The Effects of Climate on Development of Ecosystem in Oasis

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ABSTRACT

When vegetation and bare soil coexist, in consideration of some ecological conditions of plant, the total evapotranspiration rate of the oasis and the temperature of vegetation and soil in different climatic and ecological conditions are calculated by using the thermal energy balance equations of vegetation and soil. The evapotranspiration rate depends on climatic and ecological conditions. In some conditions, quasi–bifurcation and multi–equilibrium state appear in the solutions of evapotranspiration rate in the areas covered by small part of vegetation.

Key words: Energy balance equations, Bifurcation, Bi–equilibrium state

1. Introduction

The development of ecological system in oasis, to a great extent, depends on the response of ecological system to environmental conditions, such as climate and water conditions, besides the physiological and biochemical conditions of vegetation. The theory concerning the development of ecological system is generally called ecological dynamics. It is substantively the interaction between the processes of ecosystem and climate.

In recent years, many numerical models have been developed on the interaction between biosphere and atmosphere, such as BAT of Dickinson et al. (1986) and SiB of Seller et al. (1986). But after Charney's deserts theory (Charney, 1975), there are few analytical theories about ecology–climate interaction.

This paper attempts in the way of theoretical analysis to study the effects of climate on the development of ecological system in oasis, in which the dynamic process of general atmospheric circulation is temporarily neglected, but the important process of the energy balance in a simple system that includes vegetation, soil and atmosphere, is considered. Basically the response of the development of different kind of vegetation in oasis to climatic conditions is just considered. The whole oasis is assumed to be a close system in the horizontal direction, and the energy budget is balanced among vegetation, soil and atmosphere.

2. Energy budget

For the vegetation in oasis, the group energy budget is calculated by averaging all of the single plant's energy budget, for example, taking

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\[ \overline{A} = \sum_{i}^{N} A_i / N, \]  

(1)

where \( N \) is the number of the plants. The another way is to average the connective areas of vegetation. The oasis coverage is assumed to be \( S \), in which \( a \) is the coverage of vegetation and \( b = S - a \) is the coverage of bare soil. The average value is defined by the connective area, that is

\[ \overline{A}_{a,b} = (a,b)^{-1} \sum_{i} A_{i,S}^0 (da, db), \]  

(2)

where \( d \) represents one small cell.

So the average energy budget equation of vegetation in oasis is

\[ \overline{F_i}^a = \overline{F_i}^h + L_v \overline{E_i}^a + F_{i,s}^a, \]  

(3)

where \( l,s \) represent vegetation and bare soil respectively, \( L_v \) is the evaporating latent heat, \( E_i \) is the evaporating rate of vegetation. The net radiation flux in Celsius scale (\( T = T^* + T', T^* = 273 \text{ K} \)) is approximately

\[ \overline{F_i}^n = (1 - \overline{a}_{i}) Q_a - 4 \sigma T^* \overline{(T_i^a - T')} , \]  

(4)

where \( \overline{a} \) is albedo, \( \sigma \) is the Stefan–Boltzmann constant, \( \varepsilon \) is the grey body coefficient. The sensible heat flux is

\[ \overline{F_i}^h = \rho_a C_p C_d V (\overline{T_i^a} - T'_{a}), \]  

(5)

where \( T^* \) is air temperature (because the scale of climate variation is larger than the scale of oasis, the constant air temperature is taken over oasis), \( \rho_a \) is air density, \( C_p \) is air specific heat on constant pressure, \( V \) is wind speed, \( C_d \) is the aerodynamics drag coefficient for heat.

According to Dickinson (1984), the latent heat flux is taken as

\[ L_v \overline{E_i} = \rho_a L_s L_{AE} (r_e + r_s)^{-1} [B^{-1}_s L^{-1}_v C_p (\overline{T_i^a - T'_{a}}) + (1 - r) q_{sat} (T_a) ] , \]  

(6)

where \( B_s \) is the Bowen ratio, \( q_{sat} \) is the air saturation specific humidity, \( r \) is the air relative humidity, \( r_e^{-1} = C_d V \), \( L_{AE} \) is the leaf surface size coefficient, \( r_s \) is the resistance coefficient of stomata.

The last term on the right-hand side of Eq.(3) indicates that there are some vertical mixed processes over the land, so the temperature is different in the air just above vegetation and bare soil. There is also some horizontal heat exchange in the air. Now we assume that the temperature in the air near the ground is proportional to the temperature of vegetation and bare soil. The distribution of vegetation and bare soil is assumed to be uneven, so the horizontal heat exchange in the air near the ground can also be assumed to take the type of turbulence. This process can be parameterized as