Numerical Modeling of Evapotranspiration from Montane Vegetation with Verification from Actual Surface Energy Balance Measurements

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ABSTRACT

Estimating actual evapotranspiration (ET_a) is an important, yet challenging task in arid montane ecosystems. We employed a numerical model (Hydrus 1D) to estimate actual evapotranspiration from water content measurements following snowmelt in the Wasatch Range of mountains. The study area includes three watersheds in the Northern Utah equipped with eleven weather stations, each reporting soil moisture, net radiation, relative humidity, air and soil temperature and precipitation. Estimates of ET_a were taken as the sum of root water uptake and evaporation, which were compared with ET calculated from surface energy balance. Measurements of net radiation, sensible heat flux and soil heat flux were used to obtain ET as the residual latent heat flux (LET). These estimates are used to provide ET_a estimation taking account of the soil - vegetation characteristics for improved climate modeling boundary conditions.

1. THEORETICAL CONSIDERATIONS

1.1 Hydrus 1D and simulation of ET

In this study the HYDRUS-1D model is used to simulate the water movement in the soil . The model is capable of simulating the water movement in unsaturated, partly saturated or fully saturated porous media (Simunek et al., 2008). The HYDRUS-1D model for one-dimensional uniform water movement is described by the modified Richards equation using the assumption that the air phase plays an unimportant role in the water flow process, and water flow due to thermal gradients can be neglected.

$$\frac{\partial \theta(h)}{\partial t} = \frac{\partial}{\partial z}\left[K(h)\left\{\frac{\partial h}{\partial z}+1\right\}\right] - S$$

- θ volumetric water content [cm^3/cm^3];
- h soil pressure head [cm];
- t time [day];
- z spatial coordinate [cm]; positive downward;
- K(h) unsaturated hydraulic conductivity [cm/day]
- S sink term, accounting for plant water, S(h) =α(h)Sp

The soil water content θ is modeled using the van Genuchten-Mualem (VGM) model, (Mualem, 1976; van Genuchten, 1980)

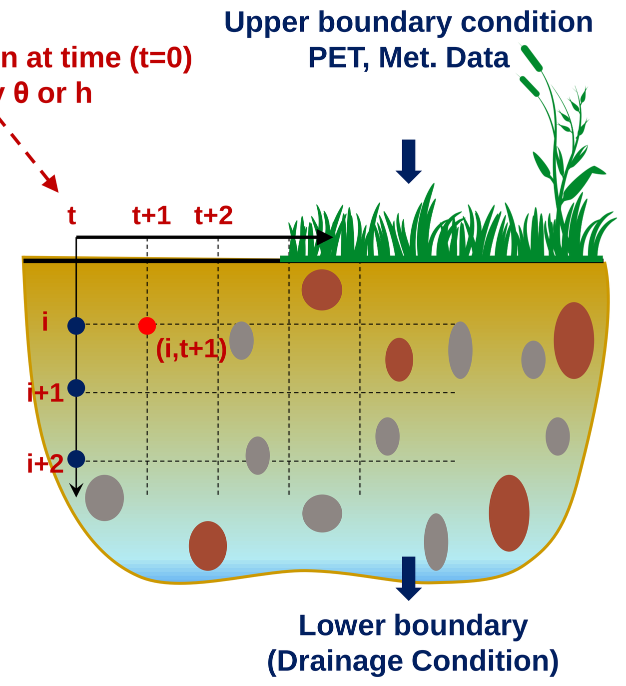
$$\theta_h = \begin{cases} \theta_r + \dfrac{\theta_s - \theta_r}{\left[1+|\alpha h|^n\right]^m}, & h<0 \\ \theta_s & h \geq 0 \end{cases}$$

The saturation-dependent hydraulic conductivity {$K(S_e)$} is expressed as,

$$K(S_e) = K_s S_e^{0.5}\left[1-\left(1-S_e^{1/m}\right)^m\right]^2$$

Where, S_e is the effective saturation [−] and defined as

$$S_e = \begin{cases} \dfrac{\theta-\theta_r}{\theta_s-\theta_r}, & h<0 \\ S_e = 1 & h \geq 0 \end{cases}$$



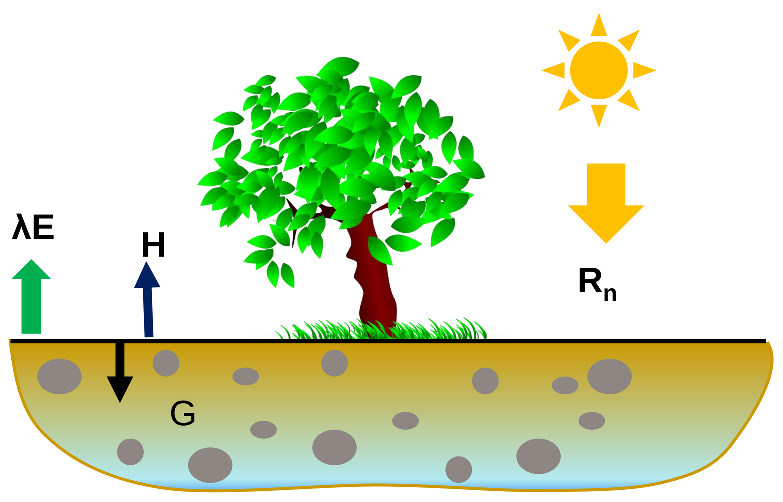
- θ_r residual water content [cm3/cm3];
- θ_s saturated water content [cm3/cm3];
- K_s saturated hydraulic conductivity [cm/day]
- α [cm-1], n [-] and m [-] are adjustable parameters.

In the HYDRUS-1D, potential evaporation is calculated using either Penman-Monteith or Hargreaves formula.

The potential evaporation is used as an input to calculate the actual evaporation fluxes based on Feddes reduction for transpiration and hCritA limit for soil evaporation (Simunek et al., 2008).

1.2 Surface energy balance approach and ET calculation

The surface energy balance of earth can be written as below:



$$R_n = G + H + \lambda E$$

- G ground heat flux (W/m^2)
- H sensible heat flux (W/m^2)
- λE latent heat flux (W/m^2)
- R_n net radiation (W/m^2)

Net radiation (Rn) is sum of the differences between the incoming and outgoing shortwave and longwave radiation.

$$R_n = R_{s(in)} - R_{s(out)} + R_{l(in)} - R_{l(out)}$$

Having the data for net radiation and the ground heat flux from the sensors the sensible heat flux is estimated using the aerodynamic profile method (Campbell, 1977)

$$H = \rho_a . c_p \frac{(T_{surf} - T_{air})}{r_a}$$

Where,

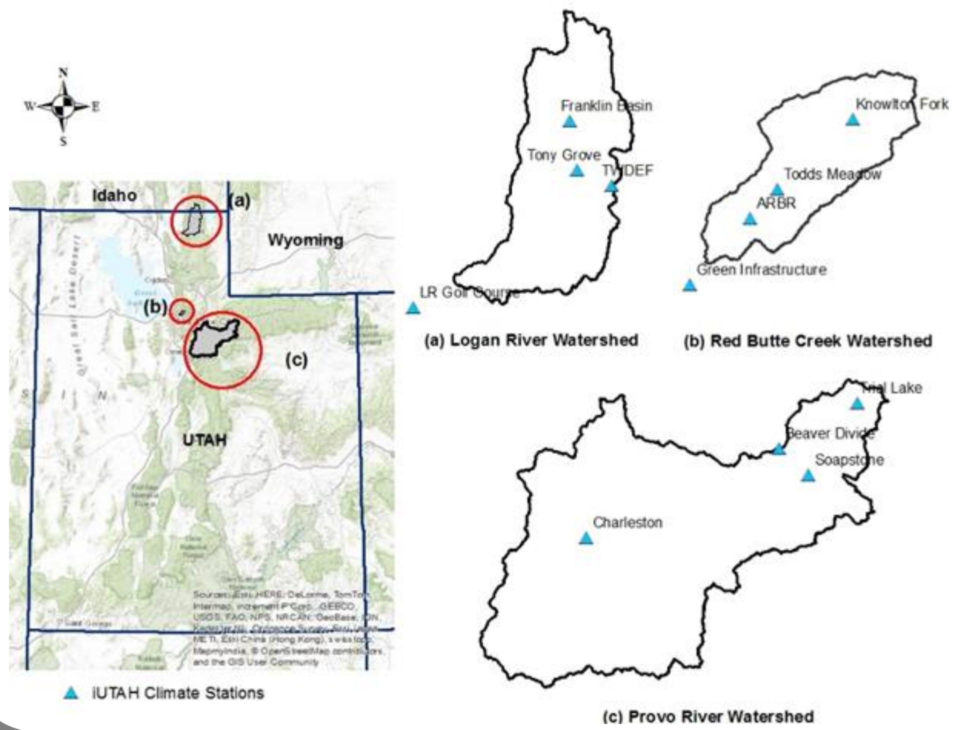
$$r_a = \frac{\ln\left(\frac{z}{z_o}\right).\ln\left(\frac{z}{z_{oh}}\right)}{k^2.\bar{u}(z)}$$

H	Sensible heat flux (W/m^2)
ρ_a	Density of air (kg/m^3)
C_p	Specific heat (J/kg)
T_{surf}, T_{air}	Surface & Air tempearture
z	Elevation of measurement (2 m)
z_o	Roughness parameter for momentum (m)
z_{oh}	Roughness parameter for heat (m)
k	Von Karman constant
u(z)	Function of wind speed ($a+bu_2$)

2. Study Area and Data

- Three watersheds in Northern Utah
- Twelve weather stations (four in each watersheds)
- Measurements every 15 minutes
- The information is collected in a data logger and uploaded in the iUTAH data repository

(iUTAH GAMUT Working Group, 2014)



Data Used

- Soil moisture (5 depths),
- Air Temperature
- Relative humidity,
- Wind speed,
- Net radiation (solar),
- Soil heat flux,
- Rainfall

3. RESULTS AND DISCUSSION

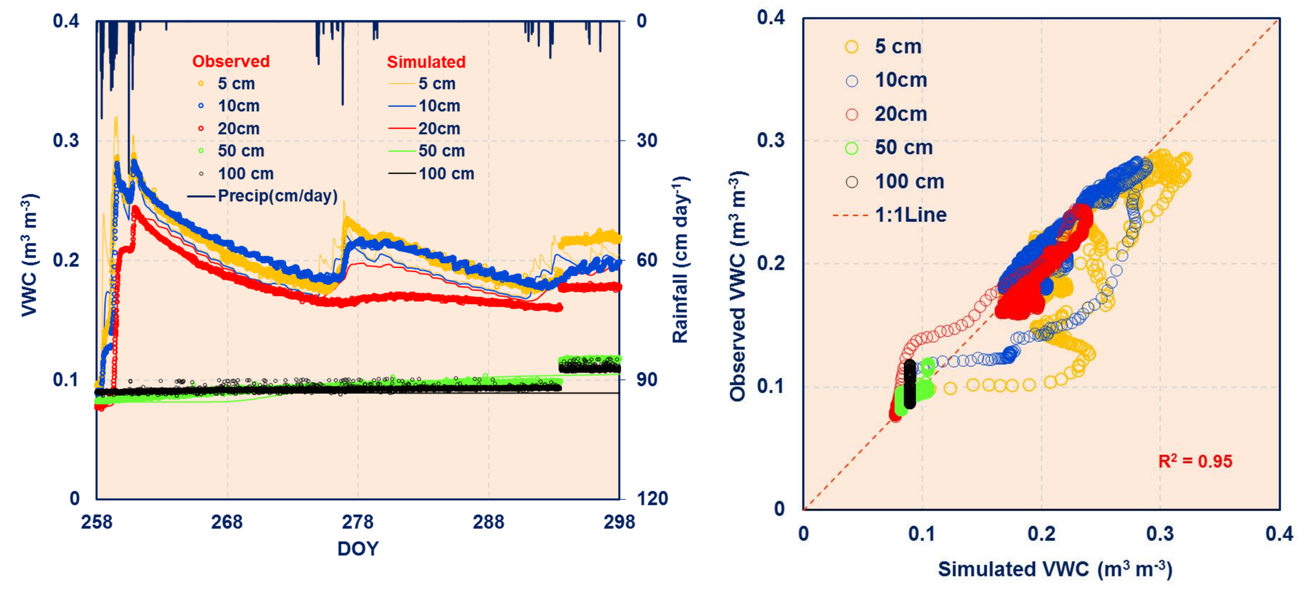


Figure: Comparison of observed and simulated results for the volumetric water content at five depths

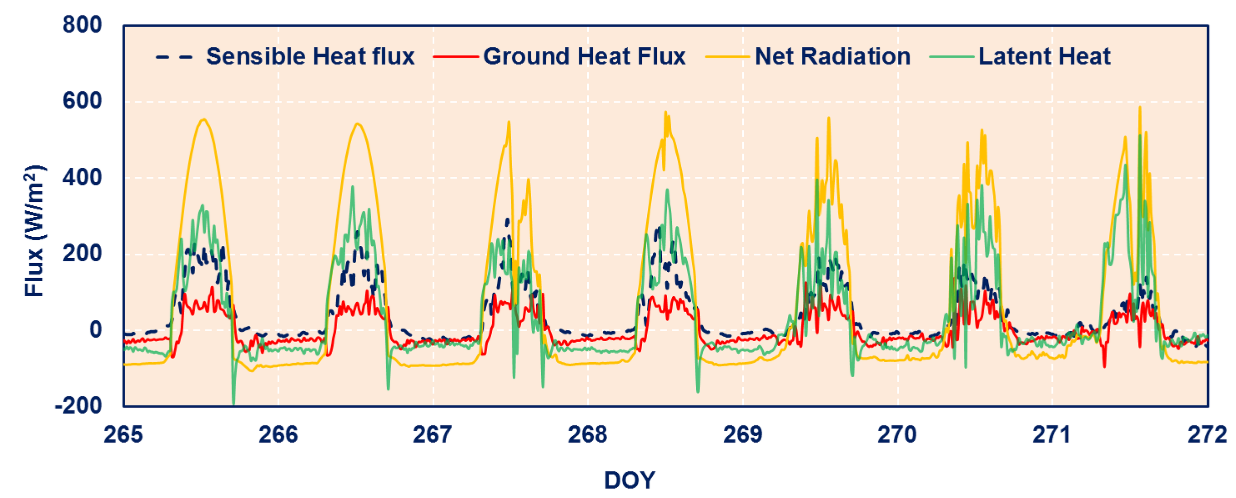


Figure: Net radiation and heat fluxes shown together from Day 265 (22 September – 29 September 2015)

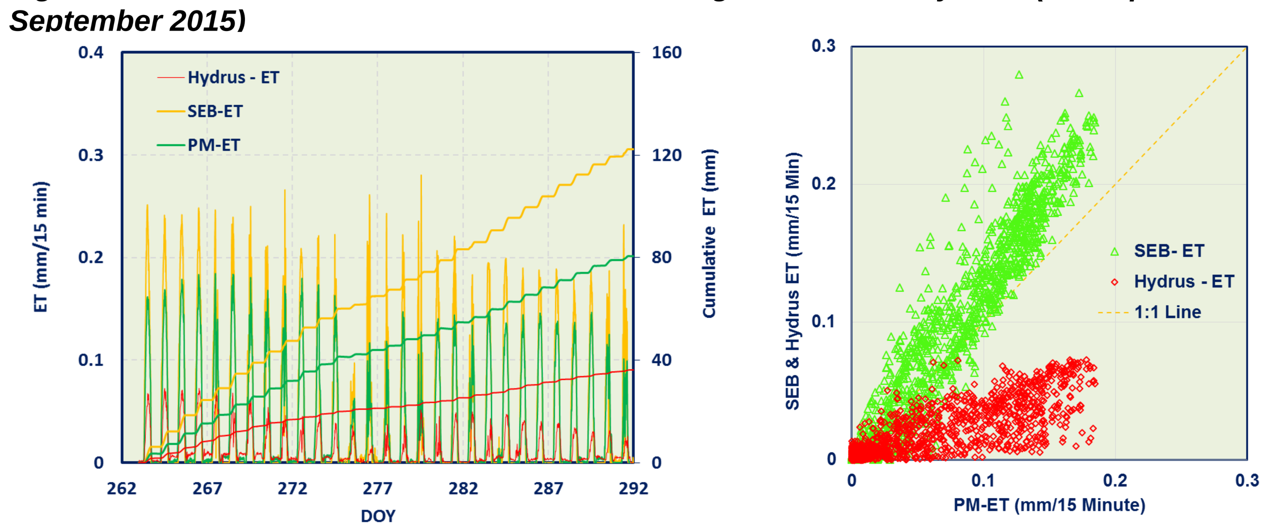


Figure: (a) Potential PM-ET , SEB-ET and Hydrus simulated ET compared together and (b) Scatter plot between PM-ET and ET simulated by Hydrus and SEB method

The ET simulated by Hydrus in one of the station Franklin Basin shows the total ET of 38 mm in 30 days period (Average: 1.26 mm/day) Potential ET for the same period is 80 mm (Average: 2.67 mm/day).

The ET calculated as residual of the surface energy balance is overestimated and higher than the potential ET calculated by PM equation. It suggest that the sensible heat flux (H) in the surface energy balance should be calculated more accurately.

4. ONGOING WORKS

Future work will include:

- Further simulation of actual evapotranspiration will be performed using Hydrus-1D, incorporating the impact of rock present in the soil
- Application and remote sensing to have better estimate of sensible heat flux
- Remote sensing application to provide spatial estimates of actual ET in the three watersheds

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