CIVE 625 – Quantitative Ecohydrology
Lab 1 (Due Date: Week of Feb 26th through March 1st)

This Lab is designed to give you experience in writing and applying a simple SVAT and, by applying it to different types of vegetation cover (forest and grass) with the same meteorological forcing data, to learn how such SVATS can calculate the relative importance of transpiration and evaporation of intercepted water and how transpiration responds to soil moisture status. The SVAT model you will create is a simple application of the Penman-Monteith equation with a surface resistance that varies with environmental conditions, applied within a simple Rutter model. The incorporation of interception is optional.

A. Aerodynamic Parameterization.

- Compute the values of d and z_0 from the canopy height (h) and leaf area index (LAI) for each canopy using *T.E. E*quations (22.2) to (22.4).
- The measurements of wind speed, temperature, and humidity are assumed all to be made at the same height (z_m = 50 m) and, for simplicity, it is assumed the aerodynamic resistance, r_a, is that calculated in neutral conditions for each hour from *T.E.* Equation (22.9). (Note: it would be possible to calculate r_a as in the last question were this considered necessary).
- Table 1 gives values for parameters, including crop specific parameters, and these are also included in relevant cells in the blank spreadsheet provided.

B. Surface Resistance Parameterization.

- Assume the surface resistance of the crops is given by the Jarvis-Stewart model described on pages 364-366 of *T.E.*, i.e., by *T.E.* Equation (24.1) with g_0 different for the different canopies but g_c = 1 for both canopies. Assume g_R, g_D, g_T, and g_{SM} are given by Equations (24.2) to (24.6).
- **IMPORTANT:** if any of the stress functions is calculated to be less than zero, it should be set to zero. Consequently, make the required calculation inside an IF statement with the general form

  = IF ((function) < 0, 0, (function))

  where (function) is that being used to calculate the specific stress factor.
- In order to calculate the value of D (in k Pa) for use when calculating g_D, you will need first to calculate the vapor pressure e (in k Pa) from the measured specific humidity, q (in kg kg^{-1}) and pressure, P (in k Pa) using Equation (2.9). You then

need to subtract e from and the saturated vapor pressure calculated using Equation (2.17) from the measured temperature in °C.

- You also need to calculate the temperature, T, in K for use in Equation (24.4) by adding the value 273.17 to the measured temperature in °C.
- The value of soil moisture to be used in g_{SM} in the current time step is the value SM_{last} (in mm of water) that was calculated as SM_{new} (in mm of water) ***during the previous time step***, as described in section E below. However, ***for the first time step it is set to the*** **prescribed initial value *SM_{init}*** (in the cell marked in yellow)
- Having first calculated g_s, calculate its reciprocal, r_s, inside an IF statement so as to restrict its calculation to values of calculate $g_s > 0.0001$.
- Table 1 gives values for parameters, including crop specific parameters, and these are also included in relevant cells in the blank spreadsheet provided.

C. Radiation Parameterization.

- Calculate the radiation balance from Equation (5.27) using the canopy specific albedo to calculate S_r, the measured hourly downward longwave radiation, L_d, and hourly estimates of upward the longwave radiation, L_u , calculated using *T.E.* Equation (5.19) with the specified emissivity of the canopy $\varepsilon_{surface}$ (see Table 1) and $\sigma = 5.67 \times 10^{-8}$ W m^{-2} K^{-4}.
- To make this calculation you will need to calculate the effective surface temperature $T_{surface}$. To calculate $T_{surface}$ use the measured air temperature, T, the calculated sensible heat, H, and the aerodynamic resistance in an equation analogous to Equation (21.30), i.e.

$$T_{surface} = T_{measured} + \frac{H\ r_a}{\rho_a c_p} \qquad \text{(K)}$$

However, because H is not calculated until R_n has been calculated, obtaining $T_{surface}$ in this way within a single time step requires an iterative process. Therefore, for simplicity, ***estimate L_u for the current time step using the average value calculate for the previous two time steps*** and assume it remains the same for the current time step, i.e. calculate the value in the i th time step from:

$$L_u^i = \varepsilon_{surface}\sigma \frac{\left(T_{surface}^{i-2}\right)^4 + \left(T_{surface}^{i-1}\right)^4}{2} \qquad (\text{W m}^{-2})$$

- This is not an uncommon approach in SVATS. Note that just taking the value for the previous time step rather than the average for the last two time step can lead to model instability. ***For the first two time steps (the cells marked in yellow) set L_u to a value you choose as being typical of values calculated for the next few hours***.

- Table 1 gives values for parameters, including crop specific parameters, and these are also included in relevant cells in the blank spreadsheet provided.

D. 1 Canopy Water Balance Parameterization **(Includes Interception)**

[This section is optional, if you chose to work without interception, simply substitute the precipitation time-series for zero values only, and move on to section D.2]

- Prior to calculating the canopy water balance, calculate the values of λ, Δ, and γ from Equations (2,1), (2.18), and (2.25), respectively.
- ***NOTE: There is an important typo on TE Page 325 in Equation (22.17).*** The subscripts on λE are interchanged and an extra (C/S) is included in the first term, ***the equation should be:***

$$\lambda E = \lambda E_I + \left(1 - \frac{C}{S}\right)\lambda E_T \tag{22.17}$$

- Represent the wet canopy behavior using a Rutter model described on pages 323-325 of *T.E*. with f_t =0 and f_s =0 in Equation (22.15). Do not use the description of drainage given as *T.E*. Equation (22.16), rather use the simpler description used in many SVAT models, as described below.
- First calculate what the rate of evaporation of intercepted rainfall (in W m^{-2}) would be from the canopy were it totally wet, λE_I (C=S), from Equation (22.14) with (C/S) = 1.
- Assume the precipitation during the current time step falls at the beginning of this time step and that any drainage from the canopy occurs immediately the maximum canopy storage, *S*, is exceeded.
- First set the ***interim*** value of canopy storage during the current time step, $C_{interim}$, equal to the sum of the precipitation during this current time step with the value of canopy *storage* ***at the end of the previous time step***, C_{final} (in previous step)
- If $C_{interim}$ is less than the maximum storage, *S*, then within this time step set C_{actual} = $C_{interim}$, otherwise C_{actual} = S. Also, if $C_{interim}$ is less than the maximum storage, the amount of water that leaves the canopy as drainage D_{canopy} = 0, otherwise D_{canopy} = ($C_{interim}$ – S)
- For simplicity assume the available energy A = R_n and calculate the rate of evaporation of intercepted rainfall (in W m^{-2}) from the canopy, λE_I (C=C_{actual}), i.e., using Equation (22.14) with the actual value of canopy storage C = C_{actual}.
- The final value of canopy storage for this time step, C_{final}, is then found by subtracting the actual loss of intercepted water in mm from C_{actual}. To convert the latent heat flux λE_I in W m^{-2} into mm of evaporated water, multiply by the number of seconds in an hour (3600) and divide by the latent heat of vaporization, λ.
- Again assuming the available energy A = R_n calculate λE, the transpiration rate (in W m^{-2}) from the canopy were it totally dry using Equation (22.18)

- Now calculate the total canopy evaporation, λE, using Equation (22.17) with $C = C_{actual}$. **[*REMEMBER the typo in this equation mentioned above.*]**
- Calculate the sensible heat flux, H, from $H = R_n - \lambda E$, then use this value of H to calculate $T_{surface}$ for the current hour for use in the radiation parameterization as described in section C.

D. 2 Canopy Transpiration.

- Assuming the available energy $A = R_n$ calculate λE, the transpiration rate (in W m^{-2}) from the canopy were it totally dry using Equation (22.18)
- Calculate the sensible heat flux, H, from $H = R_n - \lambda E$, then use this value of H to calculate $T_{surface}$ for the current hour for use in the radiation parameterization as described in section C.

E. Soil Water Balance Parameterization.

- Update the value of soil storage SM_{new} by adding the amount of canopy drainage D_{canopy} (in mm) calculated in the canopy water balance for the current time step, and subtracting the value of $(1-C_{actual}/S)\lambda E_T$ during the current time step (converted in to mm). [This is if you chose to work with interception. Otherwise, your soil moisture will only decay over time as a function of evapotranspiration].

- Calculate the value of SM_{new} inside an IF statement and so that if SM_{new} is greater than the soil moisture holding capacity SM_o, set $SM_{new} = SM_o$. In this case it is assumed that the excess soil moisture is lost to deep drainage below the plant rooting layer.

Table 1 Parameterized to be used in Your SVAT Model

A. Aerodynamic Parameterization

Name	Symbol	Value	Units	Source
Aerodynamic Resistance	r_a	calculated	s m^{-1}	Equ (22.9)
Zero plane displacement	d	calculated	m	Equ (22.9)
Aerodynamic roughness of crop	z_0	calculated	m	Equ (22.3) or Equ (22.4)
Measure wind speed for each hour	u_m	provided	m s^{-1}	meteorological data set
Leaf Area Index	LAI	4 for forest; 2 for grass	m	specified
Canopy Height	h	20 for forest; 0.12 for grass	m	specified
Measurement height for wind speed	z_r	50	m	specified
Measurement height for VPD, temperature	z_r'	50	m	specified
Aerodynamic roughness of soil	z_0'	0.003	m	Not Needed
Von Kaman Constant	k	0.4	none	specified

B. Surface Resistance Parameterization

Name	Symbol	Value	Units	Source
Surface resistance	r_s	calculated	s m^{-1}	Equ (24.1)
Surface conductance	g_s	calculated	m s^{-1}	Equ (24.1)
Canopy specific constant	g_0	15 for forest; 30 for grass	*mm s^{-1}	Equ (24.1)

Canopy cover factor	g_c	1	none	specified
Radiation stress factor	g_R	calculated	none	Equ (24.2) (set = 0 if calculated <0)
Vapor pressure deficit stress factor	g_D	calculated	none	Equ (24.3) (set = 0 if calculated <0)
Temperature stress factor	g_T	calculated	none	Equ (24.4) (set = 0 if calculated <0)
Parameter in temperature stress factor	α_T	calculated	none	Equ (24.5) (set = 0 if calculated <0)
Soil moisture stress factor	g_T	calculated	none	Equ (24.6) (set = 0 if calculated <0)
Parameter in Equ (24.2)	K_R	200	W m^{-2}	specified
Parameter in Equ (24.3)	K_{D^1}	-0.307	$(kPa)^{-1}$	specified
Parameter in Equ (24.3)	K_{D^2}	0.019	$(kPa)^{-2}$	specified
Parameter in Equ (24.4) and Equ (24.5)	T_H	313	K	specified
Parameter in Equ (24.4) and Equ (24.5)	T_L	273	K	specified
Parameter in Equ (24.4) and Equ (24.5)	T_0	293	K	specified
Parameter in Equ (24.6)	K_{M^1}	3.36E-4 (forest); 1.87E-2 (grass)	none	specified
Parameter in Equ (24.6)	K_{M^2}	-0.1	mm^{-1}	specified
Parameter in Equ (24.6)	SM_0	10 for forest; 5 for grass	mm	specified
Air Pressure	P	101.2	k Pa	specified
Air temperature (in K)	T	calculated	K	(= T^C +273.17)
Vapor pressure	e	calculated	k Pa	Equ (2.9)
Saturated vapor pressure	e_{sat}	calculated	k Pa	Equ (2.17)
Vapor pressure deficit for each hour	D	calculated	k Pa	Equ (2.20)

Measured specific humidiy	q	provided	kg kg^{-1}	meteorological data set
Measured solar radiation for each hour	S	provided	W m^{-2}	meteorological data set
Measured air temperature (in °C)	T^{C}	provided	◎C	meteorological data set
Root-accessible soil moisture	SM_{last}	= SM_{new} (last time step)	mm	calculated in section E

[*Note: g_0 is usually given in mm s^{-1} rather than m s^{-1} : <u>don't forget the factor 1000 when calculating g_s</u>!]

C. Radiation Parameterization

Name	Symbol	Value	Units	Source
Net radiation	R_N	calculated	W m^{-2}	Equ (5.27)
Reflected solar Radiation	S_r	calculated	W m^{-2}	(= a S_r)
Upward longwave radiation	L_u	calculated	W m^{-2}	Equ (5.19)
Surface temperature (in K)	$T_{surface}$	calculated [c.f. Equ (21.21)]	K	$T_{surface} = T + (H\ r_a)/(◎_a\ c_p)$
Albedo	a	0.12 for forest; 0.23 for grass	none	specified
Emissivity of crop	$\varepsilon_{\text{surface}}$	0.95	none	specified
Stefan-Boltzmann constant	σ	5.67 x 10-8	W m^{-2} K^{-4}	specified
Density of moist air	ρ_a	1.23	kg m^{-3}	specified
Specific heat of air at constant pressure	c_p	1013	J kg^{-1}	specified
Measured solar radiation for each hour	S	provided	kPa	meteorological data set
Measured downward longwave radiation	L_d	provided	W m^{-2}	meteorological data set

Sensible heat flux	H	calculated	W m^{-2}	calculated in 4

[*To estimate the value of L_u for the current time step, use average of the values calculated for the previous 2 time steps]

D. Canopy Water Balance Parameterization

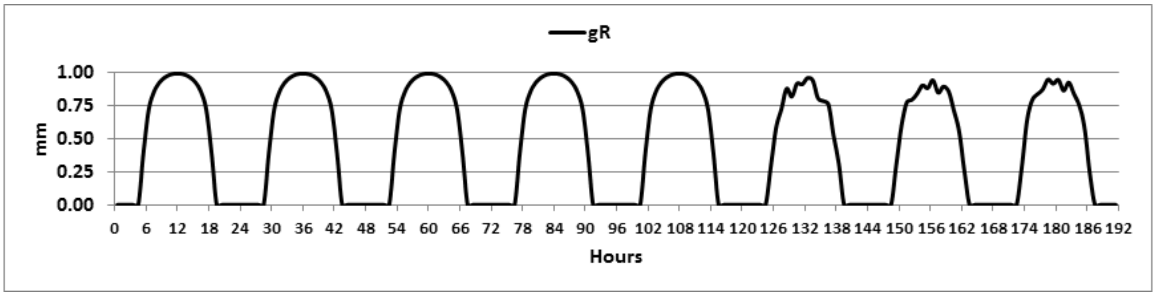
	$C_{interim}$	$= C_{final}$ (previous) $+ P$	mm	See text in section D
	C_{actual}	$= C_{interim}$, or S if $C_{interim} > S$	mm	See text in section D
Water stored on canopy	C_{final}	$= C_{actual} - (\lambda E_I)(3600/\lambda)$	mm	See text in section D
Evaporation rate for Intecepted water	λE_I	calculated	W m^{-2}	Equ (22.14) (set = 0 if calculated <0)
Transpiration rate	λE_T	calculated	W m^{-2}	Equ (22.18)
Total Latent Heat	λE	calculated	W m^{-2}	Equ (22.17)
Total Sensible Heat	H	calculated	W m^{-2}	$H = A$ -◎◎E
Drainage (per hour)	D_r	$= 0$, or $C_{interim} - S$ if $C_{interim} > S$	mm	Canopy drainage to soil
Available energy	A	calculated	W m^{-2}	(= R_N)
Latent heat of vaporization	λ	calculated	J kg^{-1}	Equ (2.1)
Gradient of saturated vapor pressure	Δ	calculated	k Pa K^{-1}	Equ (2.18)
Fraction of precip falling through holes in canopy	f_t	0	none	specified
Fraction of precip diverted to stems	fs	0	none	specified
Initial water stored on canopy	C (t=0)	0	mm	specified
Canopy water storage capacity	S_c	4 for forest; 2 for grass	mm	specified
Vapor pressure	e	calculated	k Pa	calculated in B

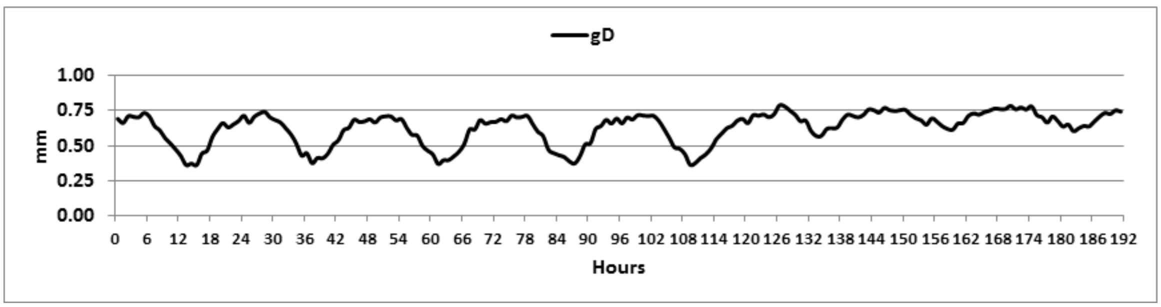
Saturated vapor pressure	e_{sat}	calculated	k Pa	calculated in B
Vapor pressure deficit for each hour	D	calculated	k Pa	calculated in B
Density of moist air	ρ_a	specified	kg m^{-3}	specified in C
Specific heat of air at constant pressure	c_p	specified	J kg^{-1}	specified in C
Precipitation rate (per hour)	p	provided	mm	meteorological data set
Measured specific humidiy	q	provided	kg kg^{-1}	meteorological data set

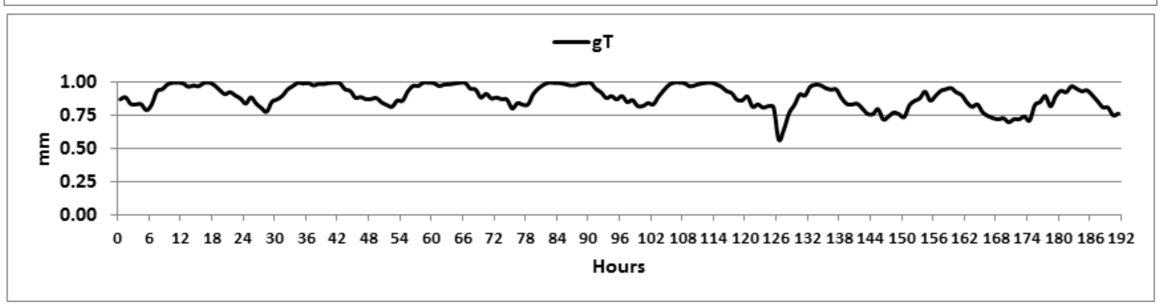
E. Soil Water Balance Parameterization

Soil moisture accessible to roots	SM_{last}	$= SM_{new}$ (last time step)	mm	
Soil moisture accessible to roots	SM_{new}	$= SM_{last} + Dr - (1 - C_{actual}/S)\lambda E_T$	mm	Limited to SM_0
Initial soil moisture accessible to roots	SM_{init}	40 for forest; 20 for grass	mm	specified
Maximum soil moisture accessible to roots	SM_o	80 for forest; 40 for grass	mm	specified

I am sending you the meteorological data you will need to force your SVAT in a spreadsheet by email. Because the coding of the stress factors used when calculating the surface resistance is complex and assumed independent of the canopy, I am giving diagrams of their behavior as a function of time below so you can check you have coded them correctly.







Having created your SVAT model as described above in the blank spreadsheet, it will make plots and table for both types of vegetation cover (in the sheets named Forest Graphs and Grass Graphs) for the time series of forcing data provided (5 identical dry days without cloud followed by 3 wet days with some cloud cover and occasional precipitation), thus.

I. Hourly values of the calculated net radiation, total latent heat flux, and sensible heat flux (all in W m^{-2}) on the same graph (5 pt).

II. Hourly values of the calculated total latent heat flux and the portion of the latent heat flux that originates from the evaporation of intercepted water (both in W m^{-2}). (5 pts)

III. Hourly values of the precipitation and the canopy storage C (both in mm). ([optional when interception is considered])

IV. Hourly values of the canopy drainage [if interception was considered] the value of SM (both in mm). (5 pts)

V. Hourly values of the soil moisture stress function g_M (no units). (5 pts)

VI. A table giving for all 8 individual days the daily average values of R_n, λE, H, and λE_I (all in W m-2), and the values of daily average Bowen Ratio and the ratio of daily average fractional contribution to daily average total evaporation that arises from the evaporation of intercepted water. (10 pts)

(a) Comment on (10 pts)

i. the relative differences in values of daily average Bowen Ratio, and

ii. the ratio of daily average fractional contribution to daily average total evaporation that arises from the evaporation of intercepted water you find for forest and grass [if interception was considered].

[Hints. What are the differences in the Bowen ratio for forest and grass? How does this value changes as the soil dries?]