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LESSON 2.
THE ENERGY BALANCE AND THE PENMAN-MONTEITH EQUATION

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PARTNERS VOOR WATER
Bundeling van krachten

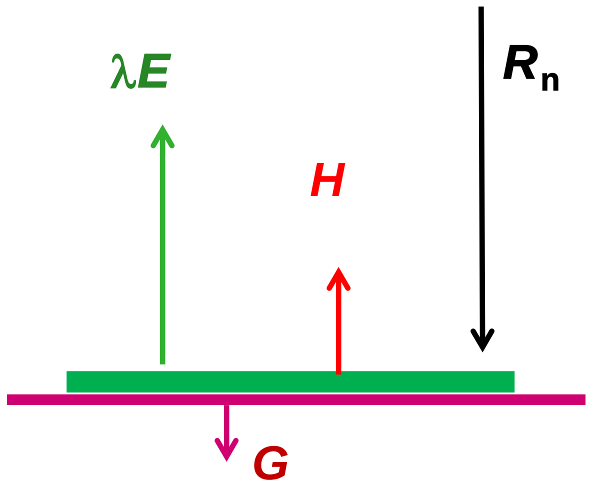
The energy balance

- Derived from surface energy balance (Wm^{-2}):

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

- R_n: net radiation (shortwave + longwave)
- G: ground/soil heat flux
- λE: latent heat flux for evaporation
- H: sensible heat flux

R_n is the source of energy, G, H and λ E are the sinks of energy



This is a 1-D (vertical) model concept

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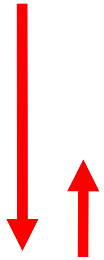
Net shortwave radiation

- Shortwave radiation from the **sun** and **sky** (0.4 – 2.5 μm)

- Reflection coefficient: albedo (or *α*)

$$R_{s,n} = R_s^{\downarrow} - R_s^{\uparrow} = R_s^{\downarrow} - \alpha R_s^{\downarrow} = (1-\alpha) R_s^{\downarrow}$$

in



reflected

Albedo values	
Water	4-8%
Gray soils	15-25%
Green grass	15-25%
Forest	10-15%
Fresh snow	80-90%

Net shortwave radiation

$$R_{n,l} = (1 - \varepsilon_s)R_{li} - R_{lo}$$

Incoming from the sky

with Stefan Boltzman's equation, For clear sky

$$R_{ldc} = \varepsilon_{ac}\sigma T_a^4$$

With an empirical equation for the atmospheric emissivity ε_{ac}

Emitted by the surface

$$R_{lu} = \varepsilon_s \sigma T_s^4$$

Where ε_s is the surface emissivity

in

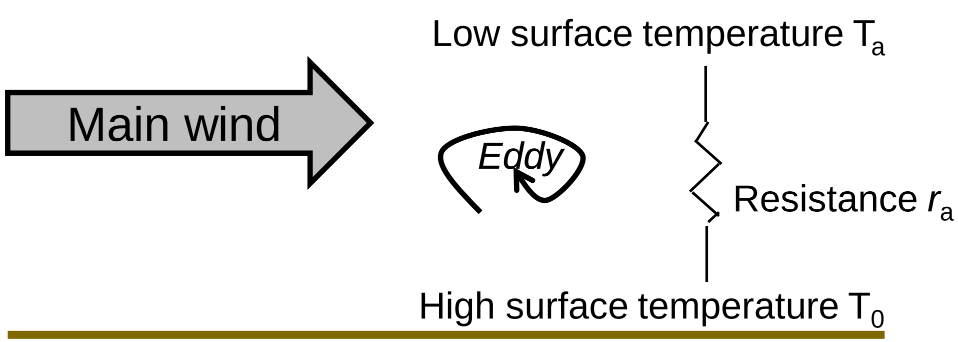
reflected emitted

Sensible heat flux

- And resistance driven vertical vapour transport in the surface layer

$$H = \rho cp \cdot \frac{T_0 - T_a}{r_a}$$

e_s: vapour pressure at the surface (hPa)
e_a: vapour pressure at some height *z* (hPa)
r_a: aerodynamic resistance between surface and z (sm^{-1})
ρ: specific mass of air ($kg\ m^{-3}$)
c_p: specific heat of air ($J\ kg^{-1}\ K^{-1}$)

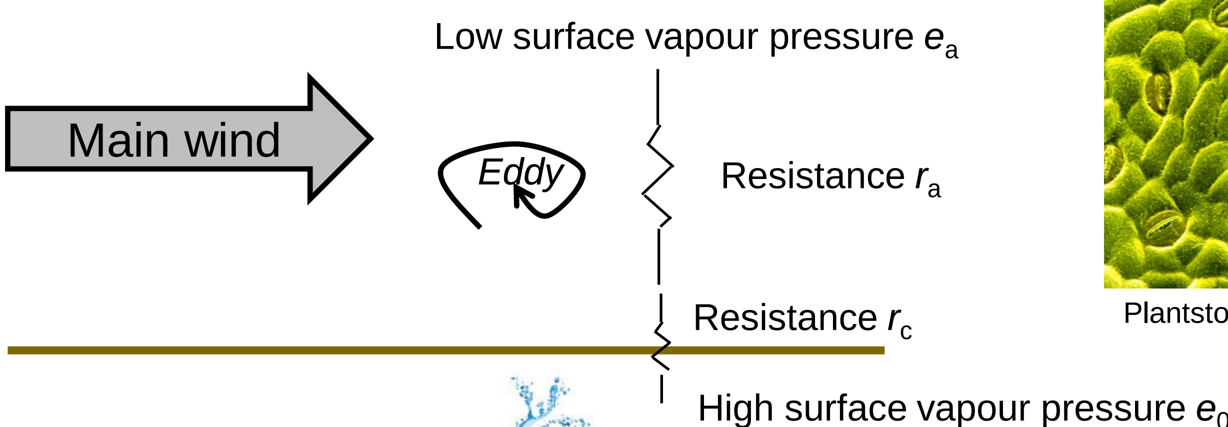


Latent heat flux

- For latent heat: extra resistance due to stomata and soil pores

$$\lambda E = \frac{\lambda \rho}{\gamma} \cdot \frac{e_s - e_a}{r_a + r_c}$$

e_s: vapour pressure at the surface (hPa)
e_a: vapour pressure at some height z (hPa)
r_a: aerodynamic resistance between surface and z (sm^{-1})
r_c: surface resistance between stomata/pores and surface (sm^{-1})
λ: latent heat for evaporation ($J\ kg^{-1}$)
ρ: specific mass of air ($kg\ m^{-3}$)
γ: psychrometer constant ($hPa\ K^{-1}$)




Plantstomata.worldpress.com

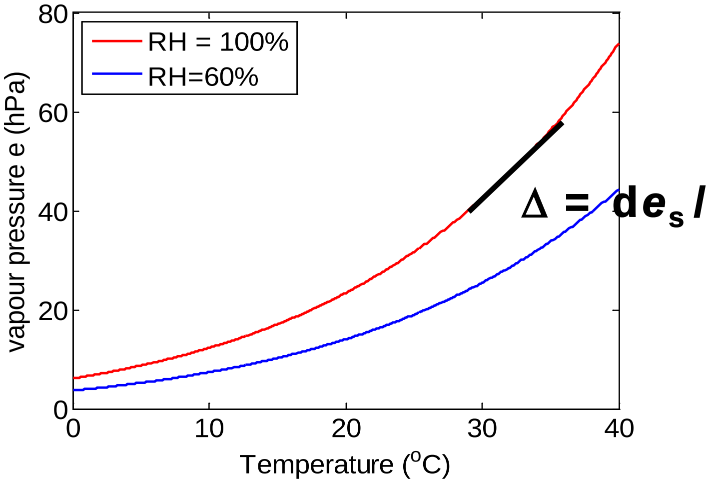
Penman-Monteith equation

Approximate:

$$e_0 = e_s(T_0) \approx e_s(T_a) + \Delta \cdot [T_0 - T_a]$$

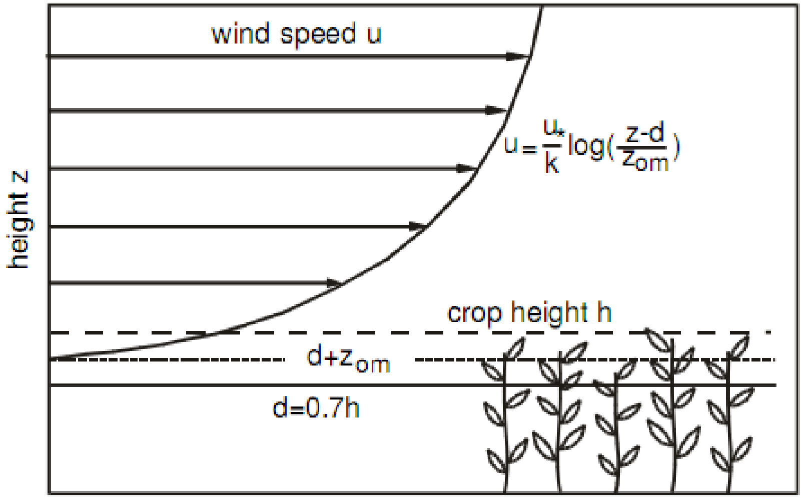
And combining the equations in the previous slides gives the equation of Penman-Monteith (Monteith 1965, Rijtema, 1965):

$$\lambda E = \frac{\Delta[R_n - G] + \frac{\rho c_p}{r_a}[e_s(T_a) - e_a]}{\Delta + \gamma\left[1 + \frac{r_c}{r_a}\right]}$$



Calculation of aerodynamic resistance

- Vapour and heat transported by eddies
- Resistance depends on (1) wind speed and (2) vertical gradient of horizontal wind speed with height (the higher this gradient, the higher the resistance)
- Vertical profile of wind speed estimated from vegetation height and density and atmospheric stability



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THANK YOU