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Simulation of water flow in plant communities

- SPAC model description, exercises and user's manual

SPAC
version 5.0

Henrik Eckersten

Institutionen för markvetenskap
Avdelningen för lantbrukets hydroteknik

Swedish University of Agricultural Sciences
Department of Soil Sciences
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Table of Contents

1 PREFACE

This report is especially designed for courses in biogeophysics. Two previous published reports, SPAC-GROWTH model description (Eckersten, 1991a) and SPAC-GROWTH user's manual (Eckersten, 1991b), are shortened and put together. This report also describes a new subroutine for soil water dynamics added to the SPAC model version 5.0 (dated 951205). The main objective of introducing the soil module is to get the model more pedagogic in terms of representing a complete water balance of the site. The soil water module includes mainly two processes; estimation of soil water potential in the root zone and soil surface evaporation. Both processes are based on information taken from the SOIL model (Jansson 1991) which is a model representing soil in much more detail. Hence, the modifications of the original description of the SPAC model mainly concern: (i) including a soil water module (ii) taken away the description of the GROWTH submodel, (iii) renaming parameter and variable names used in the computer and (iv) adjust symbols to basically follow Rosenberg et al. (1983) and Eckersten et al. (1995). In addition some new parameters of the model are described. However, note that the parameter list is not complete in this report. A more popular description of SPAC ver 5.0 (written in Swedish) is included in Eckersten et al. (1995).

The report also includes a section for exercises specially designed for studying the dynamics of the SPAC model. These exercises have been used in courses in biogeophysics in 1993 and 1994 at the Swedish University of Agricultural Sciences, and have been developed in collaboration with teachers and students of the courses. Special acknowledgements are given to Elisabet Lewan, Anders Lindroth, Emil Cienciala, Karin Blombäck and Jennie Andersson at the Swedish University of Agricultural Sciences, Uppsala. These exercises are run with help of a WINDOWS based program named SIMVB, which is a further development of SOILNVB described in Eckersten et al (1994). How to use SIMVB is also described in this report.

This model description section serves as a tool when using the model and then should be used together with the User's manual describing variables used in the program etc which is also included in this report. The link between the model description and the manual is through the symbols (see List of symbols). As regards the validity of the model, the reader is referred to other publications (see list of references) in which tests of different parts of the model have been made. The software of the model is available from the author on request.

Since the model aims to be a research tool, although hopefully suitable for many practical purposes, it includes possibilities to choose among different hypotheses (see the section on special functions) and will be modified as research makes progress.

A section of the model description usually starts with a short general summary of its contents (written in italics) followed by a more detailed verbal (and graphic) description of the calculation procedure. The section ends with the mathematical expressions. The numbers given to equations, figures and tables are related to the number of the subsection concerned.

SPAC MODEL DESCRIPTION

The model is a transpiration model based on the Soil-Plant-Atmosphere-Continuum (SPAC) concept simulating the flow of water from soil through the plant to the atmosphere. The model is developed for crops but can be applied on other species as well. The basic version of the model was described by Turner & Kowalik (1983) and Kowalik & Eckersten (1984).

The model (Fig. 300) consists of four compartments, one for easily available water located in the leaves, one for intercepted water on the canopy surface, one for soil water available for plant uptake and for soil water available for soil evaporation. The model simulates flows and states on a ground surface basis and assumes horizontally uniform stands (in terms of the model parameters). The time step of the water submodel is 1-4 minutes. Input data are minute values on global radiation, net radiation, air temperature, air relative humidity, wind speed and precipitation, registered above the canopy. Alternatively daily values on soil water potential can be used as input instead of being simulated. Also daily values of the weather driving variables can be used by choosing special functions generating minute values of temperature, air humidity etc.

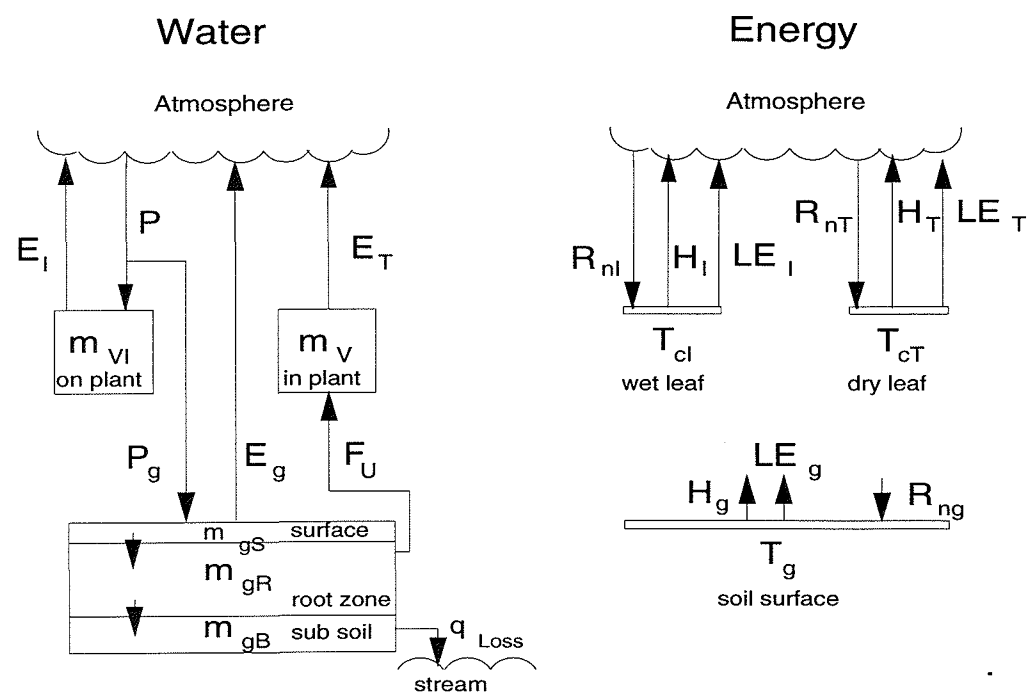


Figure 300. Schematic description of the SPAC model. Solid lines are flows of water or energy. For explanation of symbols see text and list of symbols.

The leaves contain water which is easily available for transpiration. The transpiration occurs during day-time when stomata are open and the rate is determined by the radiation energy available, the drying "power" of the air and several factors regulating the flow of water from the plant to the atmosphere. The loss of plant water is compensated by the uptake of water from the soil which, however, for several reasons can be delayed or is too small to meet the transpiration demand. If, for instance, the soil water availability is small then the plant water reservoir decreases. The plant then closes its stomata and the transpiration decreases and the plant can stabilize its water status on a new lower level. During the night the stomata are closed and the plant loses water only very slowly through the cuticle. Then the plant can recover to a plant water status close to that of the soil. The flow of water is described in terms of water potentials and resistances.

2.1 Plant water

The amount of easily available water is proportional to the leaf area. It is decreased by transpiration but increased through the root uptake created by the differences in water potentials of the plant and the soil. A closed canopy typically contains much less exchangeable water than is lost and gained daily through transpiration and uptake. Hence the water reservoir is replaced several times a day.

There is a reservoir of easily available water in the plant (m_V) from which water can be transpired (E_T). The driving force for transpiration is the vapour pressure difference (e_{cs} - e_a) between the air inside the stomata cavities and the ambient air. The flow is retarded by the resistances of stomata (r_c) and the air outside the leaf (r_a). As the plant loses water from its maximum value (m_{VMax}) the canopy water potential (ψ_c) drops below that of the soil (ψ_g). This difference is the force for uptake of water (F_U) against the resistances of the soil (r_g) and the plant (r_p). Each unit of leaf area can maximally contain m_{Vo} amount of easily exchangeable water corresponding to a maximum water potential (ψ_{cMax}). When the reservoir is emptied the canopy water potential is ψ_{cMin}. The difference in plant water content (δm_V) during a time-step (δt) is calculated with a procedure described by Kowalik & Eckersten (1984). (Eqs. 310-313).

$$\delta m_V = (F_U - E_T)\delta t \qquad E_T \geq 0 \qquad (310)$$

where:

$$F_U = (\psi_g - \psi_c)/(r_g + r_p) \qquad (311)$$

$$\psi_c = \psi_{cMax} - (\psi_{cMax} - \psi_{cMin})(1 - m_V/m_{VMax}) \qquad m_{VMax} = m_{Vo} LAI \qquad (312)$$

$$E_T = \frac{\rho_a C_p}{\gamma L} \frac{e_{cs} - e_a}{r_c + r_a} \qquad (313)$$

2.2 Canopy energy balance

The radiation energy absorbed by the canopy is used for the evaporation of water from the plant. The evaporation rate (latent heat flux) is also determined by other factors and often, during day-time, more radiation is absorbed than is needed to meet the energy demand by evaporation. Then the canopy surface becomes warmer than the ambient air. The excess heat is leaving the plant through the sensible heat flux. During night or at rainfall, normally the opposite occurs. We assume that the energy storage rate in leaf tissues is negligible in comparison with the other flows. This assumption is perhaps not so good when the other flows are small, as close to sunrise or sunset. The variables determining the partitioning of solar energy between the latent and sensible heat fluxes are for instance wind speed, air humidity and stomatal resistance.

The surface temperature (T_c) is adjusted so that the canopy energy balance is fulfilled. The radiation energy exchange between canopy and the surroundings is the net radiation intercepted by the canopy (R_{nc}) which is the net radiation above canopy (R_n) minus the corresponding value below canopy. The latter value is calculated according to Beers' law using the radiation extinction coefficient (κ) and the leaf area index (LAI). The energy balance is, in addition to R_{nc}, also affected by the fluxes of sensible heat (H_T) and latent heat (LE_T) whereas storage of heat in plant tissues is neglected (Eqs. 320-322).

The sensible heat flux is proportional to the difference between the surface temperature and the air temperature (T_a) divided by the resistance for flow of heat in the air which is assumed to be the same as for vapour (r_a) (alternative exists, see section on special functions). The latent heat flux (which is proportional to transpiration) is created by the vapour pressure difference between the surface of the stomata cavities (e_{cs}) and that of the surrounding air (e_a) having a relative humidity equal to h_a. The air at the evaporating surfaces in stomata is assumed to be at saturation. T_c is determined by changing its value, using iteration, until the sum of all three fluxes is below a certain limit (Δ_{Max}) which is close to zero (Eqs. 320, 322-324).

$R_{nc}-H_T-LE_T \leq \Delta_{Max}$	T_c *is changed until this statement is fulfilled*	(320)
where:		
$R_{nc} = R_n(1-\exp(-\kappa LAI))$		(321)
$H_T = \rho_a C_p (T_c-T_a)/r_a$		(322)
$E_T = \frac{\rho_a C_p}{\gamma L} \frac{e_{cs}-e_a}{r_c+r_a}$		(313)
$e_{cs} = a_e\exp((b_eT_c'-c_e)/(d_eT_c'-e_e))$	$T_c'=T_c+273.15$	(323)
$e_a = h_a e_s$		(324a)
$e_s = a_e\exp((b_eT_a'-c_e)/(d_eT_a'-e_e))$	$T_a'=T_a+273.15$	(324b)

2.3 Resistances

The pathway for water flow from bulk soil to the atmosphere is represented by four resistances: the soil-root resistance (r_g) from the soil, where the water potential is ψ_g, to the root surface, the plant resistance (r_p) from the root surface to the mesophyll of leaves, the stomatal resistance (r_c) from the leaf mesophyll to the air just outside the leaf surface and finally, the aerodynamic resistance (r_a) from close to the leaf surface to the ambient air above canopy. The resistances vary with environmental conditions of the air and the soil as well as with the plant conditions. If, for instance, the wind speed or the radiation or the soil water potential increases then the resistance against water flow decreases (Fig. 330).

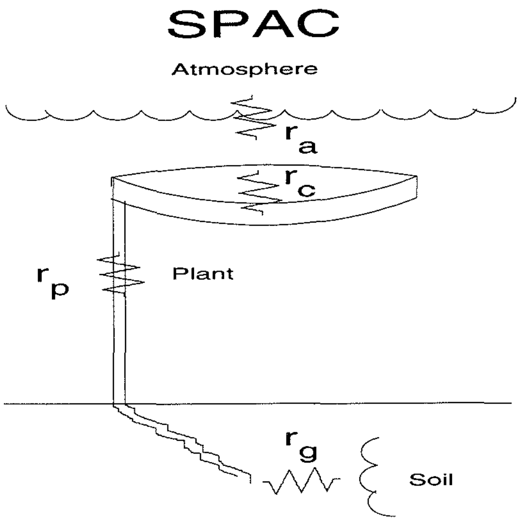


Figure 330. Schematic description of the pathway for water from soil through the plant to the atmosphere. For explanation of symbols, see text.

The soil-root resistance (r_g) is proportional to the root density factor (b_g) which accounts for the geometry of the root system. The resistance increases with decreasing unsaturated hydraulic conductivity ($a_g|\psi_g|^{-c_g}$) which in turn decreases faster with decreasing soil water potentials (ψ_g) when the "soil pore size factor" (c_g) is high, as for sandy soils for instance. (Eq. 330) (Fig. 331).

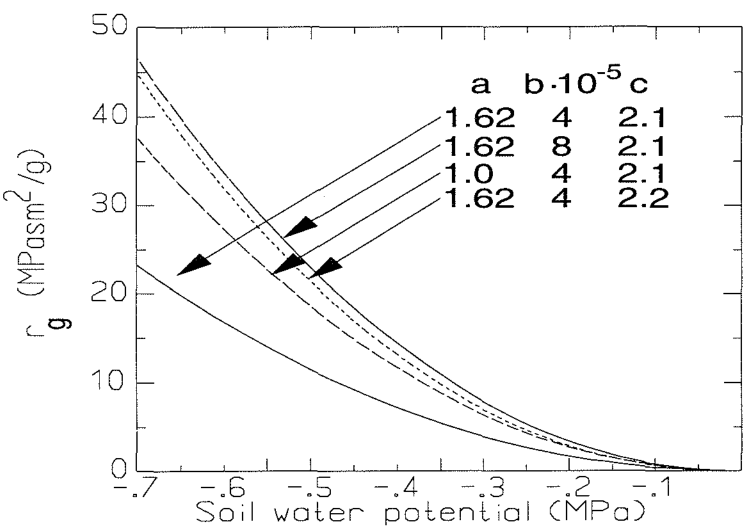


Figure 331. The soil-root resistance as function of the soil water potential.

The plant resistance (r_p) is assumed to be constant (Eq. 331).

The stomatal resistance of the whole canopy, i.e. per unit ground surface (r_c) is affected either by the incoming short-wave radiation (R_s), the canopy water potential (ψ_c) or the vapour pressure difference of the air ($vpd=e_s-e_a$). Three separate mechanisms are assumed to regulate stomata, one represented by $r_c(R_s)$, one by $r_c(\psi_c)$ and one by $r_c(vpd)$. The actual value of r_c is then the highest value given by the three functions. The User can choose which of the functions that should be active. If the User gives the resistances per unit leaf area the stomatal resistances are assumed to be coupled in parallel with each other, i.e. the stomatal resistance is inversely proportional to the leaf area index. (Note that in the program alternative ways of combining these functions are available, also more sub functions are available.) (Eqs. 332-337).

The aerodynamic resistance (r_a) is inversely proportional to the wind speed (U) measured at height (z_U). r_a is expressed as a function of characteristic heights of the stand. r_a decreases with the roughness height (z_o) and the displacement height (z_d) at which the logarithmic wind profile (derived for the conditions above the canopy) yields a wind speed equal to zero (Eq. 338) (Fig. 334).

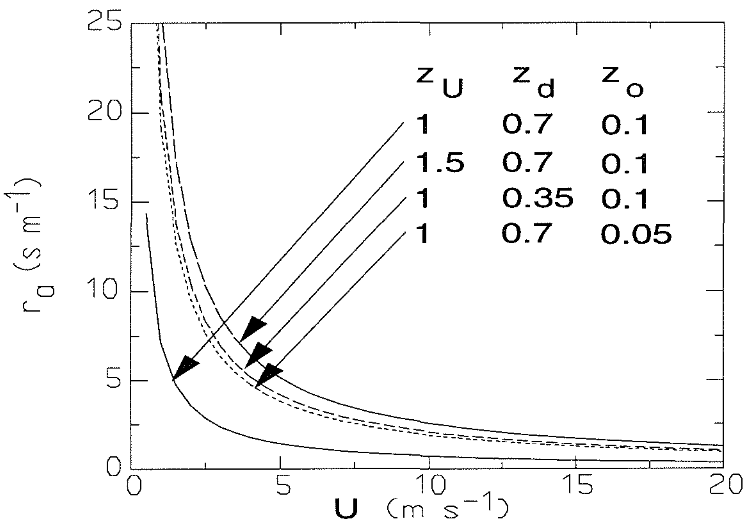


Figure 334. Aerodynamic resistance as function of wind speed.

$r_g = \dfrac{b_g}{a_g \lvert\psi_g\rvert^{-cg}}$		(330)
r_p = constant value		(331)
$r_c = \max\,(r_c(R_s(i))\,,\, r_c(\psi_c)\,,\, r_c(vpd))$	$r_{cMin} \le r_c \le r_{cMax}$	(333)
where:		
$r_c(\psi_c)$ = different functions	*see par. RESCWAT*	(334)
$r_c(R_s)$ = different functions	*see par. RESCRAD*	(335)
$r_c(vpd)$ = different functions	*see par. RESCVPD*	(336)
$r_c = r_s/LAI$		(337)
$r_a = \dfrac{\ln^2((z_U-z_d)/z_o)}{k^2 U}$		(338)

2.4 Rain interception

A fraction of the rain falling on the canopy (P) is intercepted on the vegetative surfaces and thereafter evaporated to the air. The rest (P_g) falls onto the ground and increases water content of soil. The rain is assumed to be intercepted by the canopy in a similar way as the radiation. This means that the fractional interception of the rain is the same for all sublayers of leaf area in the canopy. Hence Beers' law is used but, instead of the radiation extinction coefficient, we use the rain interception coefficient (κ_P). The upper limit of water interception (m_{VIMax}) is determined by the maximum amount of water possible to be retained by the unit leaf area (m_{VIo}) (Eqs. 340-342).

The intercepted water evaporates (E_I) in a way similar to that of the transpired water (E_T) after it has passed through the stomata. Hence, E_I is calculated using the same equations as for E_T but with the stomatal resistance (r_c) equal to zero. Since the evaporation takes place during the same time step as the interception, the reservoir for water on the canopy (m_{VI}) often becomes zero already during the current time step (Eq. 345).

Normally, not the whole canopy is wet. The canopy has a dry part ($LAI(1-m_{VI}/m_{VIMax})$) and a wet part ($LAIm_{VI}/m_{VIMax}$). From the dry surfaces transpiration can continue whereas on the wet surfaces it stops. The dry and wet surfaces have different energy balances since transpiration is retarded by the stomata resistance, whereas the evaporation of intercepted water is not. The fraction of total net radiation energy (R_n) available for transpiration is proportional to how large fraction of the canopy surface that is dry. Less number of stomata can transpire, therefore the stomatal resistance (r_c) increases in the same proportion as the available net radiation decreases. The net radiation of the dry surfaces (R_{nT}) and the increased r_c determines the temperature of the dry surfaces (T_{cT}) (see Eq. 320). For the wet surfaces the temperature (T_{cI}) is determined by the net radiation (R_{nI}) and the fact that r_c=0. (Eqs. 343-348).

$\delta m_{VI} = (P-P_g-E_I)\delta t$	$\leq m_{VIMax}-m_{VI}(t-1)+P-P_g$	(340)
where:		
$m_{VIMax} = m_{VIo}LAI$		(341)
$P_g = P\exp(-\kappa_P LAI)$		(342)
wet surfaces:		
$R_{nI}-H_I-LE_I \leq \Delta_{Max}$	T_{cI} *is determined*	(343)
where:		
$R_{nI} = R_{nc}m_{VI}/m_{VIMax}$		(344)
$E_I = E_T$ in Eq. 313 *but with:*	≥ 0 ; if $m_{VI}+P-P_g>0$	(345)
$r_c = 0$ and		
dry surfaces:		
$R_{nT}-H_T-LE_T \leq \Delta_{Max}$	T_{cT} *is determined*	(346)
where:		
$R_{nT} = R_{nc}-R_{nI}$		(347)
$E_T = E_T$ in Eq. 313 *but with:*	if $m_{VI}+P-P_g>0$	(348)
$r_c = r_c+(r_{cMax}-r_c)(m_{VI}/m_{VIMax})$		

2.5 Soil water

The link of the soil water module to the plant part of the model is through the plant uptake as given by Eq. 311. The soil water potential is simulated as function of water content of the root zone (Eqs. 365-6). In turn, the plant affects the soil water content through input of water to soil (throughfall; Eqs. 342 and 351) and output of water (uptake, Eq 361 and soil evaporation, Eqs 354-356).

The soil is divided into three layers. The surface layer (m_{gS}) receives water through rain (throughfall, P_g) and lose water through soil evaporation (E_g) to the atmosphere and percolation to the root zone ($q_{S\rightarrow R}$). The root zone (m_{gR}) receives water from the surface layer and lose water through root uptake (F_U) and percolation to the layer below root zone ($q_{R\rightarrow B}$). The layer below root zone (m_{gB}) receives water by percolation from the root zone and lose water through percolation or run off to layers below (q_{Loss}), which are not represented in the model. The amount of water in the root zone can also increase if the root depth increases ($\Delta m_{gRDepth}$, Eq. 362). Then water is taken from the layer below. If the thickness of the surface layer (z_{Surf}) is larger (i.e. deeper) than the root depth (z_r), no root uptake occurs. If no surface layer exists no soil evaporation occurs. The loss of water through percolation is the amount of water that is in excess of the amount of water at saturation (m_{gSMax}, m_{gRMax} and m_{gBMax}, respectively), defined as the relative water content at saturation (θ_s) multiplied by the depth of the layer concerned and the density of water (ρ_w).

Near saturation soil water potential in the root zone is a linear function of the relative water content (θ) which is related the bulk density of soil (ρ_g) ((Eq 366). At all other occasions it is a non linear function given by Brooks & Corey relationship (Eq. 365).

Soil surface evaporation (E_g) is determined by Penman-Monteith equation assuming the storage of heat in soil being neglectable in the energy balance. The aerodynamic resistance (r_{as}) is increased in proportion to leaf area (Eq. 355) and the surface resistance (r_{ss}) is inversely related to the relative water content of the surface layer (θ_{gS}) (Eq. 356).

Soil surface water balance:

$$\delta m_{gS} = (P_g - q_{S\rightarrow R} - E_g)\delta t \qquad (351)$$

where:

$$q_{S\rightarrow R} = m_{gS}(t-1) - m_{gSMax} \qquad >0 \qquad (352)$$

where:

$$m_{gSMax} = \rho_w \theta_s z_{Surf} \qquad (353)$$

Soil evaporation:

$$E_g = \frac{\Delta R_{ng} + \rho_a C_p vpd / r_{as}}{\Delta + \gamma(1 + r_{ss}/r_{as})} \qquad (354)$$

where:

$$r_{as} = r_a + a_{ras}LAI \qquad (355)$$

$$r_{ss} = a_{rss}/(\theta_{gS} + \theta_{rss})^{brss} \qquad (356)$$

where:

$$\theta_{gS} = m_{gS}/(z_{Surf}\rho_g) \qquad (357)$$

Root zone water balance:

$\delta m_{gR} = (q_{S\rightarrow R}+\Delta m_{gRDepth}-q_{R\rightarrow B}-F_U)\delta t$ (361)

where:

$\Delta m_{gRDepth} = m_{gB}(z_r(t)-z_r(t-1))/(z_g-z_r)$ (362)

$q_{R\rightarrow B} = m_{gR}(t-1)-m_{gRMax}$ >0 (363)

where:

$m_{gRMax} = \rho_w\theta_s(z_r-z_{Surf})$ (364)

Root zone water potential:

$\psi_g = \psi_a((\theta-\theta_r)/(\theta_s-\theta_r))^{-cBC}$ if $\theta<\theta_s-\theta_m$ (365)

$\psi_g = \psi_m(1-(\theta+\theta_m-\theta_s)/\theta_m)$ if $\theta>\theta_s-\theta_m$ (366)

where:

$\theta = m_{gR}/((z_r-z_{Surf})\rho_g)$ (367)

$\psi_m = \psi_g(\theta_s-\theta_m)$ (368)

Layer below root zone water balance:

$\delta m_{gB} = (q_{R\rightarrow B}-\Delta m_{gRDepth}-q_{Loss})\delta t$ (371)

where:

$q_{Loss} = m_{gB}(t-1)-m_{gBMax}$ >0 (372)

where:

$m_{gBMax} = \rho_w\theta_s(z_g-z_r)$ (373)

2.6 Special functions

In this section alternative or complementary calculations are presented. These are available in the model and normally activated using the switch named Special.

The stomatal resistance (r_c) can, in addition to the subfunctions given in chapter 3 also be a combined function ($r_c(R_s,vpd)$) of radiation and vapour pressure deficit (vpd). Different functions can be chosen. The function is included among the other subfunctions. (Eqs. 411-413).

The aerodynamic resistance (r_a) is modified by a factor named the Richardson number (Ri) which accounts for the effect of thermal convection on the transport of heat and vapour in the air. This factor is proportional to the gravitation force (g), the distance from the canopy top to the roughness height (z_U-z_o) and the temperature difference between the surface and the air ($T_c(t_1)-T_a$; t_1 means that the input value of the time step is used). Normally it is very small (Eqs. 414-415).

The displacement height (z_d) and the roughness length (z_o) used for calculating the aerodynamic resistance could be set proportional to the height where the wind speed is measured (z_U). (Eq. 418-419)

In the original version of the model the aerodynamic resistances for heat and vapour are given equal values. The resistance for heat (r_{aH}) could, however, be divided by a factor (a_{ra}) as compared to that for vapour (r_a) (Eq. 419a).

The net radiation above canopy (R_n) should be an input variable. However, this variable is often lacking and then it can be estimated from the global radiation above canopy (R_s) (Eq. 420).

$r_c(R_s,vpd)$ = different functions	*see par. RESCLOHA*	(412)
$r_a = r_a'/(1+10Ri)$		(414)
where:		
$Ri = g(z_U-z_o)(T_c(t_1)-T_a)/((T_a+273.15)U^2)$		(415)
$z_d = a_d z_U$		(418)
$z_o = a_o z_U$		(419)
$r_{aH} = r_a/a_{ra}$		(419a)
$R_n = a_R R_s - b_R$		(420)

SPAC SIMULATION EXERCISES

Exercise 1;
Introduction to a simulation model (SPAC)

Objective

The aim of this exercise is to give you an answer to the following questions:

- What is a simulation model?
- How is it used technically?
- What is the structure of the SPAC model?

A simulation model, what is that?

I will try to answer that question shortly by describing some often used terms.

A basic problem that we will try to solve is: What is the effect of weather on plant water dynamics? To answer this question we must have an idea of how the plant interacts with its environment.

In this case the plant and its surrounding is our system. The system is limited in space; it has a boundary. The boundary conditions is here the situation in the atmosphere (weather). These conditions vary with time and are input to the model given by driving variables.

We have some ideas of how weather influence soil and plant. These ideas are our conceptual model which often is clear in structure and theory but normally not possible to evaluate in detail or comparable with measurements in a systematic way.

The formalised model is based on the conceptual model. The theory of the conceptual model is formalised in terms that can be evaluated quantitatively. A theory expressed in words, for instance "when the atmosphere is dry the possible evaporation from the wet leaves is high", should be expressed in precis terms. How dry is the air? How wet are the leaves? How is vapour transported from the wet leaves to the dry air? All these things must be expressed in quantitative terms. The formalised model we call a mathematical model or here only model. The model represents a system including several processes going on simultaneously. The processes are represented by equations, for instance how the stomata of the leaves open when light fall an the leaves. The reason for the opening is that light causes chemical reactions in the grid cells. This is a rather general rule for plants and can be represented by one type of equation. However, the degree of opening differ between species, given a certain amount of light. In the model the degree of light dependency is represented by parameters. Hence, parameter values represent plant properties and normally differ between plant types. A parameter value is normally independent of time. If it is not, its variations is an indication that the model is not general in some way.

The result of the model concerns a certain time interval. If the time step is one minute, as it is in the SPAC model, the calculations of for instance the transpiration, concerns the evaporation from leaves to the atmosphere during the last minute. Similarly the uptake calculations concerns the amount of water taken up by roots during the last minute. These two variables are called flow variables and transport water from the plant and to the plant, respectively, thereby determining the amount of water stored in plant, which is called a state variable and is the base for the calculations of flows during the next minute. The model calculates the flows to and from the state variable which then changes minute by minute. We could say that the model imitate the plant development. This type of model we call simulation model. The state variable is hence the amount of water that exists at a certain occasion. The unit is independent of time and is the mass divided by a reference area (gH_2O/m^2). The flows which change the state over time are expressed in $gH_2O/m^2/s$. At the start of simulation state variables are given by initial values which are input to the model.

In case a flow variable depends on the state variable that it changes, there is a feedback in the system. It is a positive feedback if an increase in the state variable increases the flow into it. There is an unstable situation between state and flow. In the opposite case we have a negative feedback and a self-regulating situation (increased state decreases inflow).

All these calculations can theoretically be made by hand. However, of practical reasons we make use of a computer since it is an enormous amount of calculations to be made.

Summary:
- The system is represented by the model.
- The model has a boundary. The conditions at the boundary change with time and are model input represented by driving variables.
- The structure of the model is build up of state and flow variables.
- At start of simulation the state variables are given by initial values.
- The flow variable change the state variables.
- The flows are determined by the processes of the system.
- Processes are represented by equations and parameters.
- Properties of the system are represented by parameter values

The objective of using a simulation model differs:
- As a research tool it is used to evaluate hypotheses about interactions in nature and to get ideas for setting up new hypotheses.
- As an education tool it is used to illustrate dynamics in nature which of practical reasons otherwise are not possible to study (because the resources are limited). Both already known processes and purely theoretical processes can be studied this way.
- As a forecast tool it is used to evaluate the effect of known or possible changes of the system properties or of changes in the boundary conditions on a certain variable, for instance the transpiration.

How to run the model

- Start the SIMVB-program:
From DOS you start the SPAC model by writing: win simvb. From WINDOWS you start the model by making a double-click on the icon for simvb, if there is an icon, otherwise you use the "run" option under "Archive" by starting c:\sim\exe\simvb.exe. Note that within the SIMVB-program only single-clicks are used.

- Choose exercise:
Start by pressing "Start here" and select "BGF-course" and the exercise concerned.

- A typical procedure to make a simulation:
Select first input data under "Preparation of input". You can view the driving variables in "Presentation of input" if you want. The simulation starts by pressing "Simulation" and "normal". You can look on the results under "Presentation of output". If you want to store the results from this simulation in a file which is not overwritten by later simulations, you do it under "Store files". After having going through this procedure once you can select any option at any time. In many cases when choosing an option you come to a sub-menu. You go back to the main menu by closing the sub-menu.

- If you for some reason happen to leave the SIMVB program you restart the program as shown above and select the exercise concerned. After that, if you already have made preparations and do not need/want to do it again, then select "Check off". For further information see the SIMVB description below.

Simulation exercise

Run the program according to above, choose exercise 1. Select a "rainy day" under preparation and answer the following questions:

-1- Which parameter groups exist in the model? (Select "view parameters" in the presentation of input sub-menu)?

-2- Which are the driving variables?

-3- Make the simulation

-4- Which are the state variables that describes the storage of water?

-5- Which are the flows of water to and from the state variables?

-6- Make a picture of how the state and flow variables are connected.

-7- Store the simulation

-8- Make a comment in the comment box that you stored the rainy simulation (point the mouse on the background of the menu and press the right bottom to open the comment box, remember to save the content afterwards).

Exercise 2;
Plant

Objective

To illustrate the role of plant properties for water and energy dynamics in the soil-plant-atmosphere system.

Background

During night when it is dark stomata are closed and the plant does not transpire. If there is a shortage of water in the plant due to transpiration the previous day the plant recover its water status by uptake from soil. As the sun rises in the morning the air becomes warmer and drier and the gradient between water status in the air and the plant increases. The solar radiation is absorbed by the leaves and stomata open. The plant starts to lose water through transpiration depending on the energy balance of the canopy and of the prerequisites for evaporation. The loss of water creates a difference in water potential between plant and soil. Water uptake from soil starts which compensates for the losses. On its way from soil to the atmosphere the water flow is retarded by resistances in soil, plant, stomata and the air. A theory for this water dynamics of soil-plant-atmosphere is formulated in the SPAC model (Soil Plant Atmosphere Continuum).

1) Make a reference simulation, select Brassica under preparation of input. Store this reference simulation so that you can compare it with later simulations.

2) Other plant properties

You have three other plant stands which basically are of the same type as the reference Brassica you stored under 1) above. However, for each of them there is <u>one</u> property that differs from the reference plant. The aim of this exercise is to examine which property this is by analysing differences in flows of water, temperature and energy fluxes etc between the stands. Note that there is one precise answer in terms of a certain change in a parameter value. Try to find this answer and explain how you derived it.

You do it this way: Make a new preparation with the new plant ("Preparation of input") and make a new simulation. In "Presentation of outputs" you can compare the new simulation with the reference simulation. Answer the following questions:
- Which property (parameter) differs between the plants?
- How does it differ (parameter value change)?
- Explain how you derived it.

When you shall <u>change parameter values</u> manually, there are technically two ways to do it. Either you edit the parameter file AIN_MAN.PAR (see Edit files in the SIMVB description) or you can use the PREP-program interactively (see Use PREP program manually). The different methods have different advantages. Editing AIN_MAN.PAR keep a good control of the changes introduced from time to time. The PREP method gives you an overview of all parameters in the model and an easy way of changing their values.

Plant_A:
Plant_B:
Plant_C:

Exercise 3;
Effect of sun elevation on evaporation

Objectives

- To estimate how global radiation and net radiation change when the latitude change
- To estimate how the radiation change influence the evaporation and energy balance of a crop.

Background

Solar radiation is the most important factor influencing processes on earth. It varies a lot between different latitudes. For instance, how much more solar radiation do surface receive on latitude 40° (for instance Italy) compare to here in Uppsala (60°)? Why is the radiation higher in Italy? Is it because the sun beams reach the soil surface at a different angle or is it because the sun beams have a shorter pathway through the atmosphere? If the plants in Sweden would receive as much radiation as in Italy, just for a day, how would that influence transpiration? But, of course, if we consider longer time periods than one day, the climate should change due to the high radiation level. Which other weather variables would also change? And what would then be the effect on transpiration?

The exercise is divided into four parts:

(1) estimate the change in radiation conditions in Uppsala (60 °N) if the sun elevation would be the same as for latitude 40 °N (corresponds to Italy).

(2) estimate the plant water and temperature conditions during a sunny day in August in Uppsala.

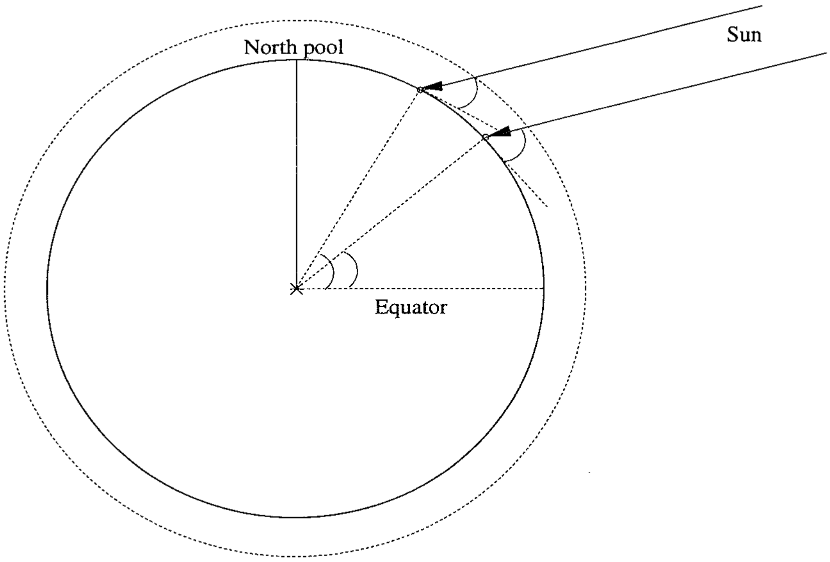
(3 and 4) estimate the change in plant water and temperature conditions due to the changed radiation climate.

---

1) Estimate the change in radiation due to latitude change

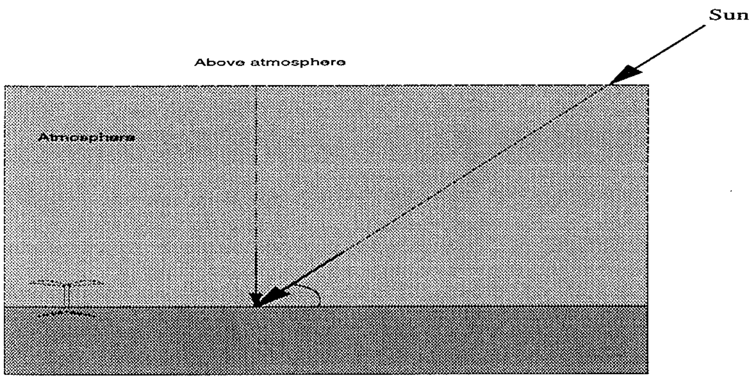
Estimate the difference in global radiation between the latitudes by estimating how it differs under clear sky conditions at noon.

First you have to know the sun elevation at 40 °N. Estimate this by making use of the fact that the difference in sun elevation between latitudes, at noon, is related to the difference in latitude. A suggestion is that you start by calculating the sun declination. Make use of the Figure below. At noon the sun elevation is at maximum, and for August 13 in Uppsala it is 45°.



Sun declination:	
Sun elevation at noon, August 13 at 40 °N:	

Estimate, with help of Beer's law and Lambert's cosine law, the global radiation at Uppsala and then the corresponding value for 40 °N assuming the same turbidity as in the air above Uppsala.



R_{sc} = Solar constant
R_s = Solar radiation at ground surface but perpendicular against the sun arrays.
R_s = Global radiation
β = Sun elevation
$x_o = 10^5$ m (100 km) = shortest distance between soil surface and the upper boundary of the atmosphere.
x = length of the pathway of the sun arrays through the atmosphere.
$\kappa_a = 0.22\ 10^{-5}\ m^{-1}$ = extinction coefficient, related to x.

What is the relative change in global radiation?	
What is the relative change in global radiation, only caused by a decreased pathway for sun arrays through the atmosphere?	

2) Reference simulation for Uppsala

Make a reference simulation and store the results so that you can compare future simulations with this one.

3) Effect of changed incoming radiation on the energy balance, transpiration and plant water storage.

Make a new simulation including the estimated change in radiation ("Preparation of input", "changes", "input variables"). Remember to change both global and net radiation.

3a) First, examine the changes in energy exchange in more detail. Give the changes between the new simulation and the previous one (choose the way to compare yourself):

Variable	Change approx.	Equation	Factor(s) mainly responsible for the change. Refer to the equation and explain why.
net radiation			
sensible heat flux			
latent heat flux			
leaf temperature			

On a daily basis, are the canopies warmed or cooled?

3b) Sum up using your own words, the important changes in both energy exchange and water conditions, and give an explanation to them.

4) Effect of changed climate on plant water and energy conditions.

For latitude 40 °N not only the global radiation changes. As a consequence of the different global radiation also other weather variables will differ (we continue to assume optimum soil water conditions).

First you change the weather factor you want to change "Preparation of input (changes)", then you make new simulations and compare the results with other simulations to answer the following questions:

Which weather factor(s) have you changed? How? Give an explanation of why this (these) variables) should be changed? Describe and give an explanation of the important changes of water and energy conditions. Compare with the case when you only changed the radiation.

Exercise 4;

Effect of plant structure on evaporation and energy exchange

Objectives

- Estimate how wind speed above the canopy differs between an agricultural crop and a forest.
- Estimate how the difference in plant structure influences evaporation and energy balance of the plant.
- Estimate properties that can explain differences in uptake rates of a crop and a spruce stand.

Background

The transport of heat and vapour in the air is related to the wind. Close to the canopy, wind is disturbed by the roughness of the surface. Turbulence occur which is very effective in transporting vapour and heat. The degree of turbulence depends on how "rough" the surface is. Is the forest more rough than an ordinary agricultural crop? Is there some concrete measure for this difference? How will this difference in surface structure influence the plant energy and water conditions? This exercise will try to answer this later questions. It will also ask you for other differences between a crop and a forest in terms of properties that determine the water dynamics. By considering the most important differences, you might predict the water uptake by spruce. You can check how well you succeed by comparing your simulations with measured data on sap flow in spruce.

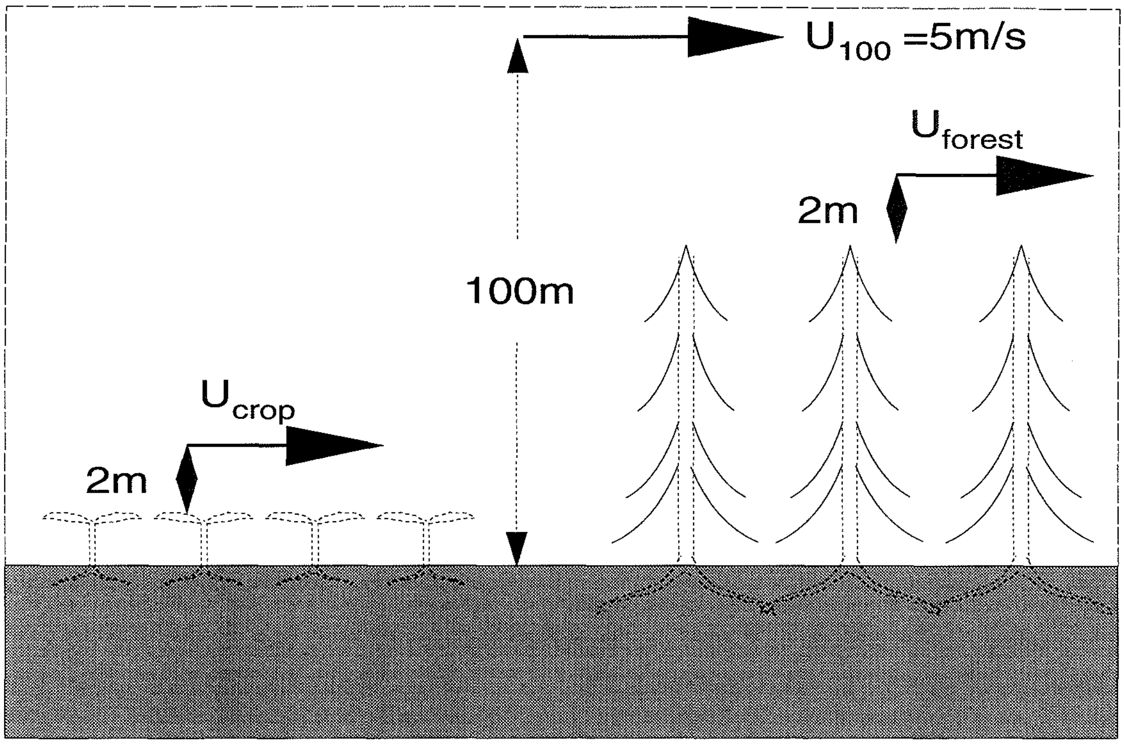
The exercise is divided into five parts:

(1) Estimate the parameters for plant structure that determine wind speed above the canopy. (2) Simulate the evaporation and energy exchange between plant and atmosphere for both an agricultural crop and a forest, and compare the results. (3) Compare the simulated water uptake with measured sap flows. (4) Calibration of the SPAC model. (5) Validation of the SPAC model.

1) Estimate plant properties and wind speed.

1a) Describe the surface properties of the different plant types. Do this by estimating the parameters in the logarithmic wind profile equation. Assume the crop to be 1 m high and the forest to be 20 m high.

Under which circumstances can the logarithmic wind profile law be used to determine the wind speed above the canopy?	
Surface properties of the crop:	
Surface properties of the forest:	



U = wind speed (m s^{-1})

1b) Estimate the wind speed 2 m above the canopies if the wind speed at 100 m is 5 m s^{-1}.

Equation:	
Wind speed 2 m above the crop:	
Wind speed 2 m above the forest:	
Ratio between wind speed above forest and crop (U(forest)/U(crop)):	

2) Make simulations with the estimated values.

- Change parameter values to those you estimated above (see SIMVB manual below).

- Make a simulation for the crop

- Store the results.

- Change parameters again, now to those of the forest.

- Change the wind speed according to the ratio between forest and crop, which you estimated above.

- Make a simulation for the forest.

- Compare the results between forest and crop (choose the way to compare yourself) and describe the important differences and the reason for them:

3) Compare the simulated uptake with measured values for sap flow in spruce.

First you have to get access to the measured sap flow data. Choose "Preparation of input", "Validation (Sap flow)"!

Then you can compare the simulated values with the measured ones by choosing "Presentation of output" "Validation".

Give a description of how well your simulation fitted measured data. Both in your own words and in terms of statistical values:

	Tree 1 & Tree 2 <u>A0, A1, R2, n</u>

4) Calibration

Above, when simulating the forest, you changed only the plant structure. However, other properties will also differ compared to a crop. Which ones do you think? Select those properties that you think will improve your plant uptake predictions. Express the properties in terms of parameters of the model. Change the parameter value(s) (as in 2 above) and make a new simulation. Repeat this until you are not able to get a better agreement between simulated uptake and measured sap flow. Note that changes of parameter values should be realistic. Consider first of all that leaf area index of a spruce stand of this type is about 8 or even more.

Changed parameters. How and why?	Best simulation Tree 1 & Tree 2 <u>A0, A1, R2, n</u>

5) Validation

Select a new period and make a new simulation with the parameter values derived for spruce with help of the calibration above.

Describe the performance of the model:	Tree 1 & Tree 2 <u>A0, A1, R2, n</u>

SPAC USER's MANUAL

This manual describes the SPAC model version 5.0 (dated 951030). It is a shortened and revised version of the original SPAC User's manual (Eckersten, 1991b).

4.1 Files

■ Input files

XXXX.BIN: The driving variable file is a PG-file. The variables in the PG-file can be organized in different ways depending on how different parameters are specified. An ASCCI file should be converted to PG-file before it can be used by the model (use the PG-program).

Two type of input files can be given. Normally minute (or about 10-minute) values are given and then they should be given in the order shown in the table below. In case daily values are given then the switch DRIVANA should be 2 and variables shoulbe given in the following order (see further Eckersten 1991b): 1) Daily maximum temperature 2) daily minimum temperature 3) Air humidity at time t_1 4) Air humidity at time t_2 5) Air humidity at time t_3 6) Global radiation 7) Wind speed 8) Precipitation 9) Soil water potential 10) Net radiation.

[]: the variable should be given in this position in the input file.

Variable	Symbol ; Explanation	(Unit)
DNETRAD	[7] R_n ; Net radiation above the canopy (see parameter STNETRAD).	(W m^{-2})
DPREC	[5] Precipitation or leaf wetness. (i) Precipitation (P). To prevent interpolation between values of DPREC the values of the adjacent minutes must be zero. (mm min^{-1}) (ii) If INTERCEPT-switch = 10 or 20: Leaf Wetness (<0.9 is wet ; >=0.9 is dry). (-)	(differs)
DRHUMAIR	[2] h_a ; Relative humidity of the ambient air.	(%)
DSOLRAD	[3] R_s ; Global radiation at the canopy top.	(W m^{-2})
DTEMPAIR	[1] T_a ; Temperature of the ambient air.	(°C)
DWATPOTG	[6] ψ_g ; Soil water potential (see SOILWPOT-switch).	(MPa)
DWINDSP	[4] U ; Wind speed in the ambient air.	(m s^{-1})

XXXX.PAR: The parameter file is an ordinary DOS-file with ASCII- characters. All parameters and their actual numerical values should be included in the file. If any parameter is missing in the file a message is displayed on the screen and a default value is selected from the SPAC.DEF file. New parameter files may be created prior the execution of the model using the EXECUTION-WRITE command.

SPAC.INI: Initial values of state variables should be given here. (Else they are zero).

Output files

SPAC.FIN: Final values of state variables.

SPAC_NNN.bin: Output variables are stored in a PG-structured where NNN is the current number of simulation. The file is a binary file to be used by the PGraph program for plotting results from the simulation. The file can be converted to ASCII format by using the PG-program.

SPAC_NNN.SUM: Contains a summary of all inputs used by the simulation and a summary of simulated results. The first part of this file (until the sign ;) corresponds to a parameter file. This means that you can repeat the simulation by renaming this file to a file with extension .PAR.

4.2 SWITCHES

The purpose of switches is to chose the simulation mode. Most switches could either be OFF or ON. Others can achieve different values.

Technical

CHAPAR

OFF *Default*	Parameter values are constant during the whole simulation period.
ON	Parameter values may be changed at different times during the simulation period. If editing directly into parameter files: the time of change and the new parameter values should be specified after the other parameter values (valid from the start of the simulation). A maximum of 20 time points can be specified.

INSTATE

OFF *Default*	The plant water is set initially so that the leaf water potential equals the soil water potential. All other state variables are initially zero.
ON	Initial values of state variables will be read from a file. The name of the file is specified by the user, the format should be similar as in the file for final values of state variables, created by the model when the OUTSTATE switch is on.

OUTSTATE

OFF *Default*	no action.
ON	final values of state variables will be written on a file at the end of a simulation. The name of the file is specified by the user and the format is the same as used in the file for initial state variables (see the INSTATE switch).

Model Specific

DRIVANA

0 *Default*	Driving variables are minute values
1-2	Some of the minute driving variables in the input file are not available, or wanted to be modified. This option allow you then to make simple modifications of the following driving variables: Soil water potential (DWATPOTG; parameters WSPSR and WSPSD) and Net radiation (DNETRAD; parameter STNETRAD). Only used if SPECIAL-switch is ON. For net radiation also when DRIVANA-switch = 2.
2	Weather driving variables are daily synoptic values. Those are used to calculate analytical minute values.

DRIVPREC

1 *Default*	The driving variable DPREC is the registration of precipitation rate (see further DPREC).
2	The the driving variable DPREC is the registration of wet or dry canopy (see further DPREC).

INTERCEPT

0	No simulations of evaporation of intercepted water on leaf surfaces. Precipitation is assumed to be zero.
1 *Default*	Evaporation of intercepted water (E_I) and transpiration (E_T) are NOT going on simultaneously. First the intercepted water is evaporated until the canopy is dry (no transpiration occurs). Then the transpiration starts.
2	Evaporation of intercepted water (E_I) and transpiration (E_T) are going on simultaneously. The total canopy net radiation (R_{nc}) is shared between the two processes in proportion to area of the two surfaces. The intercepted water receives m_{VI}/m_{VIMax} fractions of R_{nT} and the water for transpiration the rest. The stomatal resistance is increased linearly towards r_{cMax} when the fraction of dry surface decreases.

PENMANM

1 *Default*	Evaporation simulations are made using an iteration method for solving the canopy energy balance.
2	Evaporation simulations are made using the Penman-Monteith equation for calculating the latent heat flux and the energy balance. The simulation time decreases.

RESCANOP

0 *Default*	Different stomata resistance sub functions are combined by selecting the one with highest value.
1	Different stomata resistance sub functions are combined by adding them. Only used if SPECIAL-switch=1.
2	Different stomata resistance sub functions are combined by multiplication. Only used if SPECIAL-switch=1.

SOILWPOT

0 *Default*	Soil water potential is input given in the driving variable file
1	Soil water potential is simulated (Note that still the variable nr 6 in driving variable must exist although not used)

SPECIAL

OFF *Default*	Parameters in the group Special are NOT available.
ON	Parameters in the group Special are available. These parameters enables modifications or introduction of special functions normally kept fixed or not used.

TRANSP

0	No water flow simulations are made.
1 *Default*	Actual canopy evaporation (E_T and/or E_I) simulations are made.

TRANSPPOT

0	No calculations of the potential transpiration (E_{Tp}).
1 *Default*	The potential transpiration (E_{Tp}), defined as the transpiration being independent of the plants internal water status (i.e. $m_V = m_{VMax}$), is simulated using the iteration method for solving the canopy energy balance.
2	The potential transpiration (E_{Tp}) is defined as: the water content is non limiting and located on the leaf surface (i.e. surface resistance $r_c = 0$)

4.3 PARAMETERS

Note that the units sometimes are multiples of the basic SI-system.

Variable	Symbol ; Explanation	(Unit)

■ Plant_water

PLANWATX	m_{Vo} ; Maximum available plant water per unit of leaf surface.	($g\ m^{-2}$)
WATPOTGP	ψ_{gp} ; ψ_g for the potential transpiration. Only used if TRANSPPOT-switch > 0.	(MPa)
WATPOTN	ψ_{cMin} ; Canopy water potential when the plant is out of water easily available for transpiration.	(MPa)
WATPOTX	ψ_{cMax} ; Canopy water potential when plant water content is at maximum.	(MPa)

■ Aerodynamic resistance

RESAIRD	z_d ; Displacement height. (parameters should be set: SWRESAIR = 1 and RESAIRD0 = 0).	(m)
RESAIRH	z_U ; Height for measurements of wind speed. (parameters should be set: SWRESAIR = 1 and RESAIRH0 = 0).	(m)
RESAIRZ	z_o ; Roughness length. (parameters should be set: SWRESAIR = 1 and RESAIRZ0 = 0).	(m)
SWRESAIR	Switch [1] ; Switch for chosing between two functions for the aerodynamic resistance (r_a). =1: r_a=f(h,d,z_o)/U =0: r_a=f(LAI)/U.	(-)

■ Resistance_stomata

Parameters related to the resistance for vapour flow through stomata. Special care should be taken as regards the units of parameters. The units of the given functions refer to the leaf surface or the ground surface depending on the specification given by the User. The stomatal resistance function is taken the highest value of those proposed by the different "sub functions". For selection of sub functions see parameter SWRESCAN.

RADRESR	R_{sMin} ; $R_s<R_{sMin}$ --> $r_s(R_s)=r_{sMax}$. This parameter is the radiation level below which the stomatal resistance $r_s(R_s)$ is constant equal to its maximum value. Only used if SWRESCAN(2) > 0.	($W\ m^{-2}$)
RESCGROU	In analogy with RESCTEMP but SWRESCAN(4) replaced by SWRESCAN(5).	()
RESCLOHA	Coefficients used for alternative stomatal functions. Be aware of the units. Note: If SWRESCAN(3) greater or equal to 100 or GROWTH-switch = 0, than r_s should be given per units of ground surface. Only used if IF SWRESCAN(3)=1 or 100: f(ψ_c)*Lohammar eq: $f(\psi_c)= d_L*\exp(-e_L(f_L+\psi_c)+g_L)$ RESCLOHA(1): d_L(-) RESCLOHA(2): e_L(MPa^{-1}) RESCLOHA(3): f_L(MPa) RESCLOHA(4): g_L(-)	()

RESCMAX r_{sMax} ; Maximum value of stomatal resistance. It equals the resistance per unit of leaf surface through cuticular. ($s\ m^{-1}$)
Note: If all separate stomatal functions used are given per units of ground surface (i.e. all SWRESCAN(1-3), not equal to zero, are greater or equal to 100, or GROWTH-switch = 0), then r_{sMax} should be given per units of ground surface (r_{cMax}).

RESCMIN r_{sMin} ; Minimum value of stomatal resistance per unit of leaf surface. ($s\ m^{-1}$)
Note: If all separate stomatal functions used are given per units of ground surface (i.e. all SWRESCAN(1-3), not equal to zero, are greater or equal to 100, or GROWTH-switch = 0) r_{sMin} should be given per units of ground surface (r_{cMin}).

RESCRAD Coefficients for determining the stomatal resistance per unit of leaf surface as a function of incident shortwave radiation.
Note: If SWRESCAN(2) greater or equal to 100 or GROWTH-switch = 0, then stomatal resistance should be given per units of ground surface (r_c).

If SWRESCAN(2)= 1,10,100: Conductance is a polynomial function and: $r_s(R_s)=1/(a_r+b_{r2}R_s+c_rR_s^2)$
If SWRESCAN(2)= 2,20,200: Resistance is an exponential function: $r_s(R_s)=a_e*\exp(-b_eR_s)+c_e$

RESCRAD(1): a_r ($m\ s^{-1}$) or a_e ($s\ m^{-1}$)
RESCRAD(2): b_{r2} or b_e
RESCRAD(3): c_r or c_e ($s\ m^{-1}$)

RESCTEMP Coefficients for determining the stomatal resistance per unit leaf surface as a function of canopy temperature. ()
Note: If SWRESCAN(4) greater or equal to 100 or GROWTH-switch = 0, than r_s should be given per units of ground surface (r_c).

If SWRESCAN(4)= 1,100: Conductance is a polynomial function and: $r_s(T_c)=a_T+b_TT_c+c_TT_c^2$
If SWRESCAN(4)= 2,200: Resistance is an exponential function: $r_s(T_c)=a_T*\exp(b_T(T_c+c_T))+d_T$
If SWRESCAN(4)= 3,300: Resistance is a logaritmic function: $r_s(T_c)=a_T*\ln(b_T(T_c+c_T))+d_T$

RESCVPD Coefficients used for alternative stomatal functions. Be aware of the units. ()
Note: If SWRESCAN(3) greater or equal to 100 or GROWTH-switch = 0, than stomatal resistance should be given per units of ground surface (r_c).

IF SWRESCAN(3)=1 or 100:
$f(\psi_c)$*Lohammar eq:
$r_s(vpd,R_s)=c_L(R_s+a_L)(b_Lvpd+1)/R_s$
(Note! for $f(\psi_c$ see RESCVPDP)
IF SWRESCAN(3)=2 or 200:
$r_s(vpd,R_s)=a_v+b_vvpd+c_v(R_s/100)^2$
IF SWRESCAN(3)=3 or 300:
$r_s(vpd)a_e*\exp(b_e(vpd-c_e))+d_e$.
IF SWRESCAN(3)=4 or 400:
Lohammar eq (Cienciala vers.):
$r_s(vpd,R_s)=1/g_s$ where:
$g_s=(d_c+c_cR_s/(R_s+a_c))/(b_cvpd+1)$

RESCVPD(1): a_L($W\ m^{-2}$) or a_v($s\ cm^{-1}$) or a_e($s\ m^{-1}$) or a_c($W\ m^{-2}$)
RESCVPD(2): b_L(hPa^{-1}) or b_v($s\ cm^{-1}\ hPa^{-1}$) or b_e(hPa^{-1}) or b_c(hPa^{-1})
RESCVPD(3): c_L($s\ m^{-1}$) or c_v($cm\ s^{-1}\ (m^2/0.01W)^2$) or c_e(hPa) or c_c($m\ s^{-1}$)
RESCVPD(4): d_e($s\ m^{-1}$) or d_c($m\ s^{-1}$)

RESCWAT Coefficients for determining the stomatal resistance per unit leaf surface as a function of canopy water potential. ()
Note: If SWRESCAN(1) greater or equal to 100 or GROWTH-switch = 0, than r_s should be given per units of ground surface (r_c).

If SWRESCAN(1)= 1,100: Conductance is a polynomial function and: $r_s(\psi_c)=1/(a_c+b_c\psi_c+c_c\psi_c^2+d_c\psi_c^3+e_c\psi_c^4)$; (OBS! ψ_c is in units of 0.1MPa).
If SWRESCAN(1)= 2,200: Resistance is an exponential function: $r_s(\psi_c)=a_e*\exp(-b_e(\psi_c+c_e))+d_e$; (OBS! ψ_c is in units of MPa).

RESCWAT(1): a_c(m s^{-1}) or a_e(s m_{-1})
RESCWAT(2): b_c or b_e(MPa^{-1})
RESCWAT(3): c_c or c_e(MPa)
RESCWAT(4): d_c or d_e(s m_{-1})
RESCWAT(5): e_c

SWRESCAN switches for choosing arbitrarily among different stomatal resistance functions. $r_s=f(R_s$ or/and ψ_c or/and vpd,R_s or/and T_c or/and $\psi_g)$. (Polyn=polynomial function for conductances; Exp= exponential function for resistances; Loham=Lohammar equation; Layers=canopy is divided into layers of unity leaf area, in each layer the resistance is the maximum value given by all resistance functions used, if not Layers function is used then canopy resistance is the stomatal resistance divided by the leaf area index). If SWRESCAN is multiplied by 100 i.e. equal to 100, 200, 300, 400 etc. than the input functions on stomatal resistance are assumed to be expressed per units of ground surface (r_c). (see RESCWAT, RESCRAD, RESCVPD) (-)

for $r_s=f(\psi_c)$:
SWRESCAN(1): [1] ; (0/1/2 = No/Polyn/Exp)
for $r_s=f(R_s)$:
SWRESCAN(2): [1] ; (0/1/2/10/20 = No/Polyn/Exp/Polyn(layers)/Exp(layers))
for $r_s=f(R_s$ and/or vpd):
SWRESCAN(3): [0] ;
(0/1/2/3/4 = No/Loham./f(R_s,vpd)/f(vpd)/Loham.(Cienciala v.))
for $r_s=f(T_c)$:
SWRESCAN(4): [0] ; (0/1/2/3 = No/Polyn/Exp/ln)
for $r_s=f(\psi_g)$:
SWRESCAN(5): [0] ; (0/1/2/3 = No/Polyn/Exp/ln)

■ Plant resistance

RESPLANT r_p ; Plant resistance from root surface to the mesophyll of leaves. (MPa s m^2 g^{-1})

■ Soil-root resistance

RESGROA a_g ; Hydraulic conductivity of saturated soil (g m^{-2} s^{-1})

RESGROB b_g ; Factor related to the root density. (MPa)

RESGROC c_g ; Coefficient related to soil pore size distribution. (-)

■ Interception

INTERCK κ_P ; Rain interception coefficient related to leaf area. (-)

PLANINTX m_{VIo} ; Maximum amount of water intercepted per unit of leaf area index. (g m^{-2})

■ Growth

EXTCRAD	κ ; Radiation (300-3000 nm) extinction coefficient related to leaf area.	(-)
LAI	LAI; Leaf area index.	(-)

■ Soil water

These parameters are used only if the SOILWPOT-switch = 1.

BROOKPOR	a_{por} ; Pore size distribution coefficient (Brooks & Coreys equation)	(-)
BROOKPSIA	ψ_a ; Air entry pressure (Brooks & Coreys equation)	(MPa)
BROOKPSIX	ψ_x ; Lower limit of water potential for use of Brooks & Coreys equation	(MPa)
BROOKRES	θ_r ; Relative water content, lower limit for use of Brooks & Corey eq.	(-)
BULKDENS	ρ_g ; Dry weight of soil per unit bulk volume.	($g\ m^{-3}$)
ROOTDEP	z_r ; Rootdepth (should be positive)	(m)
RALAI	a_{ras} ; Coefficient for determining the aerodynamic resistance as function of leaf area index	($s\ m^{-1}$)
RSSCOEF	a_{rss} ; Coefficient for soil surface resistance; proportional against the inverse of relative water content	($s\ m^{-1}$)
RSSEXP	b_{rss} ; Coefficient for determining soil surface resistance; exponential for the relative water content	(-)
RSSTHETA	θ_{rss} ; Coefficient for determining soil surface resistance;	(-)
SOILDEP	z_g ; Depth of whole soil volume (should be positive)	(m)
SURDEP	z_{Surf} ; Depth of surface layer from which soil evaporation takes place (should be positive)	(m)
THETADM	θ_m ; Difference between soil water content at saturation and at the situation when soil water potential equals air entry pressure.	(-)
THETAS	θ_s ; Soil relative water content at saturation	(-)

■ Plotting_on_line

Variables can be plotted on screen during the simulation by selecting appropriate values on XTGD and PMAX. Using this option version of model is written on screen.

PMAX	plot maximum [1000] ; The expected maximum value among the variables selected by XTGD.	(differs)
XTGD	variables plotted on screen [4000] ; Numbers of output variables to be presented on the screen during the simulation (e.g. 4200 means 4 X-, 2 T-, zero G- and zero D variables). <=0 implies no plotting.	(numbers)

■ Special

These parameters are activating special options. It includes sensitivity parameters (names starting with S). The value for no test is given in brackets. The subscript $_o$ denotes the original value. Where both the relative and the absolute values are possible to change a constant value of the variable concerned can be chosen by setting the relative change to 0.

[] is the value normally used.

RESAIRHV	a_{ra} [1] ; $=r_{aH}/r_a$; The ratio between the aerodynamic resistance for heat and vapour.	(-)

RESAIRRI	$Ri\text{-}Ri_o$ [0] ; Relative change of the Richardson number. =0 implies Ri=0, i.e. no effect. Only used if Start parameter SWRESAIR=1.	(-)
RESPLANU	Coefficients for determining the plant resistance as a function of root uptake rate previous time step ($F_U(t\text{-}1)$). $r_p(F_U(t\text{-}1))=a_p*\exp(-b_pF_U(t\text{-}1))+r_{pMin}$ max r_{pMin} min r_{po}; (r_{po}=RESPLANT) RESPLANU(1): a_p(MPa s m^2 g^{-1}) RESPLANU(2): b_p(m^2 s g^{-1}) RESPLANU(3): r_{pMin}(MPa s m^2 g^{-1}) RESPLANU(4): Not used	
SRESCGRO	$r_s(\psi_g)/r_{so}(\psi_g)$ [1] ; Relative change of $r_s(\psi_g)$. Only used if SWRESCAN(5) > 0.	(-)
SRESCRAD	$r_s(R_s)/r_{so}(R_s)$ [1] ; Relative change of $r_s(R_s)$. Only used if SWRESCAN(2) > 0.	(-)
SRESCTEM	$r_s(T_c)/r_{so}(T_c)$ [1] ; Relative change of $r_s(T_c)$. Only used if SWRESCAN(4) > 0.	(-)
SRESCVPD	$r_s(R_s)/r_{so}(vpd)$ [1] ; Relative change of $r_s(vpd)$. Only used if SWRESCAN(3) > 0.	(-)
SRESCWAT	$r_s(\psi_c)/r_{so}(\psi_c)$ [1] ; Relative change of $r_s(\psi_c)$. Only used if SWRESCAN(1) > 0.	(-)
SRESRADD	[0] ; For calculation of stomatal resistance (r_c) as a function of stomatal resistance per unit leaf area and leaf area index (LAI). SRESRADD is the absolute change of LAI in this function. Only used if GROWTH-switch > 0.	(-)
SRESRADR	[1] ; The same as for SRESRADD but the relative change of LAI. Only used if GROWTH-switch > 0.	(-)
STDENERG	Δ_{Max} [0.1] ; Maximum allowed deviation in the canopy energy balance.	(W m^{-2})
STDWATPO	$\delta\psi_{cMax}$ [0.04] ; Maximum allowed change in the canopy water potential during a time step of δt minutes.	(MPa)
STNETRAD	a_R, b_R, c_R: Coefficients in: $R_n=a_R+b_RR_s+c_RR_n$, determining net radiation above canopy (R_n) as a function of DSOLRAD or DNETRAD. OBS! If c_R<>0 then should be: $a_R=b_R=0$, and vice versa. STNETRAD(1): a_R [-23.0] (W m^{-2}) STNETRAD(2): b_R [0.649] (-) STNETRAD(3): c_R [0] (-)	()
WATPOTCF	Coefficients for determining water potential (P_c) as function of water content previous time step ($m_V(t\text{-}1)$) $P_c(m_V(t\text{-}1))= P_{cmax}-(P_{cmax}-P_{cmin})*f$ where $f= (\exp(a*(x-x^2))-1)/(\exp(a/2)-1)$ where $x= (1-m_V(t\text{-}1)/m_{Vmax})$ NOTUSED if a=0 WATPOTCF(1): a(-) WATPOTCF(2): not used	(-)

4.4 OUTPUTS

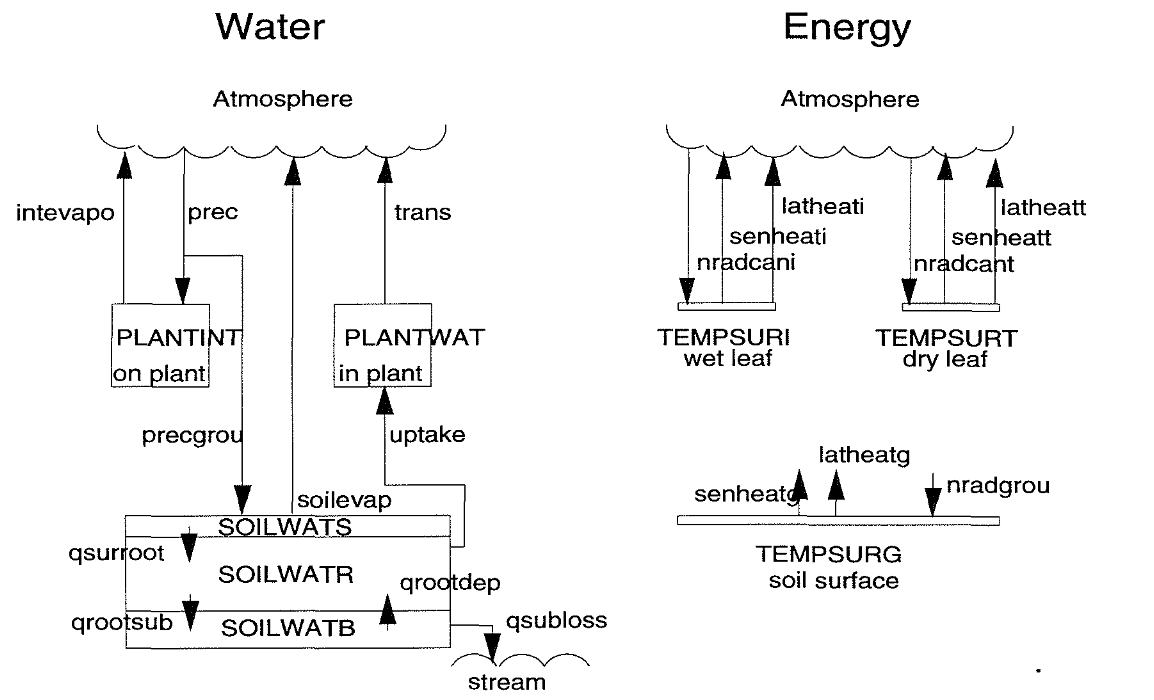


Figure. Schematic description of the SPAC model. Solid lines are flows of water or energy. For explanation of variables names see list below.

All units expressed per unit of area refers to the ground surface. Note that units of output variables sometimes are multiples of the basic SI-system.

Variable	Symbol ; Explanation	(Unit)
States:		
PLANTWAT	m_V ; Exchangeable water in canopy	(g m^{-2})
PLANTINT	m_{VI} ; Water intercepted on the canopy	(g m^{-2})
SOILWATB	(m_{gB}) ; Soil water content of sub soil below root zone. Only used when the SOILWPOT-switch = 1.	(g m^{-2})
SOILWATR	(m_{gR}) ; Soil water content of root zone. Only used when the SOILWPOT-switch = 1.	(g m^{-2})
SOILWATS	(m_{gS}) ; Soil water content of surface layer. Only used when the SOILWPOT-switch = 1.	(g m^{-2})
Other "States":		
ACCBAL	; Water mass balance check	(g m^{-2})
ACCINPUT	Σ_{Acc}(Input) ; Accumulated input of water to the system. If SOILWPOT-switch = 0: ($P+F_U$). If SOILWPOT-switch = 1: (P).	(g m^{-2})
ACCINTEV	$\Sigma_{Acc}(E_I)$; Accumulated intercepted evaporation	(g m^{-2} d^{-1})

ACCOUT	Σ_{Acc}(Output) ; Accumulated output of water from the system. If SOILWPOT-switch = 0: (E_t+P_g). If SOILWPOT-switch = 1: (E_t+E_g+q_{Loss}).	(g m^{-2})
ACCSTORE	; Total storage of water in the system. If SOILWPOT-switch = 0: (m_V+m_{VI}). If SOILWPOT-switch = 1: (m_V+m_{VI}+m_S).	(g m^{-2} d^{-1})
ACCTRANS	$\Sigma_{Acc}(E_T)$; Accumulated transpiration	(g m^{-2} d^{-1})
ACCTRPOT	$\Sigma_{Acc}(E_{Tp})$; Accumulated potential transpiration	(g m^{-2} d^{-1})
PLANTWAP	m_{Vp} ; Exchangeable water for the potential transpiration	(g m^{-2})

Flows:

INTEVAPO	E_I ; Evaporation of intercepted water.	(g m^{-2} s^{-1})
PREC	P ; Precipitation above canopy.	(g m^{-2} s^{-1})
PRECGROU	P_g ; Amount of water from precipitation falling to the ground.	(g m^{-2} s^{-1})
QROOTDEP	$\Delta m_{gRDepth}$; Change in water in the root zone due to increased root depth.	(g m^{-2} s^{-1})
QROOTSUB	$q_{R \rightarrow B}$; Percolation of water from root zone to sub soil. Only used when the SOILWPOT-switch = 1.	(g m^{-2} s^{-1})
QSUBLOSS	q_{Loss} ; Loss of water from sub soil. Only used when the SOILWPOT-switch = 1.	(g m^{-2} s^{-1})
QSURROOT	$q_{S \rightarrow R}$; Percolation of water from surface layer to root zone. Only used when the SOILWPOT-switch = 1.	(g m^{-2} s^{-1})
SOILEVAP	E_S ; Soil evaporation. Only used when the SOILWPOT-switch = 1.	(g m^{-2} s^{-1})
TRANS	E_T ; Transpiration	(g m^{-2} s^{-1})

Other "Flows":

DELTAPLA	δm_V ; Exchangeable water in canopy	(g m^{-2} s^{-1})
DELTAPLP	δm_{Vp} ; Exchangeable water for the potential transpiration	(g m^{-2} s^{-1})

Auxilaries:

BOWEN	Bowen ratio ; H_T/LE_T or H_I/LE_I). When the INTERCEPT-switch = 2 this ratio concerns the whole canopy.	(-)
LAI	LAI ; Leaf area per unit of ground surface (leaf area index).	(m^2 m^{-2})
LATHEATG	LE_g ; Latent heat flux to the atmosphere from soil surface. Only used when the SOILWPOT-switch = 1.	(W m^{-2})
LATHEATI	LE_I ; Latent heat flux to the atmosphere from wet leaf surfaces.	(W m^{-2})
LATHEATT	L(E_T or E_{Tp}) ; Latent heat flux to the atmosphere from dry leaf surfaces.	(W m^{-2})
NRADABOV	R_n ; Net radiation of the site.	(W m^{-2})
NRADCAN	R_{nc} ; Net radiation of the canopy.	(W m^{-2})
NRADCANI	R_{nI} ; Net radiation energy available for the energy balance of the intercepted water. Only used when the INTERCEPT-switch = 2.	(W m^{-2})
NRADCANT	R_{nT} ; Net radiation energy available for the energy balance of the water lost as transpiration. Only used when the INTERCEPT-switch = 2.	(W m^{-2})

NRADGROU	R_{ng} ; Net radiation at the ground surface.	(W m^{-2})
RESIAIR	r_a ; Aerodynamic resistance.	(s m^{-1})
RESICAN	r_c ; Canopy stomatal resistance per unit of ground surface.	(s m^{-1})
RESICGRO	$r_s(\psi_g)$; Leaf stomatal resistance as a function of water potential in the root zone.	(s m^{-1})
RESICRAD	$r_s(R_s)$; Leaf stomatal resistance as a function of incident shortwave radiation on the leaves.	(s m^{-1})
RESICTEM	$r_s(T_c)$; Leaf stomatal resistance as a function of canpoy temperature.	(s m^{-1})
RESICVPD	r_s(vpd) ; Leaf stomatal resistance as a function of vapour pressure deficit.	(s m^{-1})
RESICWAT	$r_s(\psi_c)$; Leaf stomatal resistance as a function of canopy water potential.	(s m^{-1})
RESIGROU	r_g ; Soil-root resistance between soil and root surface.	(MPa s m^2 g^{-1})
ROOTDEPTH	z_r ; Root depth	(m)
SENHEATG	H_g ; Sensible heat flux to the atmosphere from soil surface. Only used when the SOILWPOT-switch = 1.	(W m^{-2})
SENHEATI	H_I ; Sensible heat flux to the atmosphere from wet leaf surfaces.	(W m^{-2})
SENHEATT	H_T ; Sensible heat flux to the atmosphere from dry leaf surfaces.	(W m^{-2})
SOILWATRS	θ_S ; Soil water content at saturation. Only used when the SOILWPOT-switch = 1.	(g m^{-2})
TEMPDIFI	T_{cI}-T_a ; Difference between wet canopy surface and ambient air temperature.	(°C)
TEMPDIFT	T_{cT}-T_a ; Difference between dry canopy surface and ambient air temperature.	(°C)
TEMPSURG	T_g ; Soil surface temperature. Only used when the SOILWPOT-switch = 1.	(°C)
TEMPSURI	T_{cI} ; Temperature of wet leaf surfaces.	(°C)
TEMPSURT	T_{cT} ; Temperature of dry leaf surfaces.	(°C)
THETA	θ ; Soil relative water content (root zone). Only used when the SOILWPOT-switch = 1.	(vol %)
THETASUB	θ_{gB} ; Soil relative water content (sub soil). Only used when the SOILWPOT-switch = 1.	(vol %)
THETASUR	θ_{gS} ; Soil relative water content (soil surface). Only used when the SOILWPOT-switch = 1.	(vol %)
TRANSPOT	E_{Tp} ; Potential transpiration (only E_{Tp} values > 0 are accumulated)	(g m^{-2} s^{-1})
TRANSRAT	E_T/E_{Tp} ; Actual to potential transpiration ratio.	(-)
UPTAKE	F_U ; Water uptake by root.	(g m^{-2} s^{-1})
VPRESAIR	e_a ; Vapour pressure in the ambient air.	(hPa)
VPRESSUR	e_{cs} ; Saturated vapour pressure in the stomata cavities.	(hPa)
WATPOTC	ψ_c ; Canopy water potential.	(MPa)
WATPOTG	ψ_g ; Soil water potential used for the actual transpiration calculations.	(MPa)
WATPOTGM	ψ_m ; Upper limit for soil water potential in Brooks & Corey relationship. Only used when the SOILWPOT-switch = 1.	(MPa)

WATPOTGR	ψ_g ; Soil water potential; simulated. Only used when the SOILWPOT-switch = 1.	(MPa)

SIMVB MANUAL

The description below holds for the SIMVB.EXE version 1.1 program dated 1995-11-06. The description is taken from SOILN User's manual (Eckersten et al. 199xb) and modified and shortened to fit this report. The objectives of the SIMVB program are to enable the user to run the model technically in a simple way, to give possibility of both a strict and flexible presentation of input and output of the model, to enable a simple way of using the model as a tool for evaluation of possible changes in input, calibration, validation and to bring order to input and output files.

5.1 How to run SPAC

■ Run under DOS

Firstly, we make a short summary of which programs and files that are involved when running SPAC under DOS program in an ordinary way.

The SPAC model is executed by the program file SPAC.EXE. There are some associated files to this program. A help-file with variable descriptions etc (SPAC.HLP), a file with standard parameter values and other informations needed by the model (SPAC.DEF) and a file including titles and units of the output variables (SPAC.TRA).

The model is run by using a program file named PREP.EXE. This program helps you preparing the simulation and make the simulation, i.e. you can select parameter values, input files, simulation period etc. The PREP program illustrates well the in- and outputs of the model (type for instance, >prep spac). All information needed for PREP can be stored in a parameter file (xxxx.PAR-file). You can give instructions to PREP to take the information from that file. PREP is the program that can activate SPAC.EXE, i.e. to start the simulation. Output from the simulation are stored in two files, SPAC_001.BIN and SPAC_001.SUM. The first file (.BIN) includes the values of the simulated variables. The second file (.SUM) includes both a summary of all outputs (averages, sums, etc.) and the prerequisites for the simulation (i.e. the inputs) which can be used to repeat the simulation if it is renamed to xxxx.PAR.

You can get presentations of the results and make further evaluations of the simulation outputs (SPAC_001.BIN) with help of a special program, PG.EXE.

■ Run under WINDOWS (SIMVB)

The principal idea of programming SIMVB is to make use of already developed DOS programs and applications. The programming is restricted to this "administration" of the operative programs and routines. SIMVB.EXE is programmed in Windows-VisualBasic and is possible to run under WINDOWS if the VBRUN300.DLL file is available.

You start SIMVB from the run option of WINDOWS, or by double click on the icon (if installed) or by writing under DOS: >win simvb

In the program SIMVB you always start with the bottom denoted "Start here". Note, that in the SIMVB program you should always use only single click. Then you select model to be used and then application, which should be stored on a hard disk (or floppy). Thereafter you normally continue with "Preparation of input". (If you already have made a complete preparation, and want to have free access to any part of the program, you select "Check off". The Check option only checks the order in which you select options in the program from preparation to presentation of output during one run. If you leave the program the Check option is reseted.)

The program itself enables a good overview of the principal way of using the model. If a complete run ("Preparation of input", "Simulation", etc) has been made the different options in the schedule, in principal, can be chosen in any order at any time. However, for the first run you have to choose them in the following order:

(i) PREPARATION of INPUT.
Copies input files to the working directory. Note, that the routines under this option overwrites files at the working directory, without warnings.

(ii) PRESENTATION of INPUT.
Variables in input file named AIN_CLIM.BIN are presented.

(iii) SIMULATION.
The results are stored in files named SPAC_CUR.bin and SPAC_CUR.sum (CUR denotes the current simulation).

(iv) PRESENTATION of OUTPUT.
Variables in SPAC_CUR.bin are presented. Variables that are presented are grouped in accordance to subjects. You can also compare results with the previous run and/or simulations that have been stored, see below. You can view the summary file of the simulation as well.

(v) STORE FILES.
Here you can store the simulation results (SPAC_CUR.*) under a different name. You can also recover a previous stored simulation to the name (SPAC_CUR.*), thereby making it available for use in the presentation options etc.

(vi) EXIT the program.
You should exit the program by pressing the "EXIT" bottom on the main menu.

5.2 Alternative use of SIMVB

■ Give comments

By putting the mouse arrow on space between boxes and by making a click on the right bottom you can give comments, on whatever you want. The comments should be stored or cancelled (MAIN MENU) immediately after they have been given.

■ Type of User

You can select three type of users (Student, Teacher, Research) under "Switches etc" (MAIN MENU). Different users will get access to different parts of the SIMVB program.

Edit files

You can change a single parameter or initial state value by select "Edit files*" under "Switches etc." (MAIN MENU). Be aware of that you must write the parameter/variable name correctly. As concerns changes in parameter files: Note that changes of parameter values preferably are introduced in the AIN_MAN.PAR since values in this file have the highest priority (if you make a change in AIN_PLAN.PAR and the parameter name also appears in AIN_MAN.PAR the latter holds). Note that in initial state file at least the first position on a row should be an empty space, then write name, space and value.

Use PREP-program manually

The PREP-progam can be run in a standard (interactive) way within SIMVB. If you have made "Preparation" the prepared AIN_xxxx.PAR files are read by PREP. The files are read in the following order: AIN_SOIL.PAR, AIN_PLAN.PAR, AIN_OUT.PAR, AIN_TIME.PAR, AIN_MAN.PAR. Simulation results are stored in SPAC_cur.bin as in the normal simulation.

If you do not want to load the parameters files you have chosen with "Preparation", then select "One parameter file" and "Check off" (under "Switches etc", MAIN MENU) before entering PREP. Note that output file now is named SPAC_xxx.bin (where xxx is a number from 001-999) and if you want to make use of presentation of output options it has to be restored to SPAC_cur.bin (use "Store files" (MAIN MENU)).

Use PG-program manually

The PG-program can be used in a standard (interactive) way within SIMVB. SIMVB brings you only to the proper file. Select "PG ON" under "Switches etc" (MAIN MENU).

Use Excel-program manually

In case Excel is loaded and there is a path to it, the Excel-program can be used in a interactive way within SIMVB. Select "Excel ON" under "Switches etc" (MAIN MENU). SIMVB converts the PG-binary-file concerned to dbf or lotus123 format and brings you automatically into Excel. With help of the presentation routines of SIMVB you can select variables to be exported to Excel.

Using only one parameter file

There are two possibilities to run SIMVB with only one parameter file: one (1) is to completely govern the simulation with a single parameter file and the other (2) is to still make use of output routines of SIMVB so that presentations programs can be used in a normal way. In case of 1) store the file under name AIN_ONE.PAR and select switch "one par-file" under "Switches etc" (MAIN MENU). In case of 2) store the parameter file under the name AIN_MAN.PAR and take away (i) the declaration of file names except for FILE(9), which should be named ain_fert.bin if it is used, and (ii) the OUTFORN switch. All the other parameter files have to exist but could be empty except for a ";" at the end of the file (ain_out.par is delivered by SIMVB automatically).

Making the five parameter files

Under the option "Preparation of inputs, normal" (MAIN MENU) the five parameter files ain_soil.par, ain_plan.par, ain_out.par, ain_time.par and ain_man.par can be created automatically from the last simulation (i.e. from SPAC_CUR.SUM-file).

■ Multiple runs

Up to 6 multiple simulations can be done and plotted. (It is the presentation of output that limits the number of simulations.)

■ Initial states of previous run

Make a simulation using outputs of the previous simulation as initial states in the new simulation.

■ File list

In the "Preparation" option of SIMVB files can be selected arbitrarily by selecting "file list" in the list menus. This is a complement to the other preparation options.

■ Alternative applications under directory ...\XXXX\...

Often several versions of the same main application is wanted to be run by SIMVB. Using the "Standard" application one way of running these versions and to store them separately is to do as follows:

1) Store the main application with a full set up of input files under ...\XXXX\N\NA, as usual.
2) Store the files changed due the specific version under a separate directory named f.i. VERSION1, i.e. ...\NA\VERSION1. Do not change the name of the files and remember to store the INFO.LIS file in which you give an identification of the application stored on the directory.
3) Copy files from VERSION1 directory to working directory by pressing "Prep. from SubDir..." (this option is available if "Teacher ON" is selected under "Check etc." (MAIN MENU)).

6 LIST OF SYMBOLS

Symbol	Description	Unit
ψ_a	Water potential corresponding to air entry pressure	MPa
ψ_c	Canopy water potential	MPa
ψ_{cMin}, ψ_{cMax}	Minimum and maximum canopy water potential	MPa
ψ_g	Soil water potential	MPa
ψ_m	Soil water potential at upper limit of Brooks & Coreys eq.	MPa
δ	Generally used for a difference during a time step	-
Δ	Slope of saturated vapour pressure curve in Penman eq.	Pa $^oC^{-1}$
Δ_{Max}	Maximum allowed deviation in canopy energy balance	W m^{-2}
$\Delta m_{gRDepth}$	Change of water in the root zone due to increased root depth	g m^{-2} s^{-1}
$\Delta\psi_{cMax}$	Maximum allowed change of ψ_c from one iteration to another for accepting the water balance.	MPa
γ	Psychrometric constant (=67)	Pa K^{-1}
κ	Radiation extinction coefficient related to leaf area	-
κ_P	Rain interception coefficient related to leaf area	-
ρ_a	Specific density of moist air (=1204.7)	g m^{-3}
ρ_g	Density of bulk soil	g m^{-3}
ρ_w	Specific density of water ($=1 \cdot 10^6$)	g m^{-3}
θ	Soil relative water content (root zone)	-
θ_{gS}	Soil relative water content of soil surface layer	-
θ_m	Difference between θ_s and relative water content at upper limit of Brooks & Corey eq.	-
θ_r	Relative water content, lower limit for use of Brooks & Corey eq.	-
θ_{rss}	Relative water content coeficient used for soil surface resistance estimates	-
θ_s	Soil relative water content at saturation	-
a_g	Coefficient of saturated soil hydraulic conductivity	g m^{-2} s^{-1}
a_i, b_i, c_i, d_i, e_i	Coefficient names: i= τ(water use eff.), =c($r_s(\psi_c)$), =d(displacement height), =e(saturated vapour pressure), =h(canopy height), =L(Lohammar eq.), =Li(Lindroth eq.), =o(roughness height), =r($r_s(R_s)$), =R(net radiation), =ra(aerodynamic resistance), =ras(within canopy aerodynamic resitance), =rp(plant resistance), =rr(soil-root resistance), =rss(soil surface resistance), =v($r_s(R_s$,vpd)), =m_V(plant water), =w(analytic humidity)	differs
b_g	Root density resistance factor	MPa
c_{BC}	Pore size distribution coefficient in Brooks & Coreys eq.	-
c_g	Soil pore size distribution factor	-
C_p	Specific heat per unit mass of air (=1.004)	J g^{-1} K^{-1}
e_a	Vapour pressure of the air above canopy	hPa
E_I	Evaporation rate of intercepted water	g m^{-2} s^{-1}
E_g	Soil (ground) surface evaporation	g m^{-2} s^{-1}
e_s	Saturated vapour pressure of the air.	hPa
e_{cs}	Saturated vapour pressure of the air inside the stomata cavities.	hPa
E_T	Transpiration rate	g m^{-2} s^{-1}
E_{Tp}	Potential transpiration rate	g m^{-2} s^{-1}
F_U	Water uptake by roots	g m^{-2} s^{-1}
g	Gravitational acceleration	m s^{-2}
h_a	Relative air humidity above canopy	-
H_I	Sensible heat flux from wet canopy to the air	W m^{-2}

H_g	Sensible heat flux from ground surface to the air	W m^{-2}
H_T	Sensible heat flux from dry canopy to the air	W m^{-2}
j	Number of water balance iteration	number
k	von Karman's constant (=0.41)	
L	Latent heat of water vaporisation (=2451.8)	J g^{-1}
LAI	Leaf area per unit ground surface (leaf area index)	-
m_{gB}	Water in the layer below root zone	g m^{-2}
m_{gBMax}	Water in the layer below the root zone at saturation	g m^{-2}
m_{gR}	Water in the root zone	g m^{-2}
m_{gRMax}	Water in the root zone at saturation	g m^{-2}
m_{gS}	Water in the soil surface layer	g m^{-2}
m_{gSMax}	Water in the soil surface layer at saturation	g m^{-2}
m_V	Easily exchangeable water in the plant	g m^{-2}
m_{VI}	Water intercepted on the canopy surface (per unit ground surface)	g m^{-2}
m_{VIMax}	Maximum water intercepted on the canopy surface (per unit ground surface)	g m^{-2}
m_{VIo}	Maximum water intercepted on the canopy surface per unit leaf area	g m^{-2}
m_{VMax}	Maximum easily exchangeable water in the plant (per unit ground surface).	g m^{-2}
m_{Vo}	Maximum easily exchangeable water in the plant per unit leaf area.	g m^{-2}
P	Precipitation above canopy	g m^{-2} s^{-1}
P_g	Precipitation to the ground	g m^{-2} s^{-1}
q_{Loss}	Loss of water from soil through percolation and runoff	g m^{-2} s^{-1}
$q_{S\rightarrow R}$	Loss of water from surface layer to root zone	g m^{-2} s^{-1}
$q_{R\rightarrow B}$	Loss of water from root zone to soil layer below root zone	g m^{-2} s^{-1}
r_a	Aerodynamic resistance	s m^{-1}
r_{aH}	Aerodynamic resistance specially for heat	s m^{-1}
r_{as}	Aerodynamic resistance from soil surface to above canopy	s m^{-1}
r_c	Stomatal resistance per unit ground surface	s m^{-1}
$r_c(\psi_c)$	Sub function of the stomatal resistance only dependent on the canopy water potential	s m^{-1}
$r_c(\psi_g)$	Sub function of the stomatal resistance only dependent on the water potential in the root zone	s m^{-1}
$r_c(R_s$,vpd)	Sub function of the stomatal resistance dependent on the radiation and vapour pressure deficit of the air.	s m^{-1}
$r_c(R_s)$	Sub function of the canopy resistance dependent on the radiation	s m^{-1}
$r_c(T_c)$	Sub function of the stomatal resistance only dependent on the canopy temperature	s m^{-1}
r_c(vpd)	Sub function of the stomatal resistance dependent on the vapour pressure deficit of the air.	s m^{-1}
r_{cMax}	Maximum stomatal resistance	s m^{-1}
r_{cMin}	Minimum stomatal resistance	s m^{-1}
r_g	Soil-root resistance	MPa s m^2 g^{-1}
r_{ss}	Soil surface resistance	s m^{-1}
Ri	Richardson number	-
R_n	Net radiation above canopy	W m^{-2}
R_{nc}	Net radiation of the canopy	W m^{-2}
R_{ng}	Net radiation of soil surface	W m^{-2}
R_{nI},R_{nT}	Net radiation of the wet and the dry part of the canopy, respectively	W m^{-2}
r_p	Plant resistance	MPa s m^2 g^{-1}

r_s	Stomatal resistance per unit leaf area	s m^{-1}
R_s	Incident radiation intensity (300-3000nm) on a horizontal surface	W m^{-2}
R_{sMin}	Radiation limit below which the stomatal resistance achieves its maximum value.	W m^{-2}
t	Time	differs
t_1	Time at the beginning of a time-step	s
t_2	Time at the end of a time-step	s
T_a	Air temperature	°C
T_{cI}, T_{cT}	Canopy surface temperature of wet and dry surfaces	°C
T_c	Canopy surface temperature	°C
t_o	t at start of simulation	day number
T_g	Soil surface temperature	°C
U	Wind speed above canopy	m s^{-1}
vpd	Vapour pressure deficit of the air	hPa
z_b	Depth of whole soil profile	m
z_d	Displacement height	m
z_o	Roughness height	m
z_r	Root depth	m
z_{Surf}	Depth of soil surface layer	m
z_U	Height above ground of wind measurements above canopy	m

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