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Predicting regional hydrological response to climate change using a water-energy coupled balance model based on the Budyko and Bouchet hypotheses

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Areal evaporation (E) on the long time scale is primarily controlled by the available energy and water. Thereinto the available energy can be measured by potential evaporation (E_0), and the available water can be represented by precipitation (P). In other words, E can be expressed as a function of E_0 and P. The function is called water-energy balance equation, which can be expressed as $E = E_0 P \Big/ (P^n + E_0^n)^{1/n}$, with n being a parameter representing the catchment characteristics. Due to the feedback of atmosphere on land surface, E increases as a result of increasing$P$; and it will lead to a decrease in E_0 according to the complementary relationship between actual and potential evaporation. If we express P, E_0 and E as a point $(P,\ E_0,\ E)$ in the state space, as a result of precipitation changing from P_1 to P_2, the state changes from an initial state $(P_1,\ E_{0,1},\ E_1)$ to a new state, not being $(P_2,\ E_{0,1},\ E_2)$, but $(P_2,\ E_{0,2},\ E_2)$. In other words, the water-energy balance equation cannot evaluate the change in E because of E_0 having a change. To calculate $(P_2,\ E_{0,2},\ E_2)$, another function is introduced from the complementary relationship (CR) between potential and actual evapotranspiration as $bE + E_0 = (1+b)\ \ E_w$, where b is a constant of proportionality; E_w is the wet environment evapotranspiration, which can be calculated from the net radiation (R_n) by the Priestley-Taylor equation. It can be notable that these two equations have two independent variables (P and R_n, not being interrelated, i.e.$\partial P/\partial R\mathrm{n} = 0)$, therefore the two dependent variables (E and E_0) can be resolved. This implies that a relatively stabile state $(P,\ E_0,\ E)$ can be reached

in a given catchment under particular radiation and precipitation. Simultaneously, equations $dE = \partial E/\partial P \cdot dP + \partial E/\partial E_0 \cdot dE_0$ (derived from the water-energy balance equation) and $bdE + dE_0 = (1+b)\, dE_w$ (derived from the CR) lead to the expression $dE = [\partial E/\partial P \cdot dP + (1+b)\, \partial E/\partial E_0 \cdot dE_{\mathrm{w}}]/(1 + b\partial E/\partial E_0)$. The regional response of the hydrologic cycle (dE and $dR = dP - dE$) to climate changes dE_w (dT and dR_n) and dP can be predicted.