Forest Hydrology: Lec. 12

Lecture content

- Evapotranspiration
  - the energy balance equation
  - the gas law
  - saturation water pressure

Radiation

- In the absence of restrictions due to water availability at the evaporative surface, the amount of radiant energy captured at the earth surface is the dominant control on regional evaporation rates.
- Understanding surface radiation balance, and how to quantify it, is therefore crucial to understanding and quantifying evaporation.

The energy balance equation (flux per unit area, W m^{-2})

$$\underbrace{S(1-\alpha)+F_{\downarrow}-\varepsilon_s\sigma T_s^4}_{\text{net radiation } R_{net}}=H+L+G$$

- S = solar radiation
- α = albedo: water 0.06; conifer forest 0.09; Amazon broadleaf forest 0.12; grassland 0.2–0.4
- $F_{\downarrow}$= downward infrared radiation, depends on temperature, water vapor, and clouds
- T_s = surface temperature
- H = sensible heat transfer (+ is surface to atmosphere)
- L = latent heat transfer in water evaporating or condensing (+ is evapotranspiration, – is condensation)
- G = heat conducted into soil

Latent energy

Type of latent energy	symbol	Energy value (J kg^{-1})	Constant temperature	Phase change
Latent heat of vaporisation	λ_v	2.45×10^6	20^0C	Liquid to vapour
Latent heat of melting	λ_m	3.34×10^5	0^0C	Solid to liquid
Latent heat of fusion	λ_f	-3.34×10^5	0^0C	
Latent heat of sublimation	λ_s	2.83×10^6	0^0C	Solid to vapour

Convert latent heat flux into mass flux of water

$$L = \rho_w \lambda_v E$$

$$\mathrm{Wm^{-2}(Jm^{-2}s^{-1})} = \frac{\mathrm{kg}}{\mathrm{m^3}} \frac{\mathrm{J}}{\mathrm{kg}} \frac{\mathrm{m}}{\mathrm{s}}$$

$$\text{or } E = \frac{L}{\rho_w \lambda_v}$$

- L = latent heat flux
- E = evapotranspiration rate (m s^{-1})
- ρ_w = density of water (1000 kg m^{-3})
- λ_v = latent heat of vaporization (2.5×10^6 J kg^{-1}) (or, better, with T in degree Celsius and λ_v in MJ/kg)

$$\lambda_v = 2.501 - 0.002361T$$

- Latent heat exchange per unit area converts a volume of water (per unit area) to vapor
- The energy required for this conversion is
  - the volume of water per unit area (E)
  - multiplied by the latent heat of vaporization
    - energy required to convert a kg of water to vapor
  - and by the density of water
    - which converts the mass per unit area to a volume per unit area

Example

Problem: Calculate the daily evapotranspiration from a forest in the Alps if R_n = 200Wm^{-2}, G and H are negligible, and the temperature is approximately constant.

$$et = \frac{R_n}{\rho_w \lambda_v} = \frac{200\ \mathrm{W\,m^{-2}}}{\left(1000.0\ \mathrm{kg\,m^{-3}}\right)\left(2.5\times10^{6}\ \mathrm{J\,kg^{-1}}\right)} = 8.0\times10^{-8}\ \mathrm{m\,s^{-1}} = 0.7\ \mathrm{cm\,day^{-1}}$$

Bare minimum about the gas laws

- Ideal gas law $PV=NkT$
  - P pressure, V volume, N number of molecules, k Boltzmann's constant (1.38×10^{-23} J K^{-1}), T absolute temperature (K)
- Because N is big and k is small, we often use $PV=N_m R^* T$ instead
  - N_m number of moles (1 mole has 6.022×10^{23} molecules—Avogadro's number N_a)
  - $R^*=N_a k=8.314$ J mol^{-1}K^{-1}, the *universal gas constant*
- Equation of state $P=\rho R^* T/m$
  - ρ density (kg m^{-3}), m molecular weight (kg mol^{-1})

Force, pressure, gases

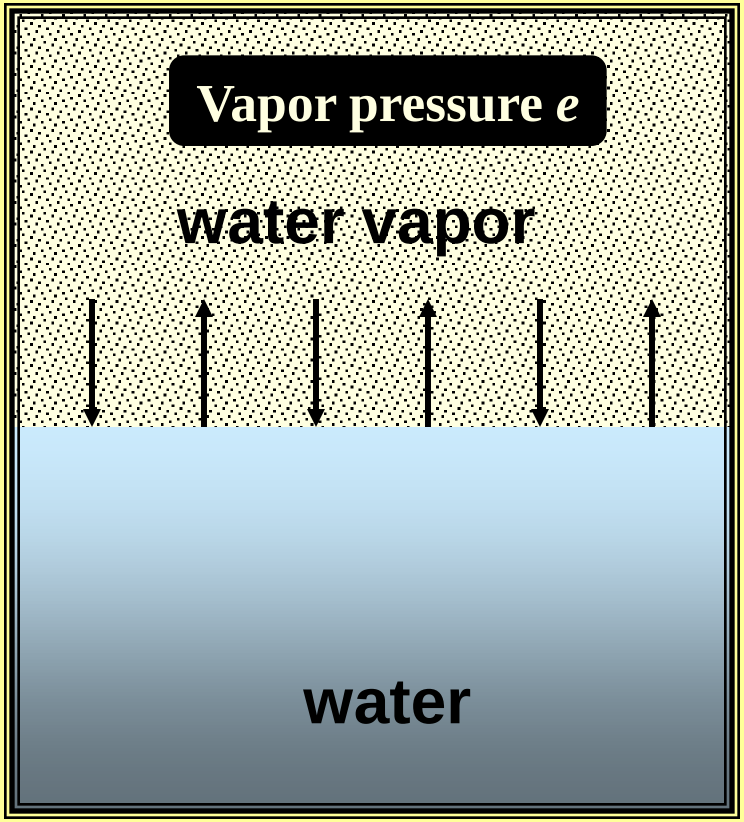
- In the International System, force is measured in *Newtons* (N)
  - Lifting an empty coffee cup requires about 1 N
- Pressure is measured in *Newtons per square meter* (Nm^{-2}), also called a *Pascal* (Pa)
  - Atmospheric pressure at sea level is about 100 kPa
  - Pressure on your feet when you stand is about 15 kPa
  - The *millibar* (mb) is also used, 1 mb = 100 Pa
- An *atmosphere* is defined as 101.325 Pa (1013.25 mb)

Gas laws, applied to the atmosphere

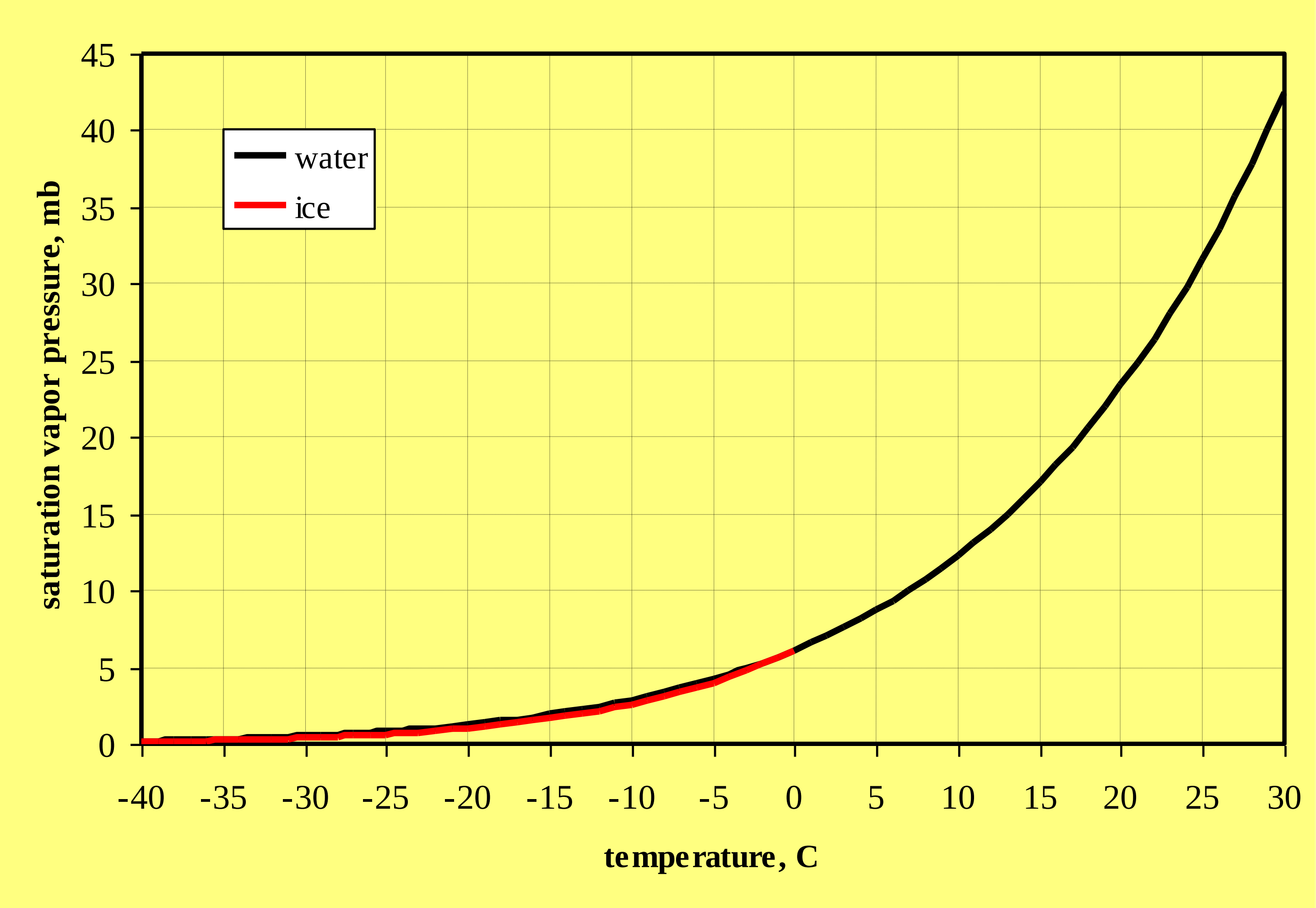
- Dalton's law $P = P_1 + P_2 + P_3 \ldots = \rho R^* T / \langle m \rangle$, where $\langle m \rangle$ is the average molecular weight
- The atmosphere is dry air ($\langle m_d \rangle = 0.02894$ kg mol^{-1}) and water vapor ($m_w = 0.018$ kg mol^{-1})
  - So $P = P_d + e$ (pressure of the dry air + vapor pressure)
  - $e = \rho_w R^* T / m_w$, where ρ_w is the water vapor density, or *absolute humidity*
  - $\langle m_a \rangle$=average molecular weight of air = 0.0287 kg mol^{-1}

Evaporation and condensation of water

- Evaporation is the difference between two rates, a *vaporization rate* determined by temperature, and a condensation rate determined by vapor pressure.
- If molecules can diffuse away from the surface, vapor pressure remains low, and the difference between these two rates is positive, so evaporation continues.
- If, on the other hand, the air above the water is thermally insulated and enclosed, the vapor pressure increases until the rates of vaporization and condensation are equal and there is no more evaporation. The air is then said to be saturated. At a given temperature this equilibrium occurs for a particular vapor pressure e_s, called *saturated vapor pressure*.



Saturation vapor pressure
(at standard atmospheric pressure)



Saturation vapor pressure

- This approximate expression give pressure in kPa as a function of temperature T in degree Celsius.

$$e_s = 0.6108 \exp\left(\frac{17.27 T_a}{T_a + 237.3} \right)$$

- It is important in building physically based models of evaporation that not only is e_s a known function of temperature, but so is Δ (kPa/ C), the gradient of this function, de_s/dT.

$$\Delta = \frac{4098 e_s}{(T_a + 237.3)^2}$$

Basic principle

- **Net radiation (*R_{net}*) drives the sum of sensible (*H*) and latent (*L*) heat exchange with the atmosphere and heat flow into or out soil (*G*)**
  - ***G* is normally small**
  - **Temperature, vapor pressure, and soil moisture determine how *R_{net}* is partitioned between *H* and *L***
    - **i.e., the magnitude of the temperature gradient vs. the vapor pressure gradient**