Forest Hydrology: Lec. 16

Lecture content

- Evapotranspiration

  Penmann equation and the potential ET;

  Empirical models for potential ET:

  Priesley-Taylor;

  Hargreaves-Samani;

  Climate, hydrological balance and ET: Budyko diagram and vegetation

  Field measurements of potential Evaporation

The Penman equation
Potential Evaporation Equation

Since potential evaporation occurs from an extensive free water surface, it follows that using Canopy Conductance approximating infinity is the appropriate value of surface resistance for estimating potential evaporation from the Penman-Monteith equation.

Free water surface evaporation is that which occurs from a thin film of water having insignificant heat storage and thus it closely represents the potential evaporation from adequately watered 'simple' natural surfaces such as wet leaves and saturated bare soil.
In this case, we obtain the Penman equation

$$ET_p = \frac{\Delta R_n + \gamma \rho_a c_p c_a \left(e_s(T_z) - e_z\right)}{\left[\Delta + \gamma(1 + c_a / c_c)\right] \rho_w \lambda_w} \approx \frac{\Delta R_n + \gamma \rho_a c_p c_a \left(e_s(T_z) - e_z\right)}{\left[\Delta + \gamma\right] \rho_w \lambda_w}$$

This value = 1
for ET potential

The Penman - Monteith equation
Reference Crop Evaporation

The reference crop evaporation is a further idealized standard evaporation rate, defined with reference to the Penman – Monteith equation and with the following parameters:

-idealized grass crop, with a fixed crop height of 0.12 m;
- albedo = 0.23;
- canopy conductance = 69 m s-1.

This is an extensive surface of short green grass cover of uniform height, actively growing, completely shading the ground, and not short of water.

The concept of reference crop evaporaporation is widely used in irrigation and plant water use assessment.

The Priestly-Taylor equation - 1

The Penman equation can be divided into two terms:

$$ET_p = \frac{\Delta R_n}{(\Delta + \gamma)\rho_w \lambda_w} + \frac{\gamma \rho_a c_p c_a (e_s(T_z) - e_z)}{(\Delta + \gamma)\rho_w \lambda_w}$$

The first term depends on net radiation,
The second term depends on mass transfer.

It is observed that the first term frequently exceeds the second by a factor of about 4, and this suggests the possibility of a simpler empirical relation between potential evaporation and radiation.

The Priestly-Taylor equation - 2

Accounting for the proportionality between first and second term, an empirical equation, called the Priestly-Taylor equation, can be written down, with the general form:

$$ET_p = \alpha \frac{\Delta R_n}{(\Delta + \gamma)\rho_w \lambda_w}$$

$$\alpha = 1{,}26$$

In fact there is now more substantial evidence supporting such empirical relationship, at least on a regional average (as opposed to crop-specific) basis, for region with uniform vegetation cover, or with land cover which is heterogeneous at the scale of a few kilometers.

The equation simplifies the estimation of the potential evaporation. On the other hand, it can only be used after regional calibration, and at time steps not shorter than daily-weekly periods (depending on local conditions).

The Hargreaves equation for potential ET - 1

The 1985 Hargreaves equation is one of the simplest and most accurate empirical equations for estimation of potential evapotranspiration:

$$ET_p = 0.0023 \cdot R_{net} (T_m + 17.8) \sqrt{TR}$$

$$ET_p = potential\ ET (mm/d)$$

$$R_{net} = extraterrestrial\ radiation\ (mm/d)$$

$$T_m = daily\ mean\ temperature (°C)$$

$$TR = temperature\ range (°C)$$

Temperature range is the difference between mean daily max and min air temperature.

The Hargreaves equation for potential ET - 2

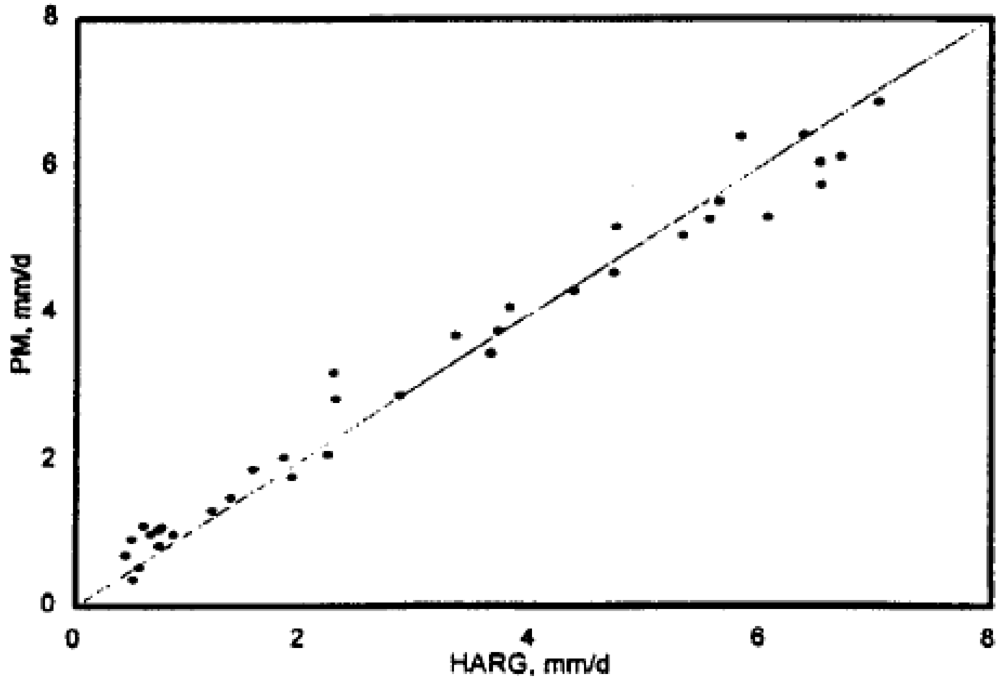
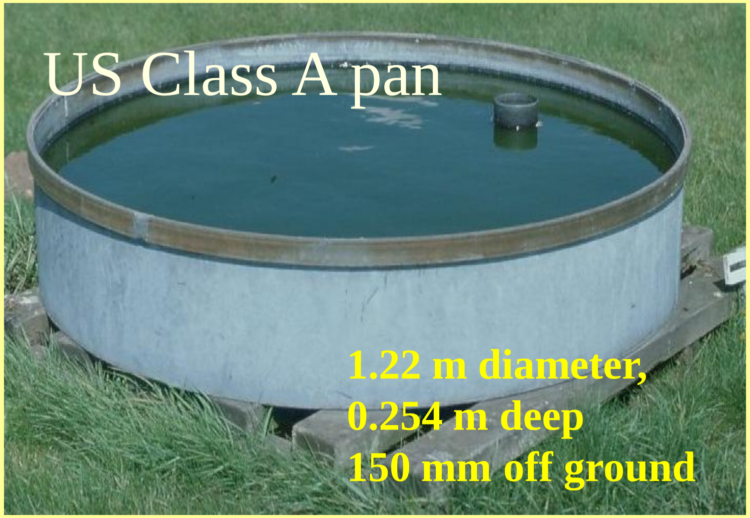


FIG. 6. Comparison of ETo from FAO-MOD and from Hargreaves et al. (1985) Adjusted for T_{bias}, Roosevelt, Utah

Comparison between Hargreaves and Penman Equations for a station in UTAH (US) (daily time step)

Evaporation measurement: evaporation pans



Evaporation = Change in water level - rain in

The pans are containers with controlled and monitored water quantities. The pans are exposed to climate and weather in the location of interest. Pan evaporation is then correlated with the expected evaporation from a natural water body.

Evaporation measurement: evaporation pans

- Pan-evaporation
  - Direct measurement method

$$E_{pan} = W - (V_2 - V_1)$$

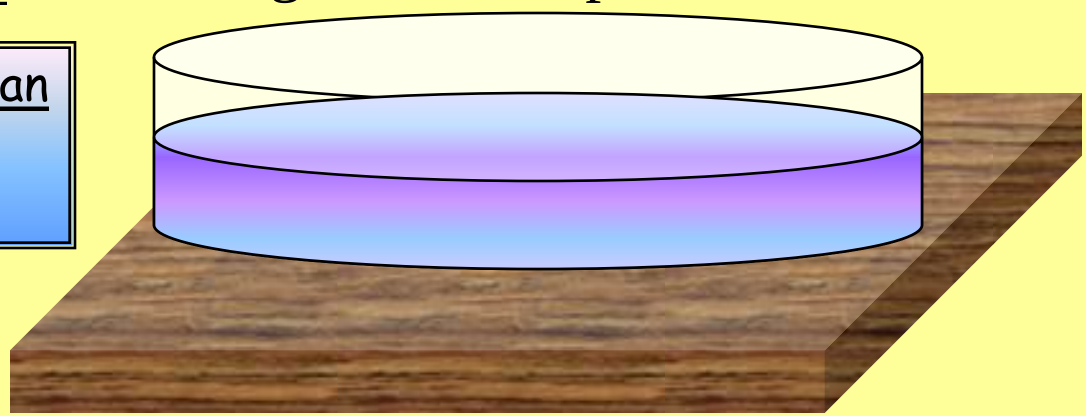
where

W = precipitation during time Δt

V_1 = storage at beginning of period Δt

V_2 = storage at end of period Δt

Class-A evaporation pan
Diameter = 1.22 m
Height = .254 m

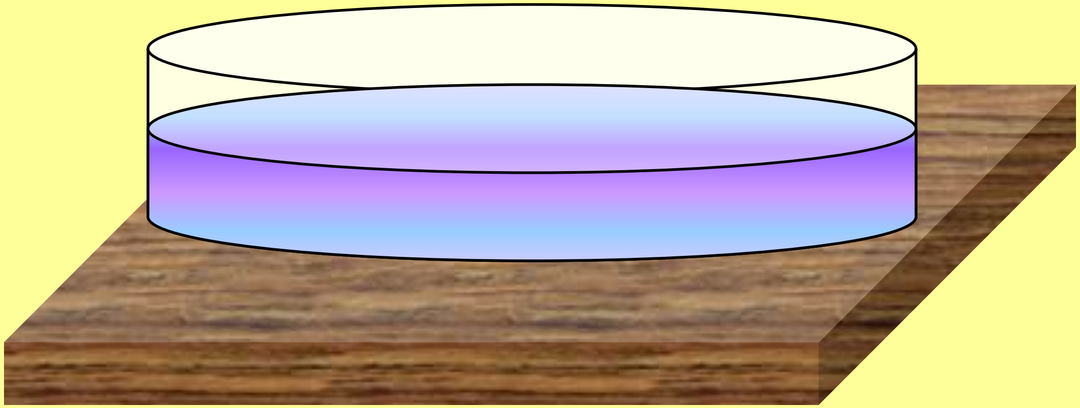


Pans

- All pans measure more evaporation than natural water bodies because of their smaller size, boundary effects induced by heat transfer through pan material, and wind effects caused by the container itself. This lead to commonly accepted pan coefficients. The coefficients, which vary with pan type and location, multiply the pan records to obtain actual evaporation estimates. For Class A pan, the coefficient is around 0.7 and is relatively stable.

0.7 average

$$\textit{Evaporation estimates} = (PC)E_{pan}$$



Pans

The WMO recommends to adopt the US Class A evaporation pan as the standard instrument, based not only on this instrument's wide use, low cost, simplicity of maintenance and measurement, but also on the results of the extensive evaporimeter comparisons carried out under the aegis of the WMO's Commission for Instruments and Methods of Observation (CIMO).

This investigation, conducted at 18 sites throughout the world between 1964 and 1973, compared measurements from three evaporimeters widely used in the two largest national networks. These were the Former Soviet Union's 20m2 tank (5m in diameter, 2m in depth buried to within 7.5 cm of its rim) and GGI 3000 tank (61.8 cm in diameter, 68.5 cm in depth buried to within 7.5 cm of its rim) and the USA Class A pan (1.21m in diameter, 25.5 cm in depth, and mounted on a wooden open frame platform set on the ground). Measurements from these evaporimeters (which were not protected from animal or bird depredations by the use of screens or nets) were compared on a mean monthly basis with open water evaporation estimated from meteorological measurements at the same sites using Penman's combination equation (WMO, 1976).

CIMO international evaporimeter comparisons (WMO, 1976)

	Mean annual evaporation (mm per day)			
	Estimated open water (E_o)	$20\,\mathrm{m}^2$ tank (X)	GGI 3000 tank (GGI)	Class A pan (A)
Average (all sites)	3.9	3.8	4.8	5.7
Maximum (Poona, India)	5.4	5.5	7.1	7.9
Minimum (Tisice, Czechoslovakia)	1.9	2.2	2.5	3.1

Linear regressions pooled data from all sites (mm per day): $E_o = 0.840X + 0.54$, $r = 0.91$; $E_o = 0.563\mathrm{GGI} + 1.16$, $r = 0.85$; $E_o = 0.517A + 0.95$, $r = 0.89$; $X = 0.685\mathrm{GGI} + 0.59$, $r = 0.97$; $X = 0.613A + 0.44$, $r = 0.98$.

Energy balance and water balance controls on evapotranspiration

Evapotranspiration appears in both energy balance and water balance;

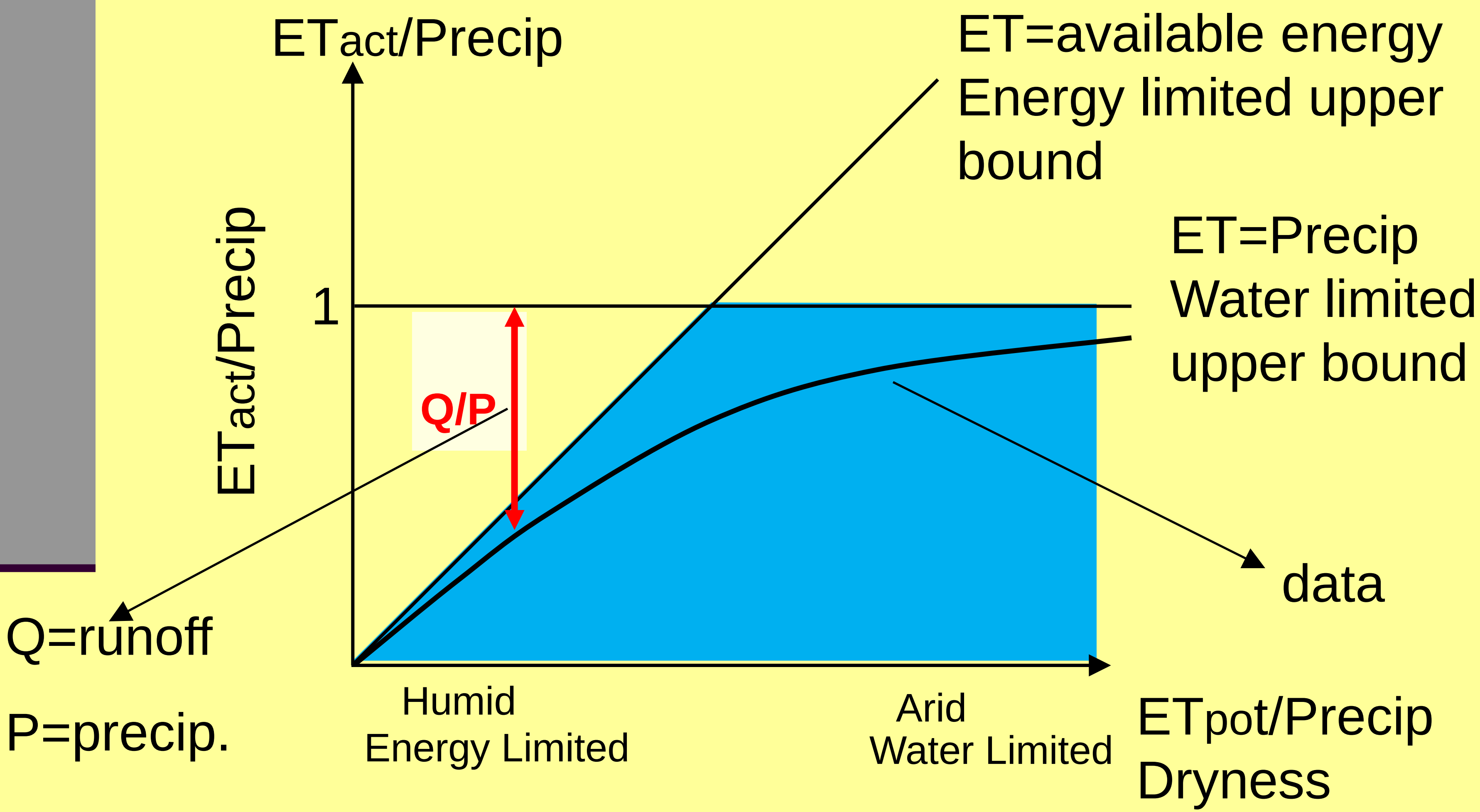
Question:
Can we address how the energy and water budgets together control evaporation rates?

In terms of water budget:
Actual evapotranspiration is limited by precipitation

In terms of energy balance:
Actual evapotranspiration is limited by potential evapotranspiration

Energy balance and water balance controls on evapotranspiration – Budyko 1

Evapotranspiration appears in both energy and water balance



Following Budyko, M. I., (1974), Climate and Life, Academic, San Diego, 508 p.

Energy balance and water balance controls on evapotranspiration – Budyko 2

The character of annual water balance can be represented on the so-called Budyko diagram which presents the ratio *ETa/P as a function of ETp/P.*
ETa/P is a measure of annual water balance
it measures the way rainfall is partitioned into evaporation and runoff.

On the other hand,
the ratio *ETp/P is a measure of the climate, and is called the dryness index (or index of* dryness).
Large *ETp/P (>1) represents dry or arid climate,*
while small ETp/P (<1) represents a wet or humid climate. Thus the Budyko diagram encapsulates a major climatic control on annual water balance.

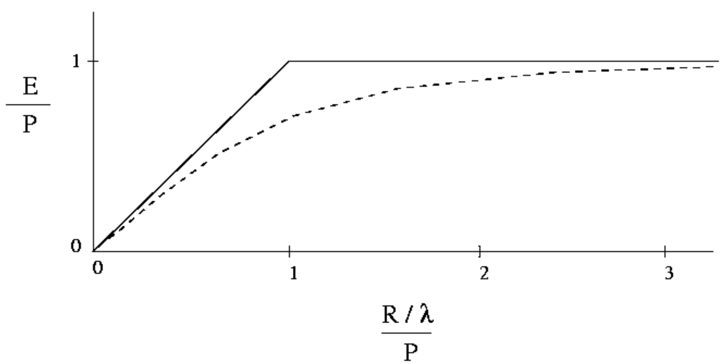
Energy balance and water balance controls on evapotranspiration – Budyko 2

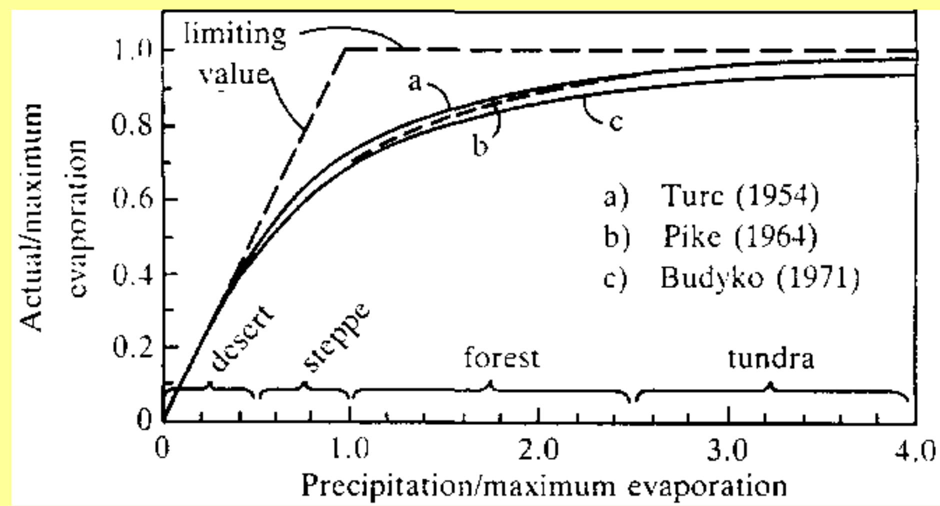
The original ideas of Budyko

Let P = annual precipitation (mm/day)
R/λ = annual net radiation (scaled to units of mm/day)
E = annual evaporation (mm/day)

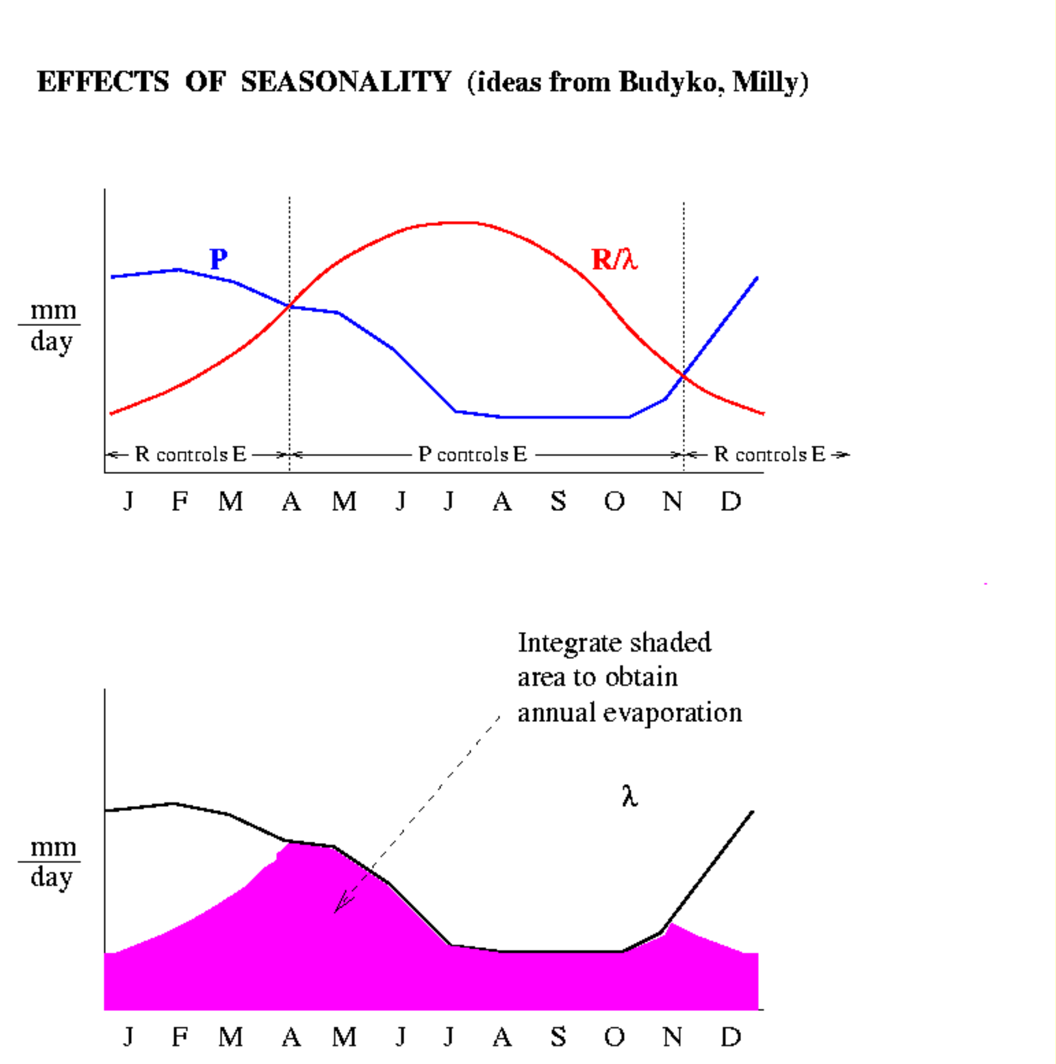
Budyko (1974) first assumed that:

1. E can be no greater than P and R/λ (in the absence of year-to-year storage changes).
2. For $\frac{R}{\lambda} \gg P$, $E \longrightarrow P$
3. For $\frac{R}{\lambda} \ll P$, $E \longrightarrow \frac{R}{\lambda}$





Energy balance and water balance controls on evapotranspiration – Budyko 2



Seasonality, however, is important, together with the effect of soil moisture storage