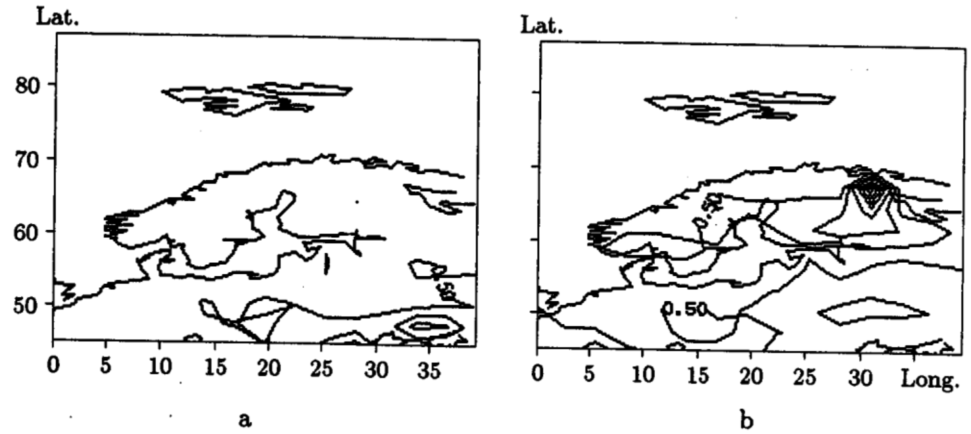

Figure 8. a) Microbial respiration flux CO_2; b) roots, stem and leaves respiration flux CO_2, August

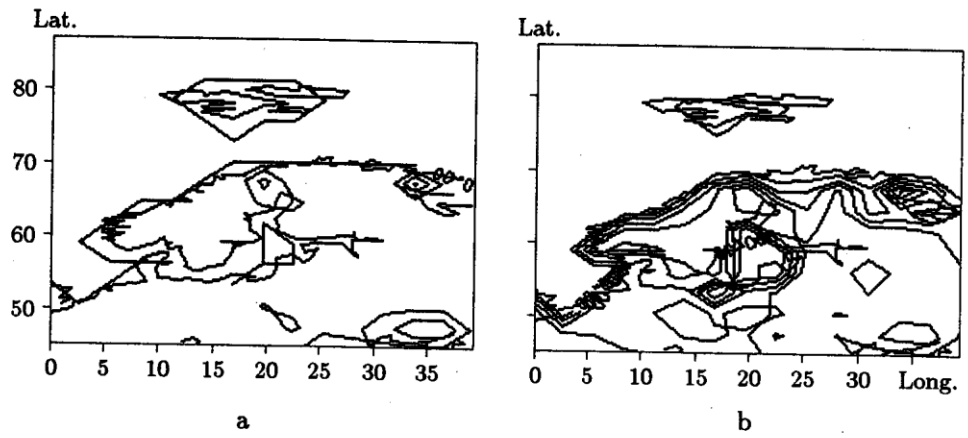

Figure 9. a) sensible heat flux; b) latent heat flux, August

References

[1] Sellers P.J., Mintz Y., Sud Y.C., Dalcher A. A simple biosphere model (Si B) for use within General Circulation Models // J. Atmos. Sci. – 1986. – Vol. 43. – P. 505–531.

[2] Bonan G.B. A land surface model (LSM version 1.0) for ecological, hydrological, and atmospheric studies: Technical description and User's Guide // NCAR Technical Note, NCAR/TN-417+STR, January 1996.

[3] Krupchatnikoff V.N., Yantzen A.G. The process parameterization of the atmosphere and the land surface exchange in the general circulation model (ECSib). – Novosibirsk, 1994. – (Preprint/RAN Sib. otd. VC; 1013) (in Russian).

[4] Bonan G.B. Atmosphere–biosphere exchange of carbon dioxid in boreal forests // J. Geophys. Res. – 1991. – Vol. 96D. – P. 7301–7312.

[5] Bonan G.B. Comparison of two land surface process models using prescribed forcing // J. Geophys. Res. – 1994. – Vol. 99D. – P. 25803–25818.

[6] Bonan G.B. Land–atmosphere CO_2 exchange simulated by a land surface process model coupled to an atmospheric general circulation model // J. Geophys. Res. – 1995. – Vol. 100D. – P. 2817–2831.

[7] Fomenko A.A, Krupchatnikoff V.N., Yantzen A.G. A finite-difference model of atmosphere (ECSib) for climatic investigations // Bull. NCC. Ser. Num. Mod. in Atmosphere, Ocean and Environment Studies. – 1996. – Iss. 2. – P. 11–19.

[8] Krupchatnikoff V.N., Maev V.K., Fomenko A.A. A model of the atmosphere on a limited area with high resolution // Izv. AN. SSSR. Ser. FAO. – 1992. – T. 28, № 6. – P. 33–45 (in Russian).