Slope or Drainage Flows Predicted By CALMET

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Owen Pitts – Air Assessments

As used in CALMET

As described by Scire and Robe (1997), a new slope flow parameterization has been implemented into CALMET. It is based on the shooting flow parameterization of Mahr (1982). Shooting flows are buoyancy-driven flows, balanced by advection of weaker momentum, surface drag, and entrainment at the top of the slope flow layer. Following Mahrt, it is assumed, for the derivation of the slope flow speed only, that the flow is steady, its depth is constant, and the terrain slope is constant. Coriolis effects and cross-slope components are neglected. The slope flow speed can be expressed as:

$$S = S_e [\ 1 - \exp(-x/L_e)]^{1/2} \qquad (2\text{-}8)$$

$$S_e = [\ h\ g\ (\Delta\theta/\theta) \sin\alpha / (C_D + k)]^{1/2} \qquad (2\text{-}9)$$

$$L_e = h / (C_D + k) \qquad (2\text{-}10)$$

where, S_e is the equilibrium speed of the slope flow,
L_e is an equilibrium length scale,
x is the distance to the crest of the hill,
$\Delta\theta$ is the potential temperature deficit with respect to the environment,
θ is the potential temperature of the environment,
C_D is the surface drag coefficient,
h is the depth of the slope flow,
α is the angle of the terrain relative to the horizontal,
k is the entrainment coefficient at the top of the slope flow layer, and

As used in CALMET

As the flow moves down the slope, it is cooled by the local heat flux. The potential temperature deficit, $\Delta\theta$, is a function of the magnitude of the local sensible heat flux (Q_h) at the surface and the distance to the crest (x). With the commonly-used assumptions of constant h and Q_h (Briggs, 1979), the heat budget requires:

$$d(h\ \Delta\theta)/dt = Q_h\ \theta\ /\ (\rho\ c_p\ T) \tag{2-11}$$

Assuming d/dt = Sd/dx and integrating along the slope, produces:

$$S\ h\ \ \Delta\theta = Q_h\ \theta\ x\ /\ (\rho\ c_p\ T) \tag{2-12}$$

Substituting (2-12) into (2-9), and then into (2-8), yields the following equation for the speed of the slope flow:

$$S = \{[Q_h\ g\ x\ \sin\alpha\ /\ [(\ \rho\ c_p\ T)\ (C_D + k)]\}^{1/3}\ [\ 1 - \exp(-x/L_e)]^{1/3} \tag{2-13}$$

For downslope flows, values of $C_D = K = 4 \times 10^{-2}$ are within the range of observed values in vegetation-covered areas (e.g., Briggs, 1981, Mahrt, 1982, Horst and Doran, 1986).

Summary of Slope flow formula

Apart from the dependence on the relative physical dimensions of the terrain, the slope and the position of interest, the formulation dependence to the meteorology is primarily via the sensible heat flux (Q_h) to the power of 1/3.

Other parameters such as the absolute value of the temperature and density will vary by a small amount and have less influence.

Now according to Eq. 2-13, as $Q_h \Rightarrow 0$, the slope flow $\Rightarrow 0$.
(or a small value, see later comment on restriction).

$Q_h \Rightarrow 0$, when the wind speed $\Rightarrow 0$ which is not intuitive and contrary to prognostic models.

Sensible Heat Flux (Q_h) During Stable Conditions

$$Q_h = - \rho\, c_p\, u_*\, \theta_*$$

Where, u_* is the surface friction velocity, m/s)

$u_* = ½ (C_{DN}\ u) [1 + C^{0.5}]$

$C = 1 - 4 u_o^2 / (C_{DN}\ u^2)$

$u_o^2 = (\gamma\, z_m\, g\, \theta_*) /T$

C_{DN} is the neutral drag coefficient [$k/\ln(z_m/z_0)$]

γ is a constant ($\cong$ 4.7)

z_m is the measurement height of the wind speed, u

θ_* is the temperature scale

$\theta_* = \min [\theta_{*1}, \theta_{*2}]$

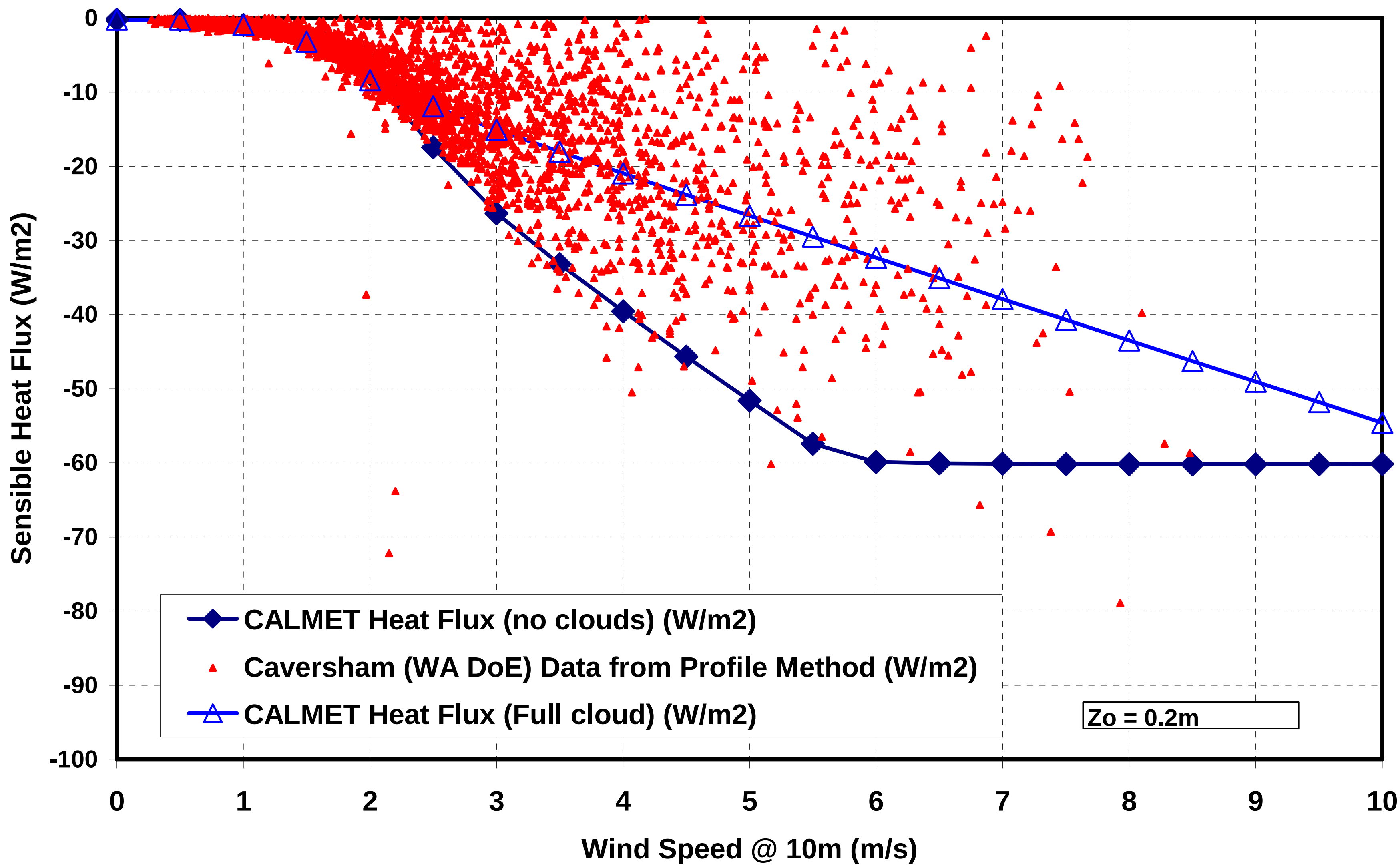
$\theta_{*1} = 0.09 (1 – 0.5 N^2)$

$\theta_{*2} = T\, C_{DN}\ u^2 / (4\, \gamma\, z_m\, g)$

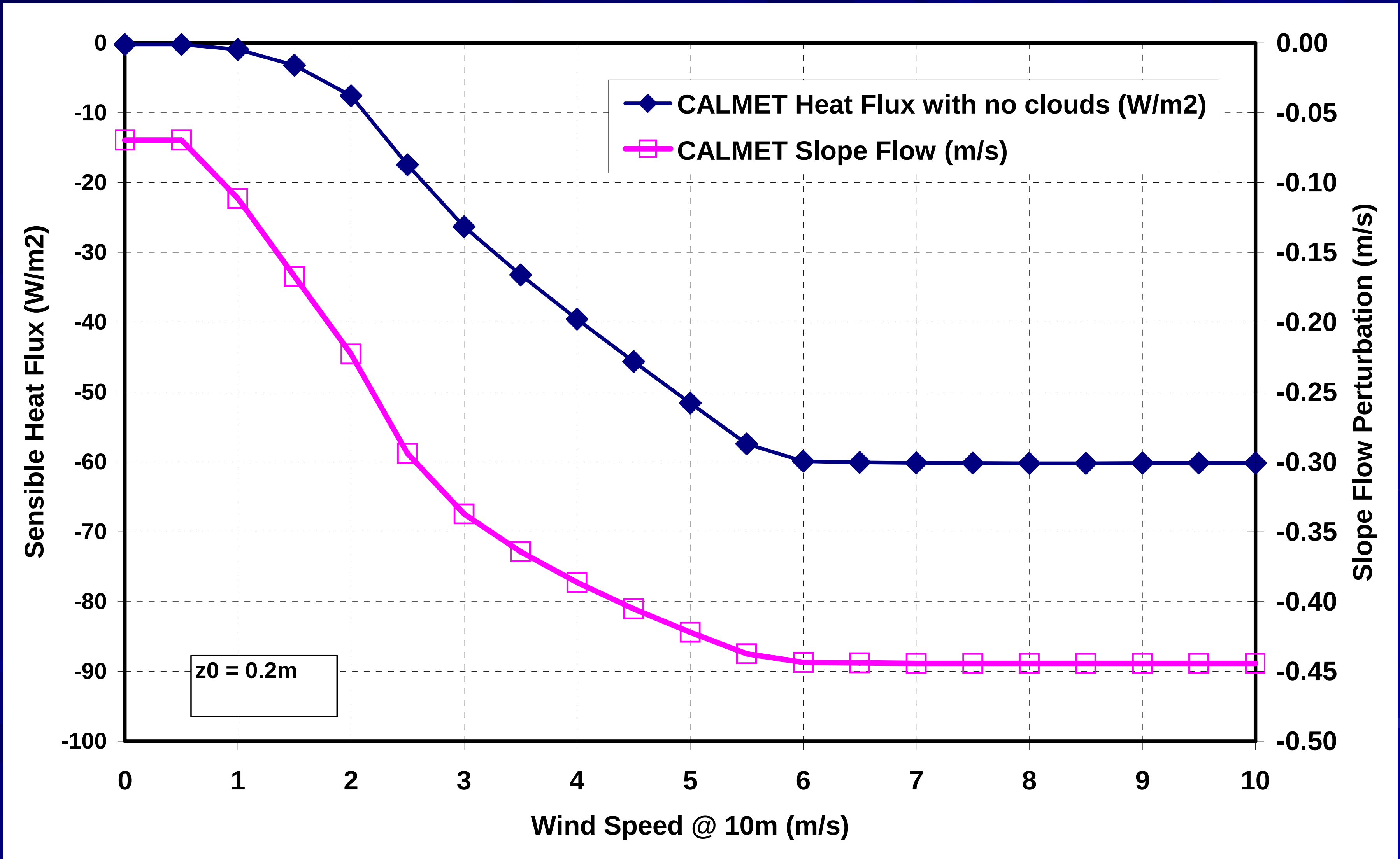
where, N is the fractional loud cover (0 to 1)

Note: In CALMET, u is set to a be a minimum of 0.5 m/s and u_* is set to be a minimum of 0.05 m/s.

Stable Heat Flux Estimates (z_o=0.2m)

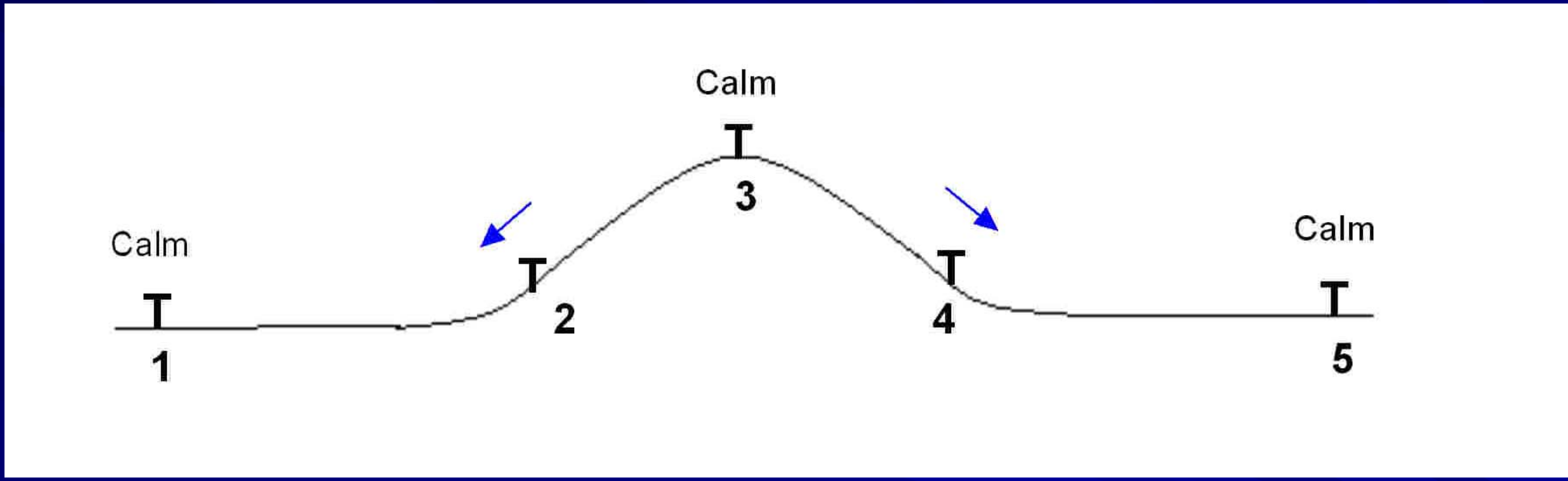


Stable Heat Flux and Slope Flow Estimates (z_o=0.2m)

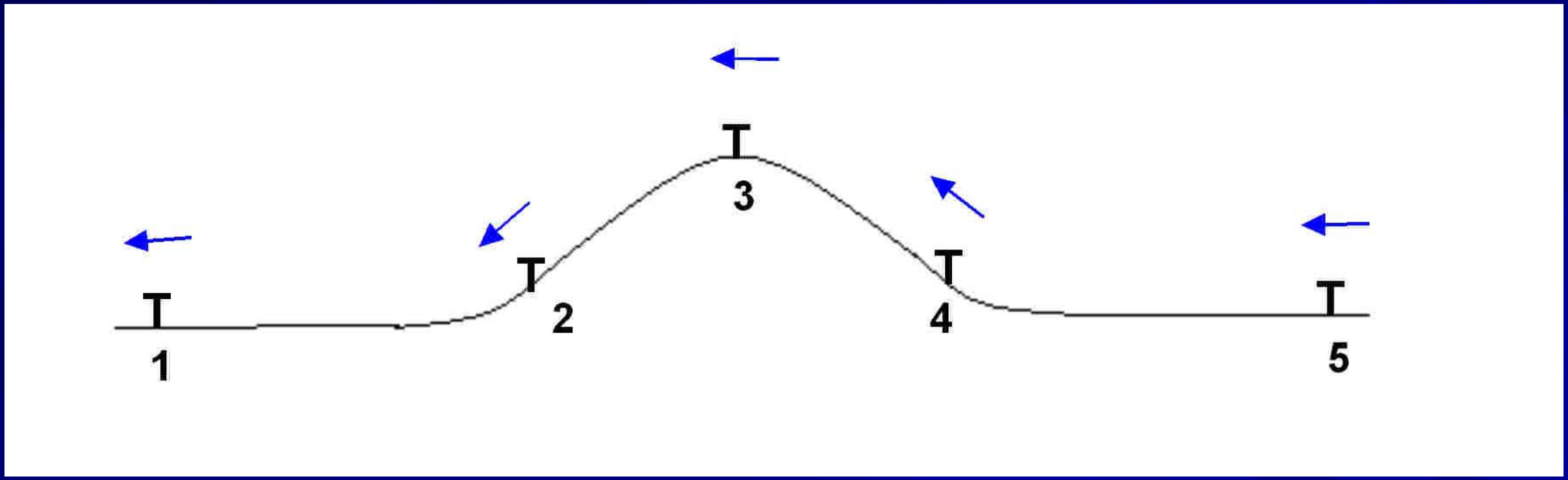


Can CALMET double count flows?

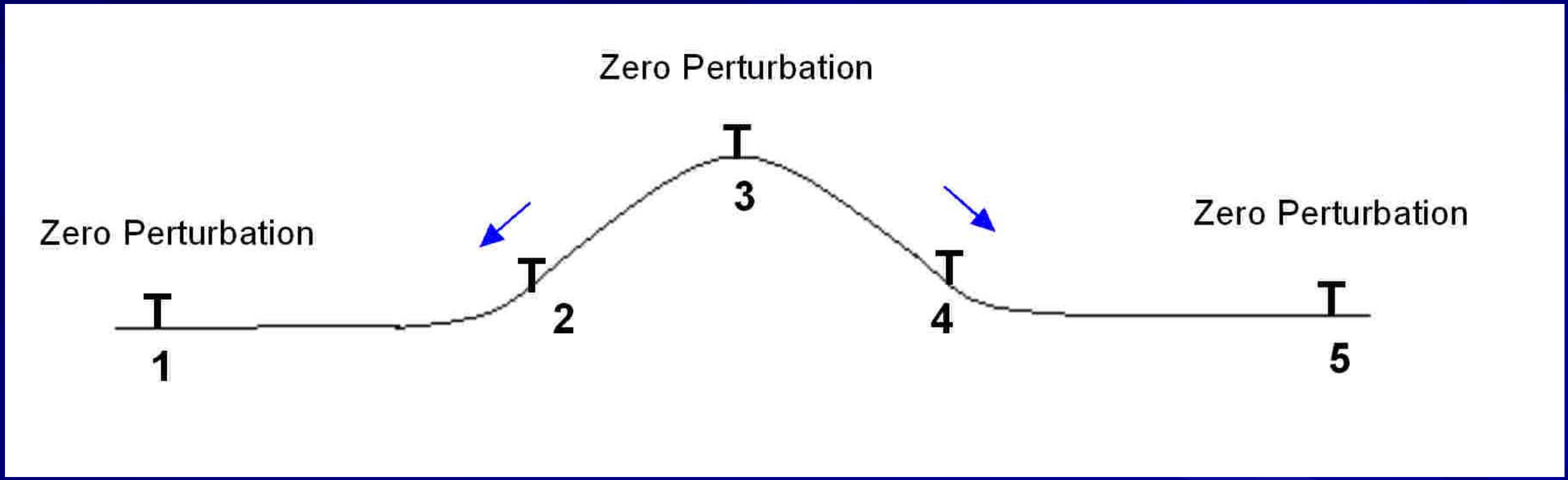
Example: Actual flows for a night on a 2-D ridge. Nocturnal drainage flow down ridge slopes.



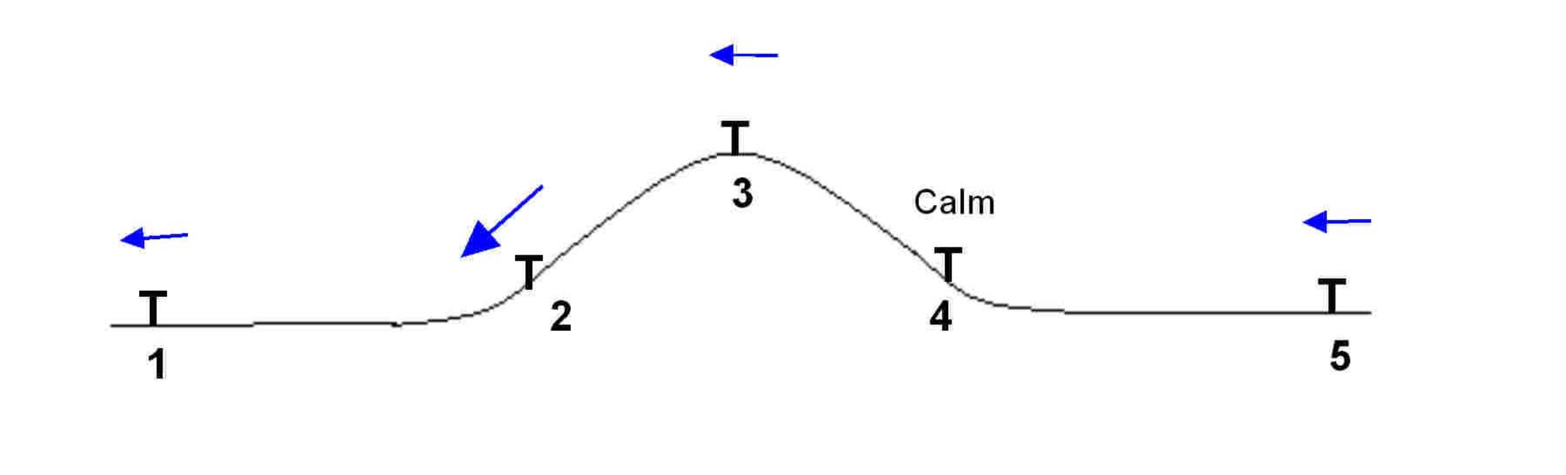
Winds after interpolation if only the site 2 winds are available. I.e. a westerly is developed everywhere



Winds developed by CALMET for the slope flow. That is the slope flow perturbation to be added to the winds from the diagnostic step.



Winds after slope flow and blocking affects are added to diagnostic winds. I.e the step 1 wind results. Here CALMET adds a slope flow component to locations 2 and 4 respectively. At location 2 increasing the westerly, whilst at location 4 countering the westerly.



As such, does CALMET work best when surface winds used are not influenced by slope flows or blocking affects. I.e. sites such as 1 and 5 are preferable?

Conclusions / Recommendations

-For low wind speeds, the heat flux tends to zero and therefore in the current CALMET formula, the slope flow tends towards zero.

- There is a need for better slope flow formulation within CALMET which does not tend to near zero (small wind speeds) at zero ambient wind speed.

- Does CALMET work best for surface observations without local influences from terrain affects? As such, is some guidance required and does it indicate need for prognostic winds for first step?