Energy and water balances

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Energy, H_2O, CO_2 in irrigated crops

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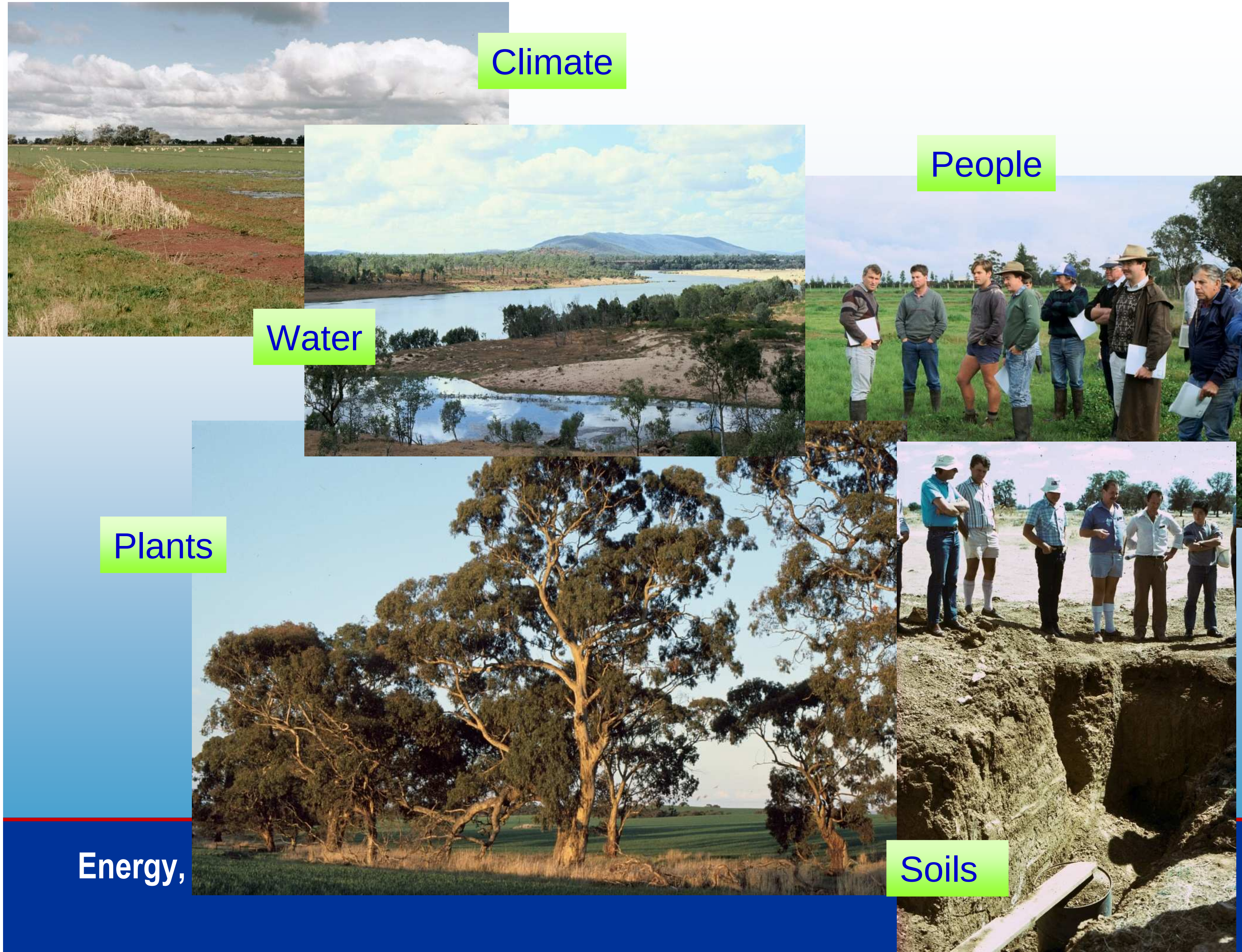

Energy,

Climate, soils, water and plants

- Aim of my research:
  - Quantify and represent key driving processes to enable prediction
- Outline of this presentation:
  - Energy, water, nutrient and carbon balances
  - Weather data
  - Radiant energy – the driver
  - Water balance
  - Evapotranspiration - measure and estimate

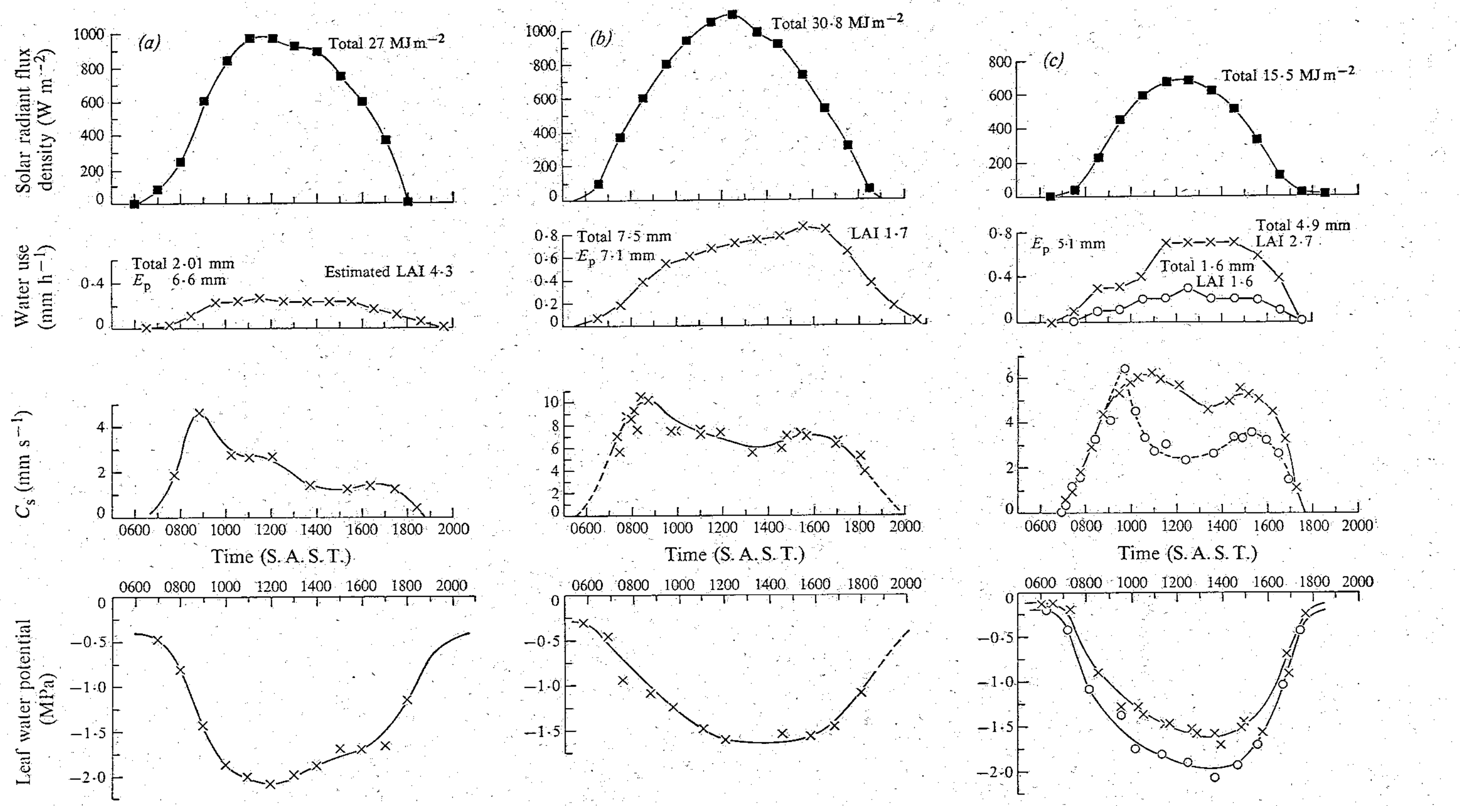

Fig. 1. Results of intensive measurements on (*a*) well watered Valencia orange trees at Addo, 15 Mar. 1978; (*b*) well watered soybeans at Roodeplaat, 16 Jan. 1980; and (*c*) wheat that was well watered (×) or in a drying soil profile (○) at Roodeplaat, 31 July 1978.

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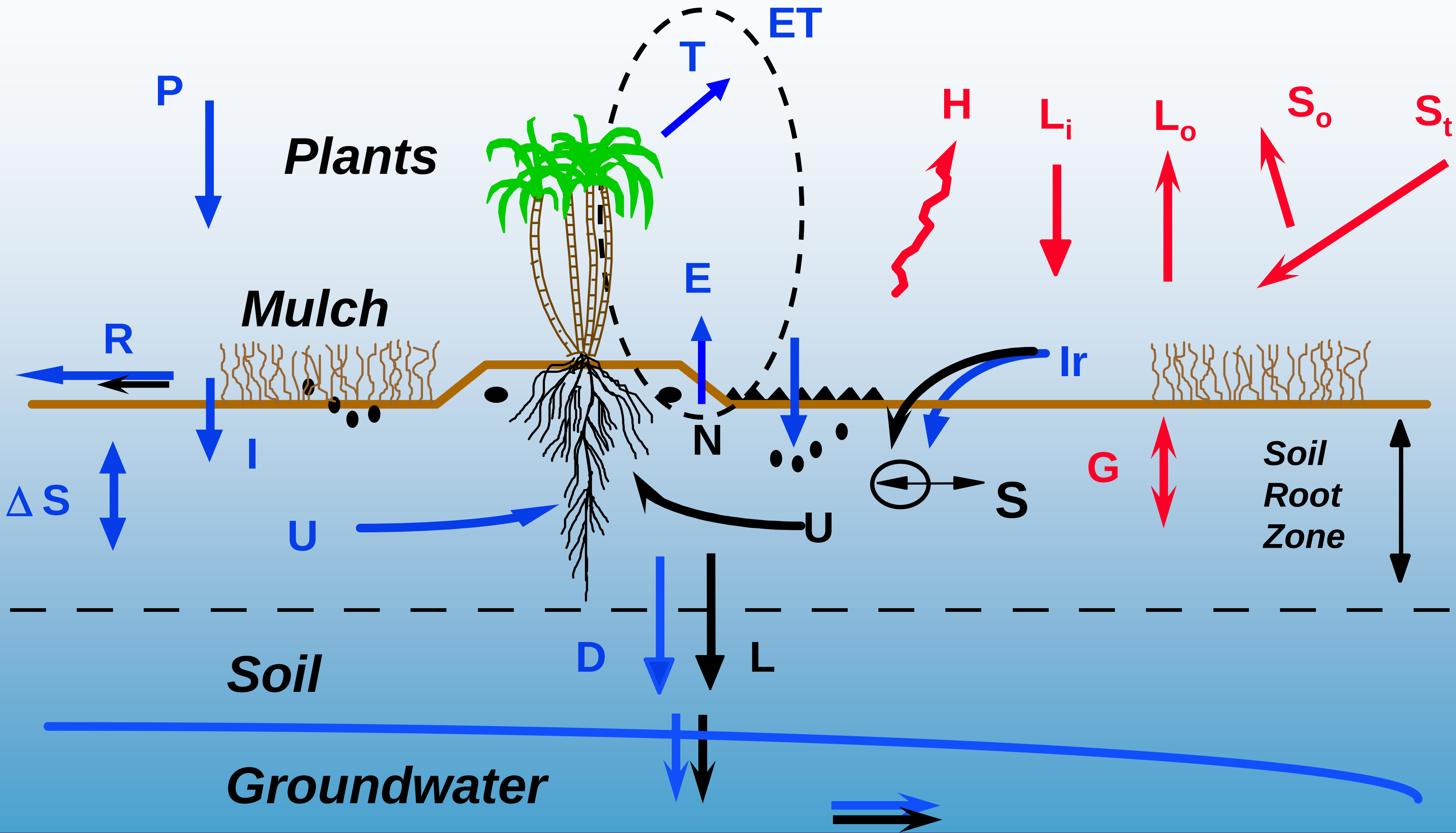
Water, solute and energy balance

(ET is just one part of the system)



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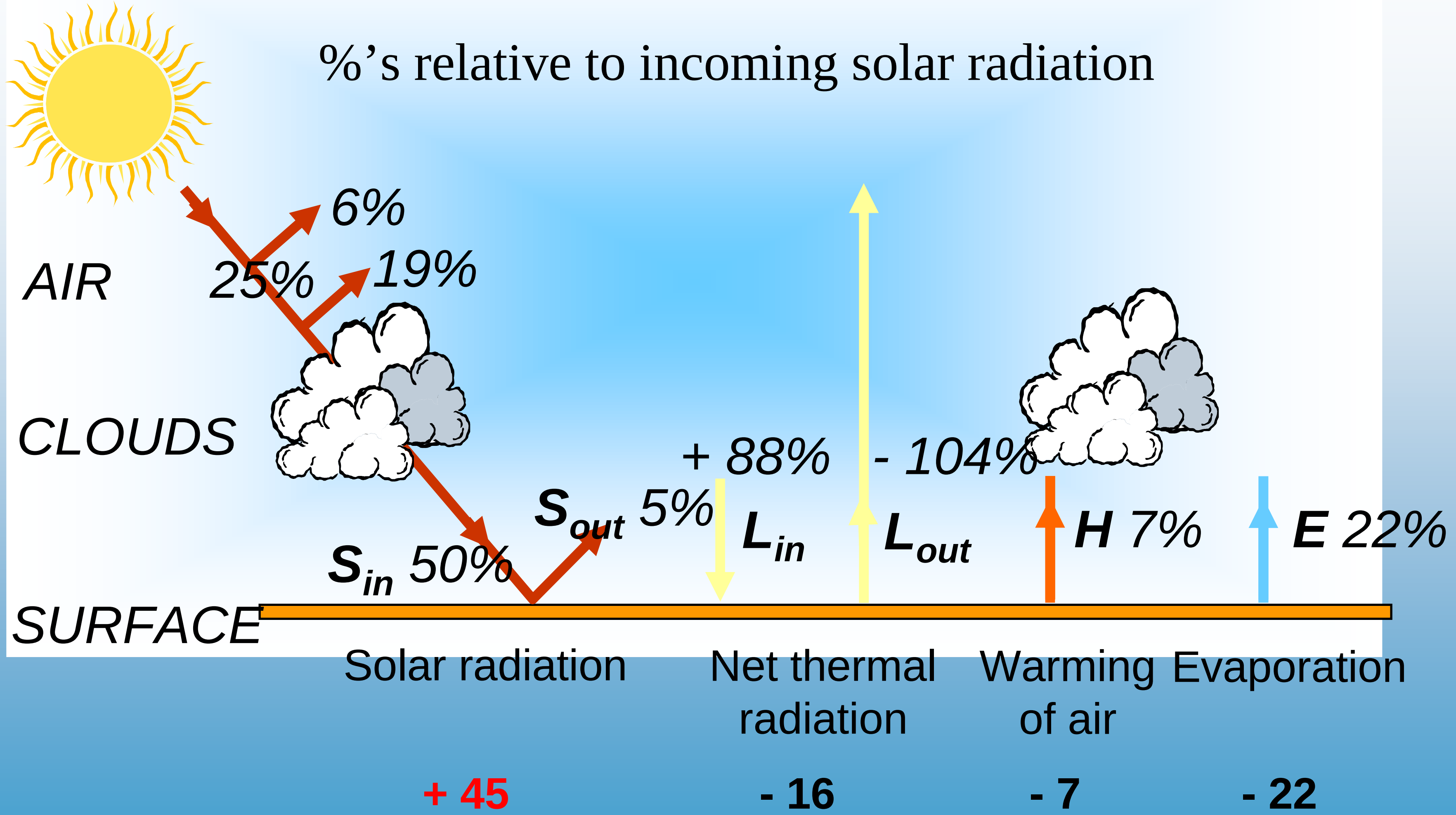
Climate

- Collection and access to quality weather data is fundamental to any natural resource assessment

Date	Td_{max}	Td_{min}	Dew point	Wind	Rain	Solar irradiance	Et_o
	deg C	deg C	deg C	km/day	mm	MJ/m^2	mm
1-Jan-92	31.7	12.3	18.0	224	0.0	28.8	7.0
2-Jan-92	33.5	19.0	15.4	195	0.0	28.3	9.4
3-Jan-92	34.3	18.2	16.5	183	0.0	29.2	9.3
4-Jan-92	33.7	18.8	12.5	127	0.0	27.5	9.4
5-Jan-92	31.3	12.1	8.6	351	0.0	29.0	10.7

The surface energy balance



The surface energy balance

- Net radiation at surface, R_n

  $R_n = L_{in} – L_{out} + S_{in} – S_{out}$

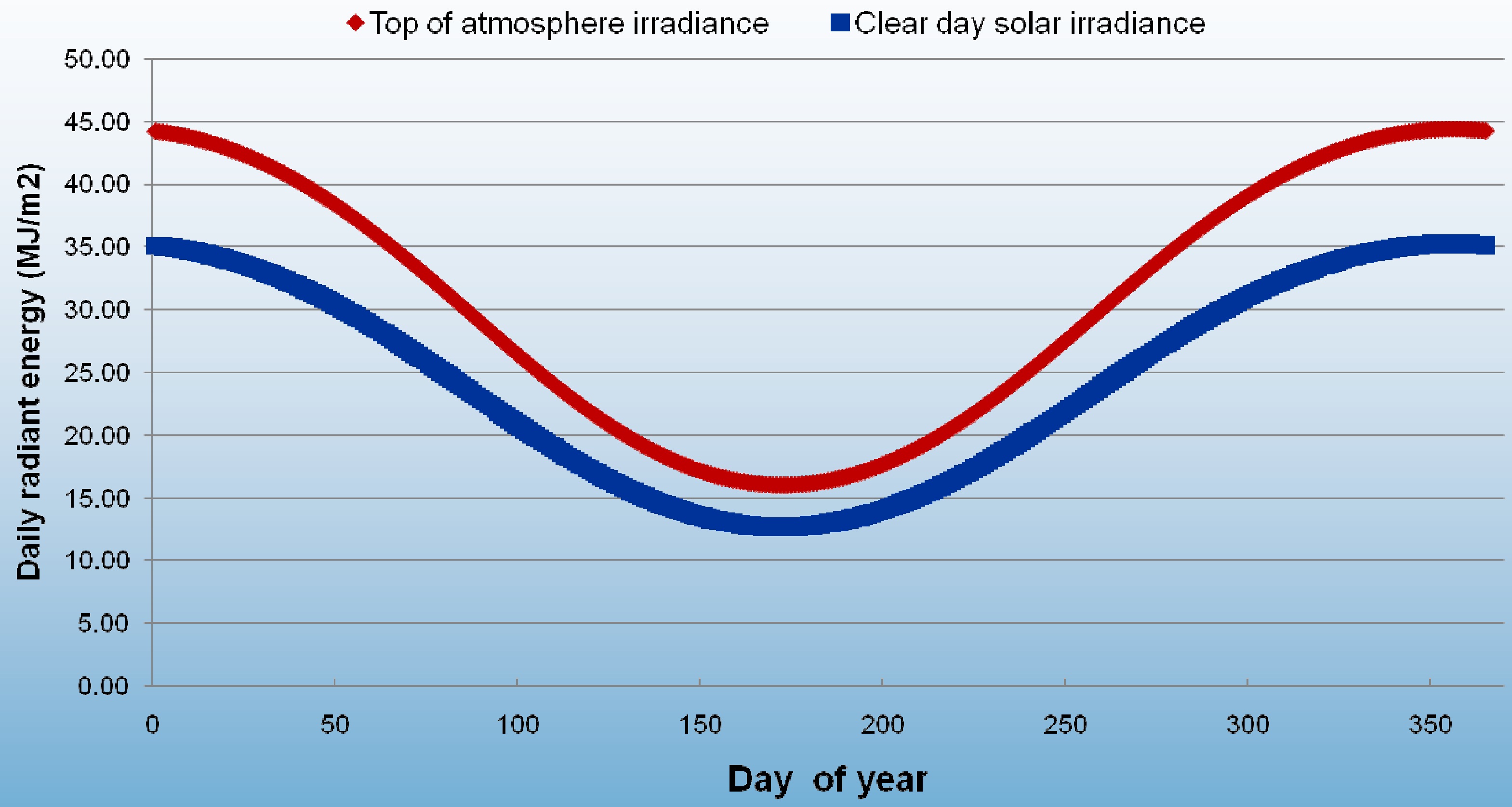
  or

  $\mathbf{R_n = L_{in} – L_{out} + S_{in}(1 – \alpha)}$

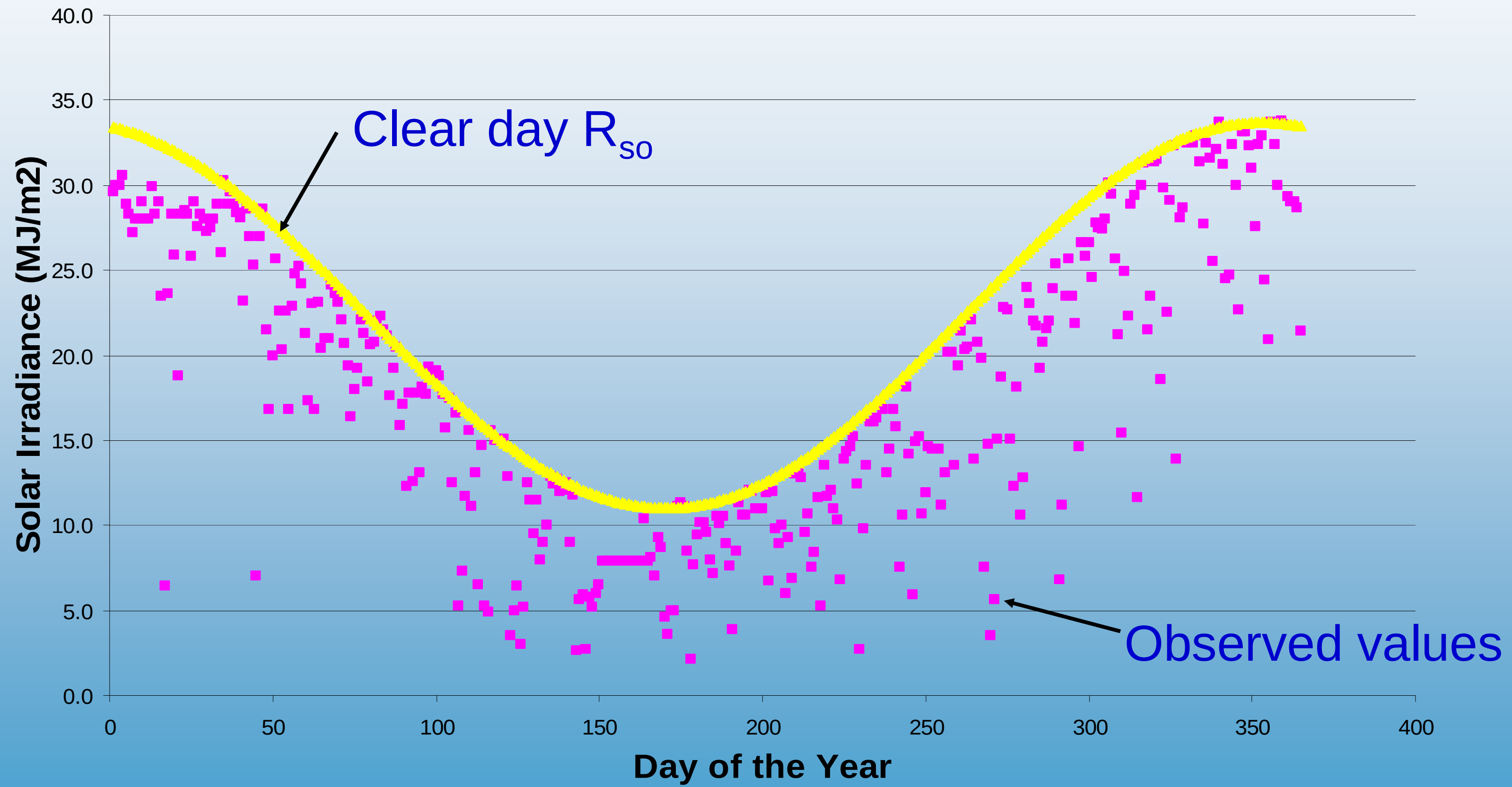
  where α is the surface albedo
- Available energy, A

  $\mathbf{A = R_n – G = H + \lambda E}$

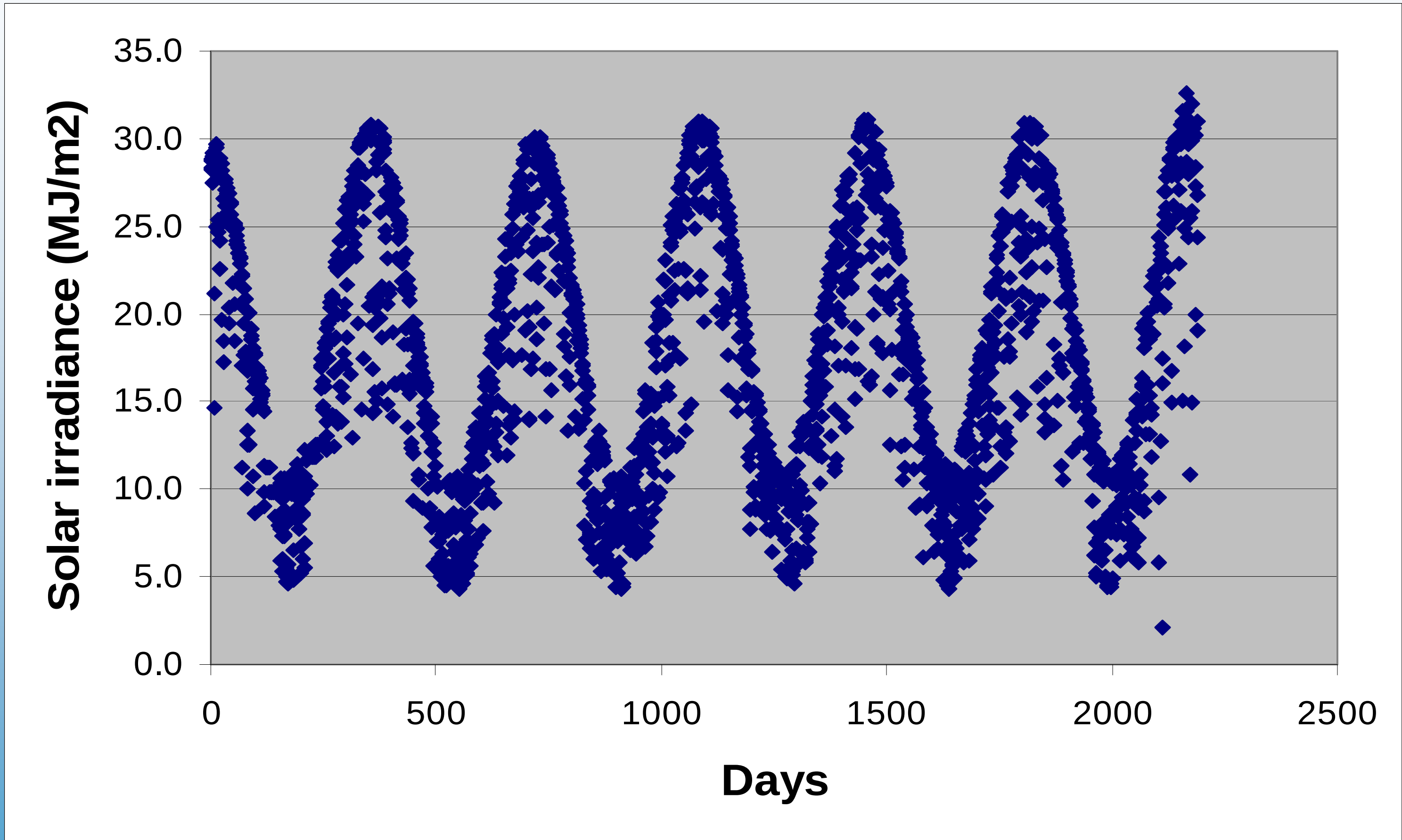
Incoming energy – latitude -34º 17’



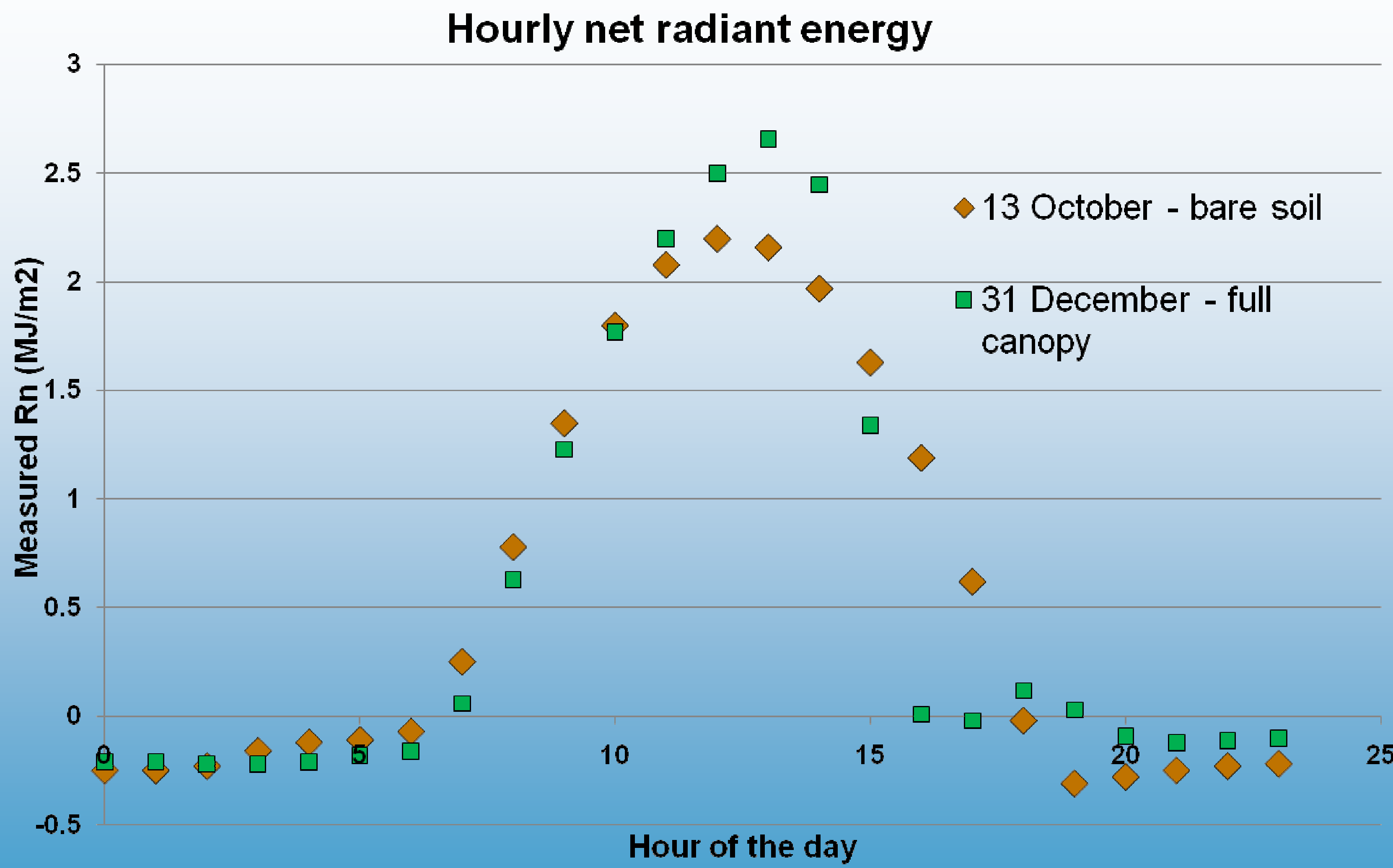
Climate - solar irradiance (Griffith 1979)



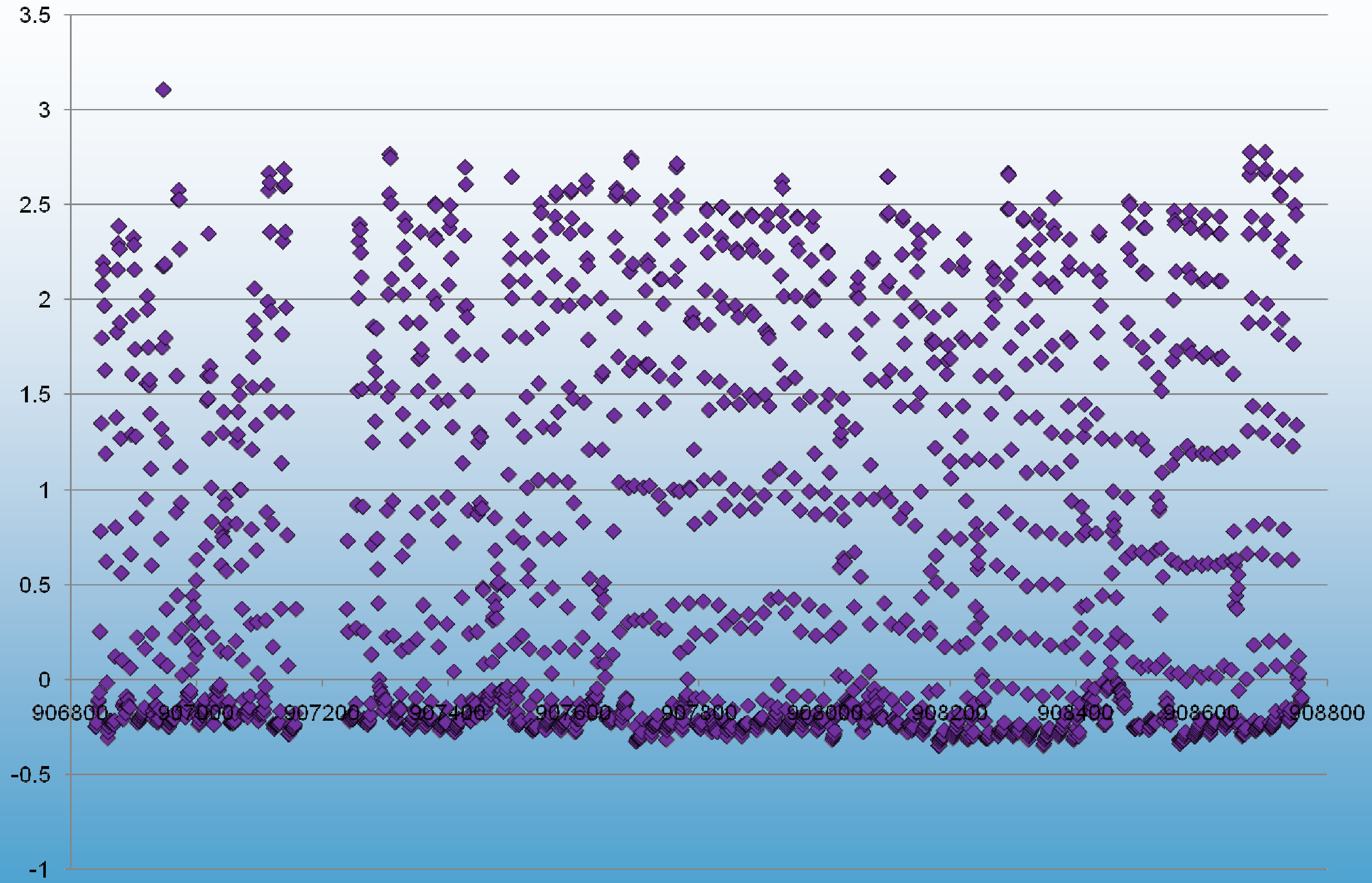
Climate - daily solar irradiance



Measured Rn over soil and crop



Hourly net radiant energy



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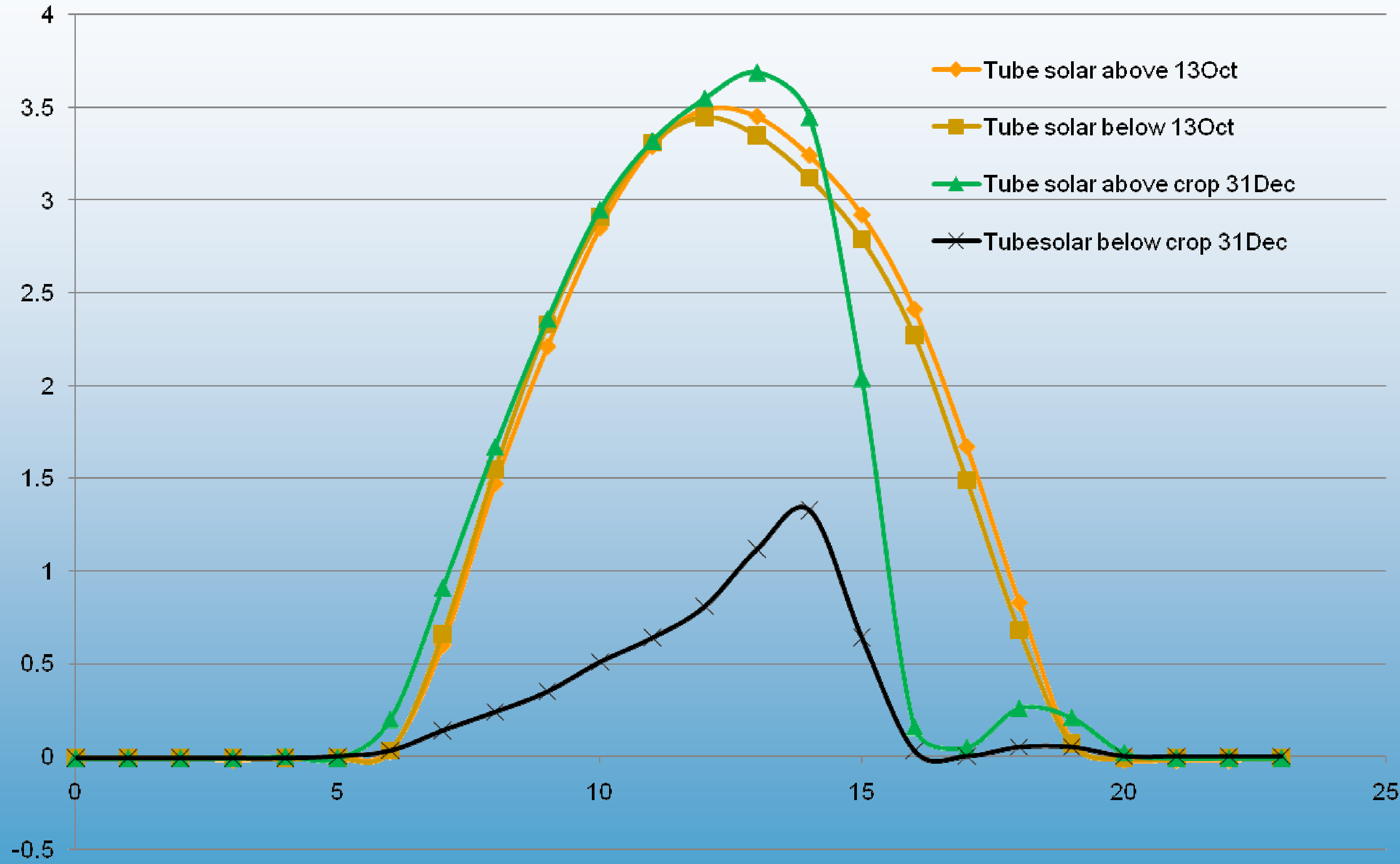
Tube solarimeters to track canopy cover



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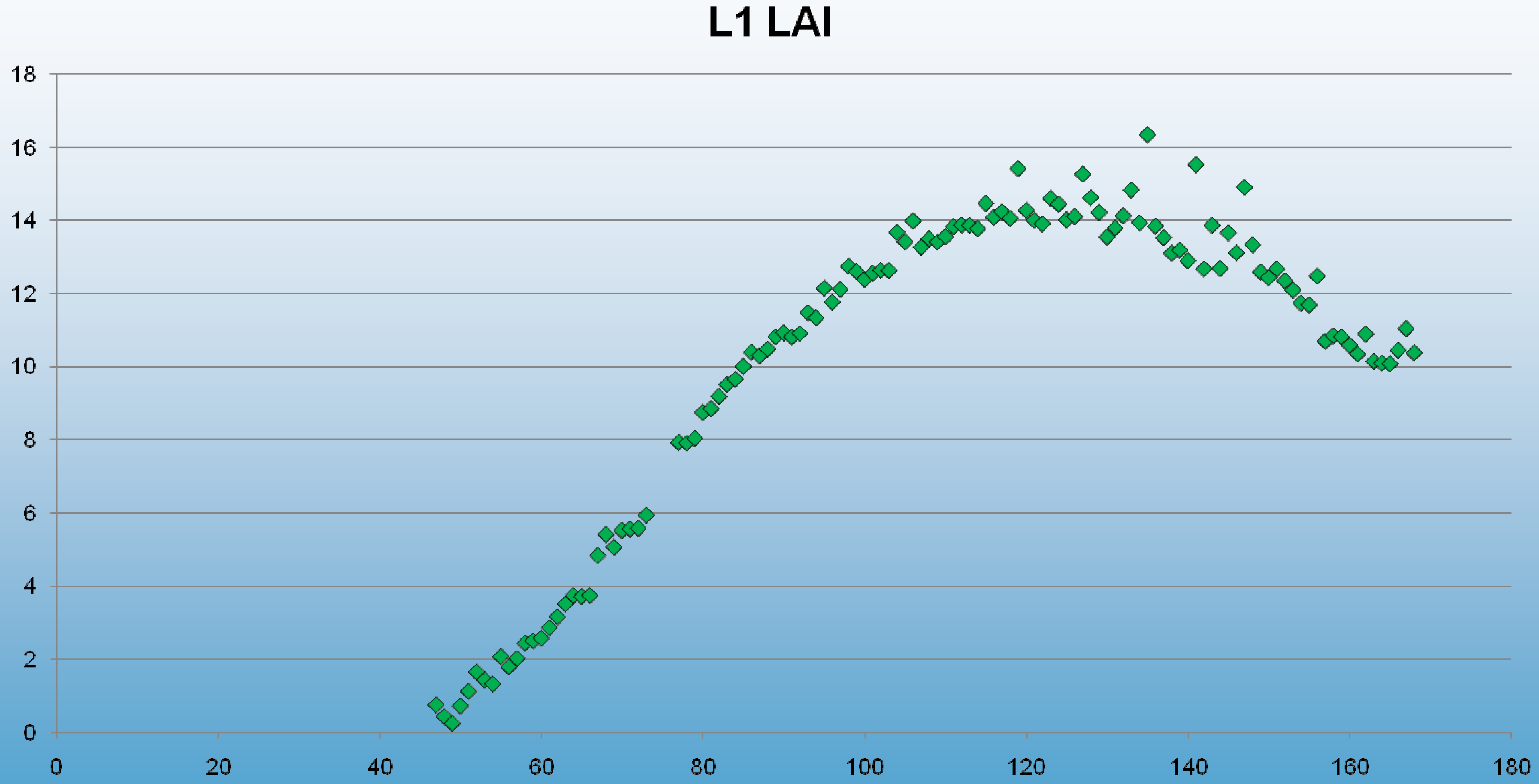
Leaf area index of irrigated wheat - derived from f (Rs_{above}/Rs_{below})



Climate

- Incoming energy is the driver of all of our earth surface processes – weather, photosynthesis, erosion
- Quality minimum data sets including Rs are fundamental to the science of natural resources
- The paucity of on-ground measures of Rs is, and will continue to be regretted
- Climate variability and the rate of climate change will increasingly shape our natural resource base

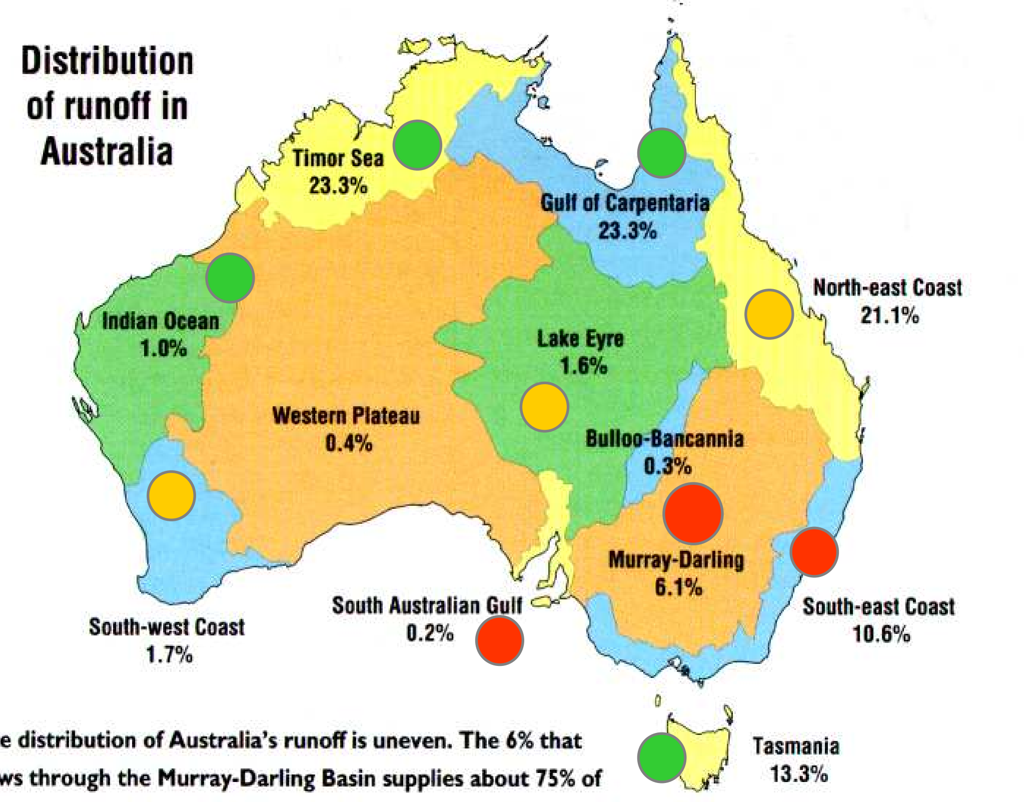
The atmosphere is changing!

Over 10 years of measuring CO_2 exchange in plant canopies ambient CO_2 increased from 315 ppm to 330 ppm.

Water

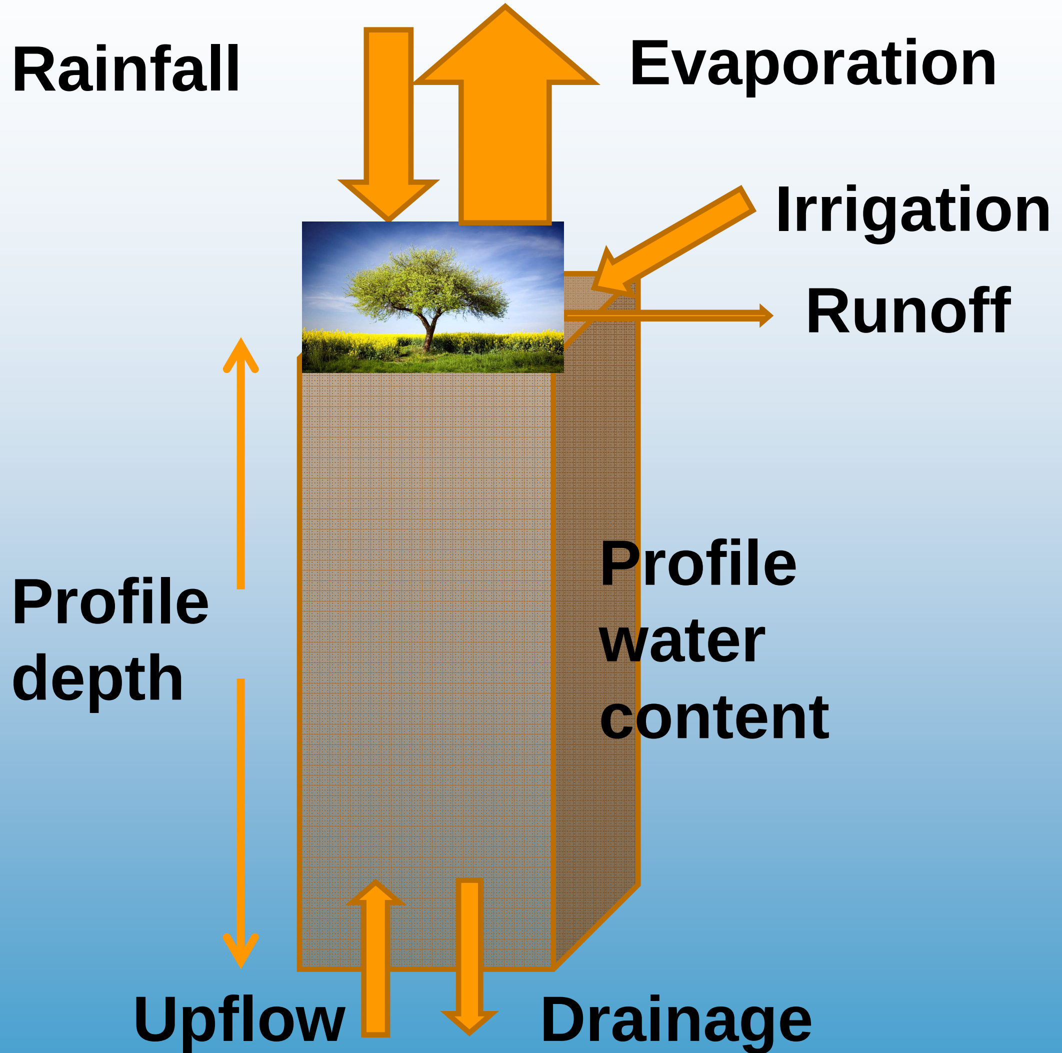
Water resource commitment

- <20%
- 20-80%
- >80%



The distribution of Australia's runoff is uneven. The 6% that flows through the Murray-Darling Basin supplies about 75% of the nation's irrigated agriculture. (Source of data: *Review of Australia's Water Resources and Water Use Vol. 1*, AGPS 1985.)

$$R_a + I + U \pm \Delta S - D - R_o - E_t = 0$$



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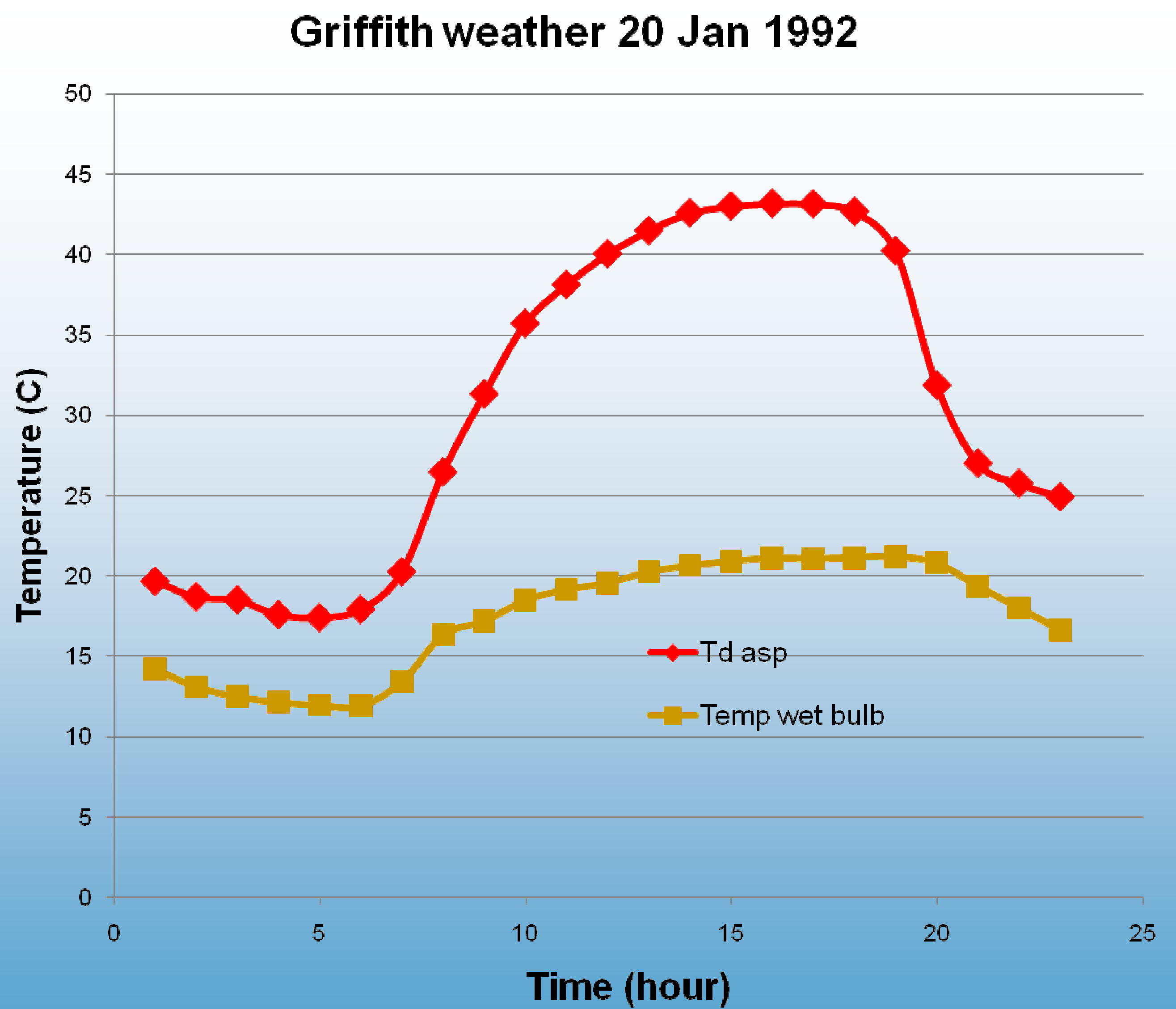
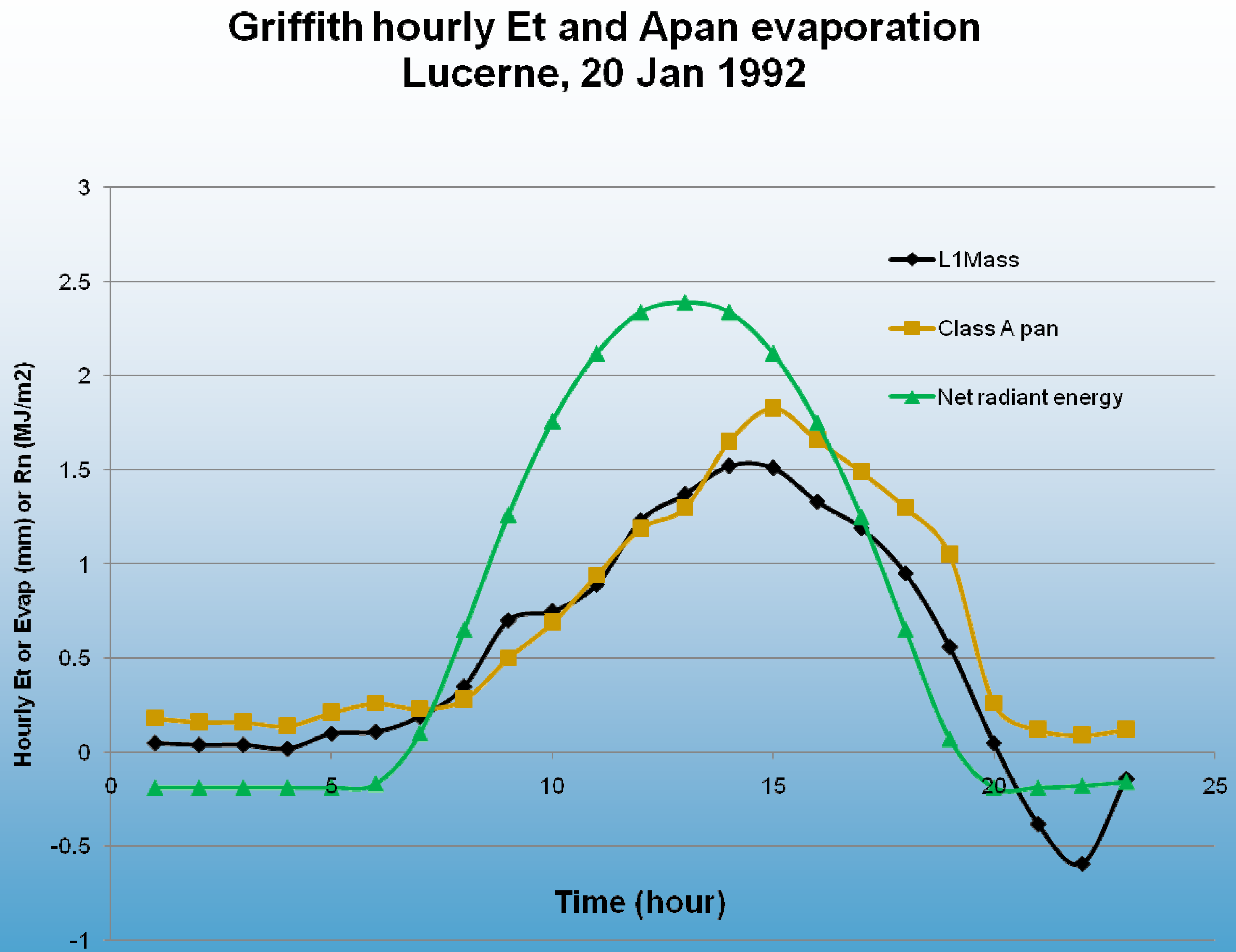
$$R_a + I + U \pm \Delta S - D - R_o - E_t = 0$$

	Initial soil water (mm)	Final soil water(mm)	Rainfall (mm)	Potential Evaporation (mm)	Vegetation coefficient	Actual evaporation	Upflow	Drainage	Runoff	Irrigation	Imbalance
Annual	800	800	570	1400	0.8	1120	25	50	15	100	-490
Daily - winter	800	800	0	3	1	3	0	0.2	0	0	-3.2
Daily - summer	700	700	0	10	0.8	8	1.5	0	0	0	-6.5

Weather station & Class A pans

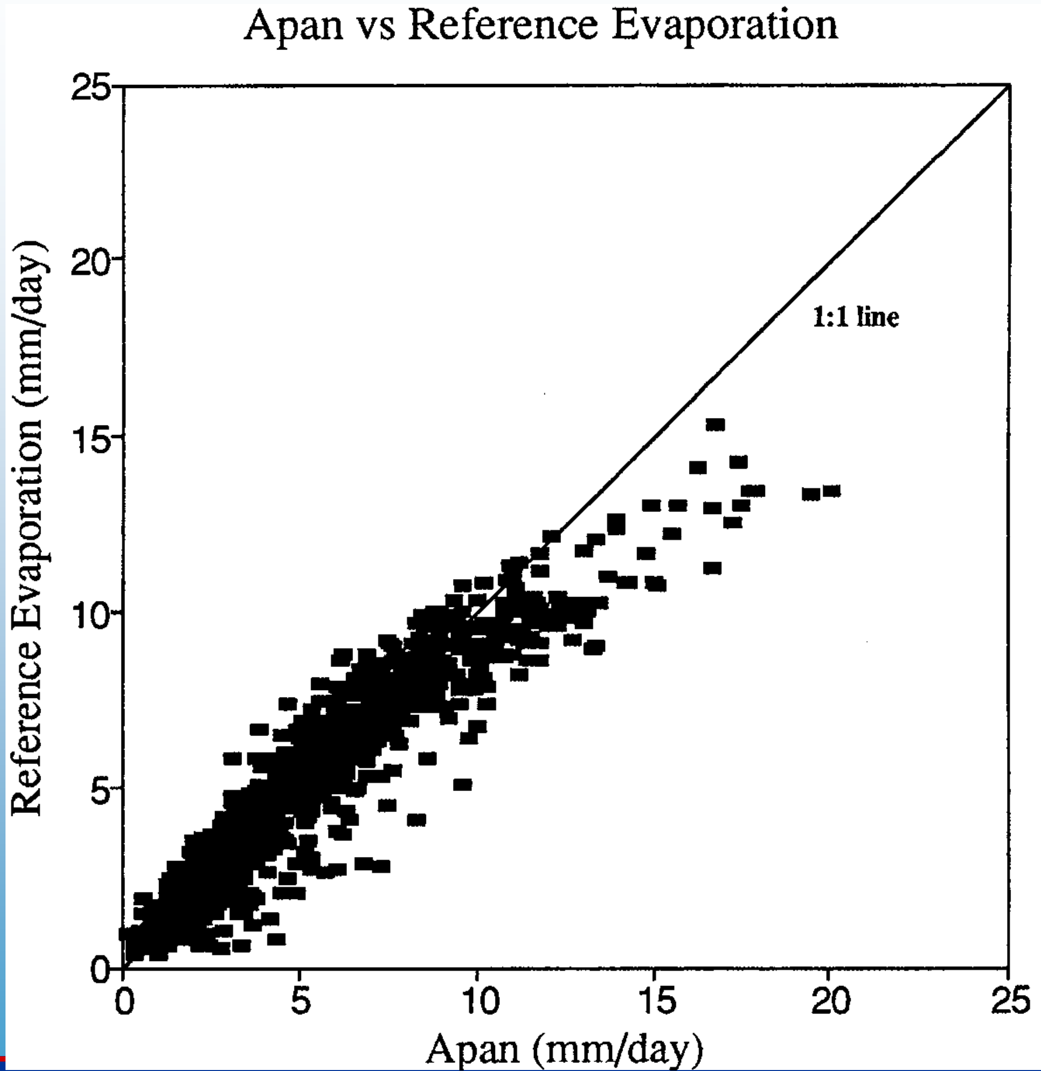


Rs = 30.9 MJ/m2, Rn = 16.9 MJ/m2, Tmax = 42.2 C, Tmin =17.1C



Rs = 30.9 MJ/m2, Rn = 16.9 MJ/m2, Et = 13.02 mm, Apan = 15.81 mm
At 20 C, 1 mm / day = 2.45 MJ / m2 .day, Rn only accounts for 6.9 mm ??

Apan values reflect estimated Et



Penman (1948) combination equation

$$E_o = \left[\left(\frac{\Delta}{\Delta + \gamma} \right) (R_n - G) + \left(\frac{\gamma}{\Delta + \gamma} \right) f(U)(e_o - e_d) \right] / L$$

<u>Definition and units</u>:

E_o (mm) evaporation in depth of water units

Δ ("delta" – kPa/^{o}C) slope of saturation vapour pressure – temperature curve at nominated temperature (ambient mean)

γ ("gamma" – kPa/^{o}C) psychrometric constant – 0.067

R_n (MJ/m^2.day) net radiant energy

G (MJ/m^2.day) ground heat flux

f(U) (MJ/ m^2.kPa.day) wind function with wind run U (km/day)

e_o (kPa) mean daily saturated vapour pressure at mean dry bulb temp

e_d (kPa) mean daily actual vapour pressure at dew point temperature

L (MJ/kg) latent heat of vaporisation of water

Water - estimation of plant evaporation

Penman (1948)

$$E_o = \left[\left(\frac{\Delta}{\Delta + \gamma} \right) (R_n - G) + \left(\frac{\gamma}{\Delta + \gamma} \right) f(U)\,(e_o - e_d) \right] / L$$

Griffith (Meyer) calibration f(U) = 6.24 + 0.038U

- Despite limitations, this is still valid
- Priestly Taylor (with Meyer temperature adjustment)
- FAO 56 Penman Monteith
- Shuttleworth(2006) may have new estimation

Estimating evapotranspiration (Et)

- Sensitivity of components of the Penman equation
  - Radiant energy (R_n) – [0.69]
  - Wind (U) – [0.55]
  - Vapour pressure gradient (VPD, e_o- e_a) – [0.48]
  - Temperature (T_m) – [0.41]

[Meyer, 1988]

Inference:

All components are important and impact of errors in values will be in the order

Rn > U > VPD > Tm

FAO "Standardised" Penman - Monteith equation

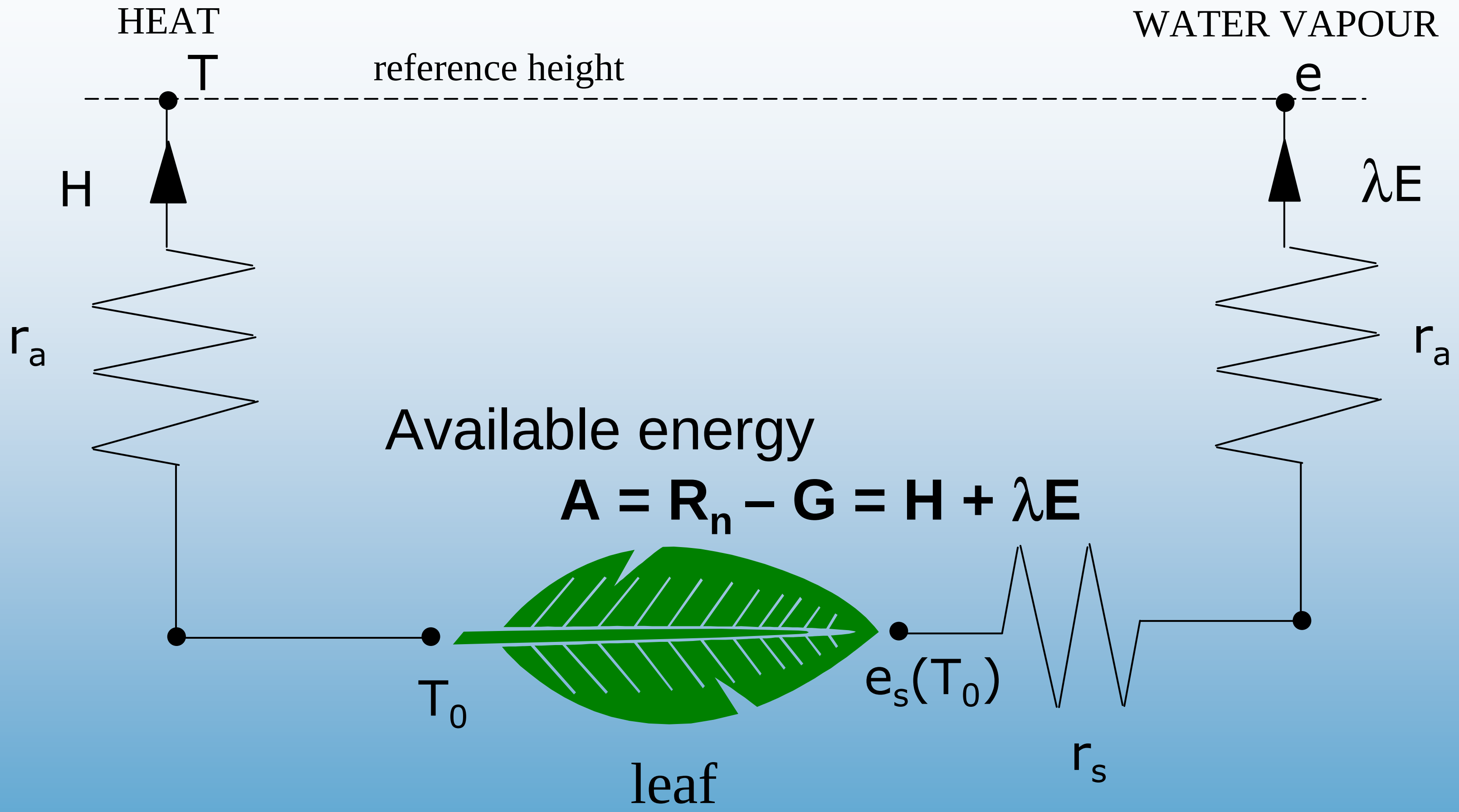
$$ET_o = \frac{0.408\,\Delta(R_n - G) + \gamma \frac{900}{T+273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34\,u_2)}$$

ET_o	reference evapotranspiration [mm day^{-1}],
R_n	net radiation at the crop surface [MJ m^{-2} day^{-1}],
G	soil heat flux density [MJ m^{-2} day^{-1}],
T	mean daily air temperature at 2 m height [°C],
u_2	wind speed at 2 m height [m s^{-1}],
e_s	saturation vapour pressure [kPa],
e_a	actual vapour pressure [kPa],
e_s-e_a	saturation vapour pressure deficit [kPa],
Δ	slope vapour pressure curve [kPa °C^{-1}],
γ	psychrometric constant [kPa °C^{-1}].

Reference surface defined:

"A hypothetical reference crop with an assumed crop height of 0.12m, a fixed surface resistance of 70s/m and an albedo of 0.23."

The Penman-Monteith equation; or the 'big leaf' model

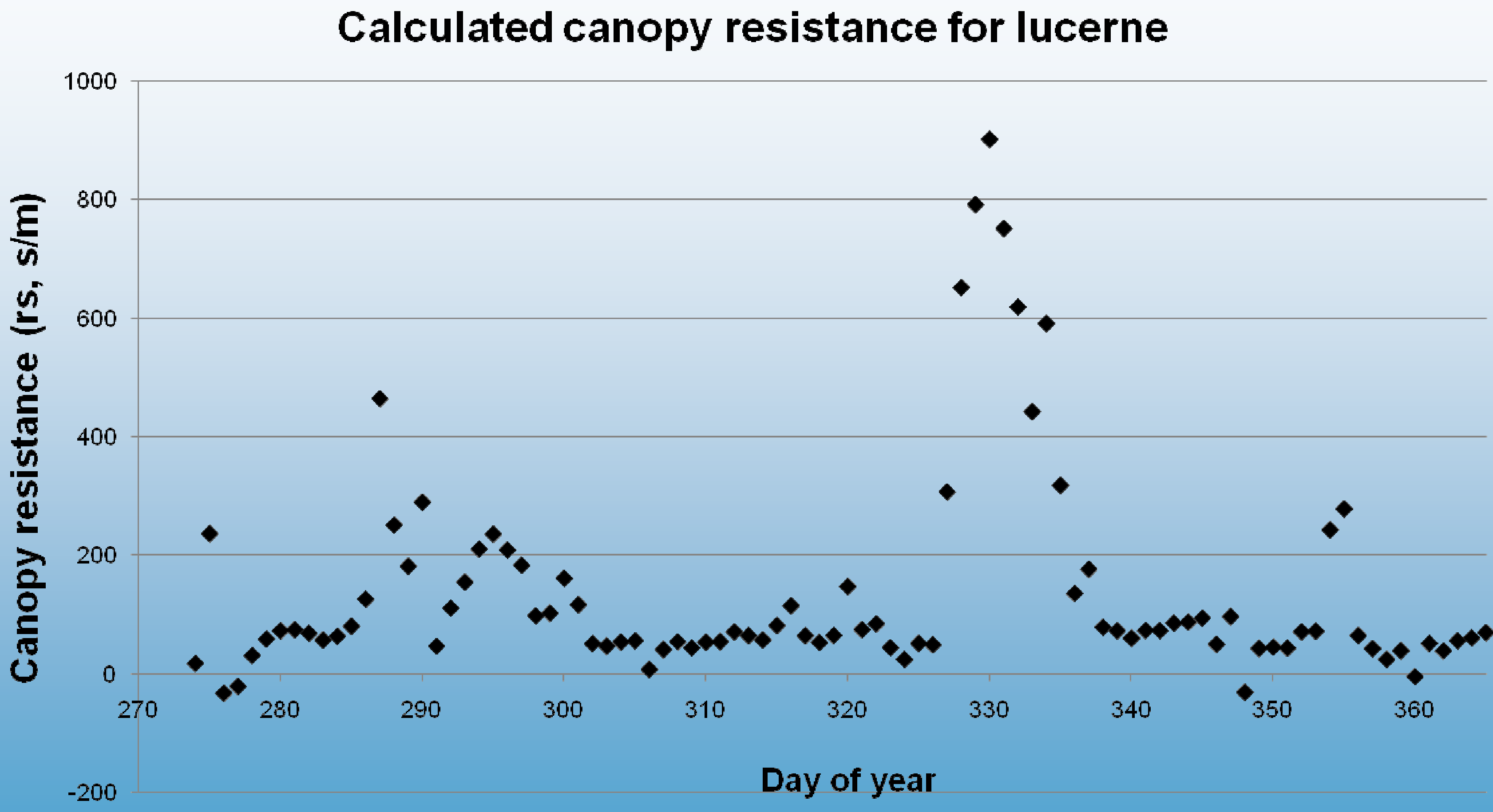


The network of diffusion resistances representing evaporation from an established crop canopy which intercepts all of the sun's radiant energy.

The Penman-Monteith equation

$$\lambda E = \frac{\Delta A + \rho c_p \{e_s(T) - e\} / r_a}{\Delta + \gamma(1 + r_s / r_a)}$$

It’s never straight forward!!



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Water

- Still unable to directly and routinely measure soil drainage
- Quantifying (separating) incoming water at the ground surface into runoff, ponded and infiltrated water still very poorly process based (c.f. SCS curve nos.)
- Groundwater – out of sight, very difficult to quantify

Soils

Energy, H_2O, CO_2 in i

Soils

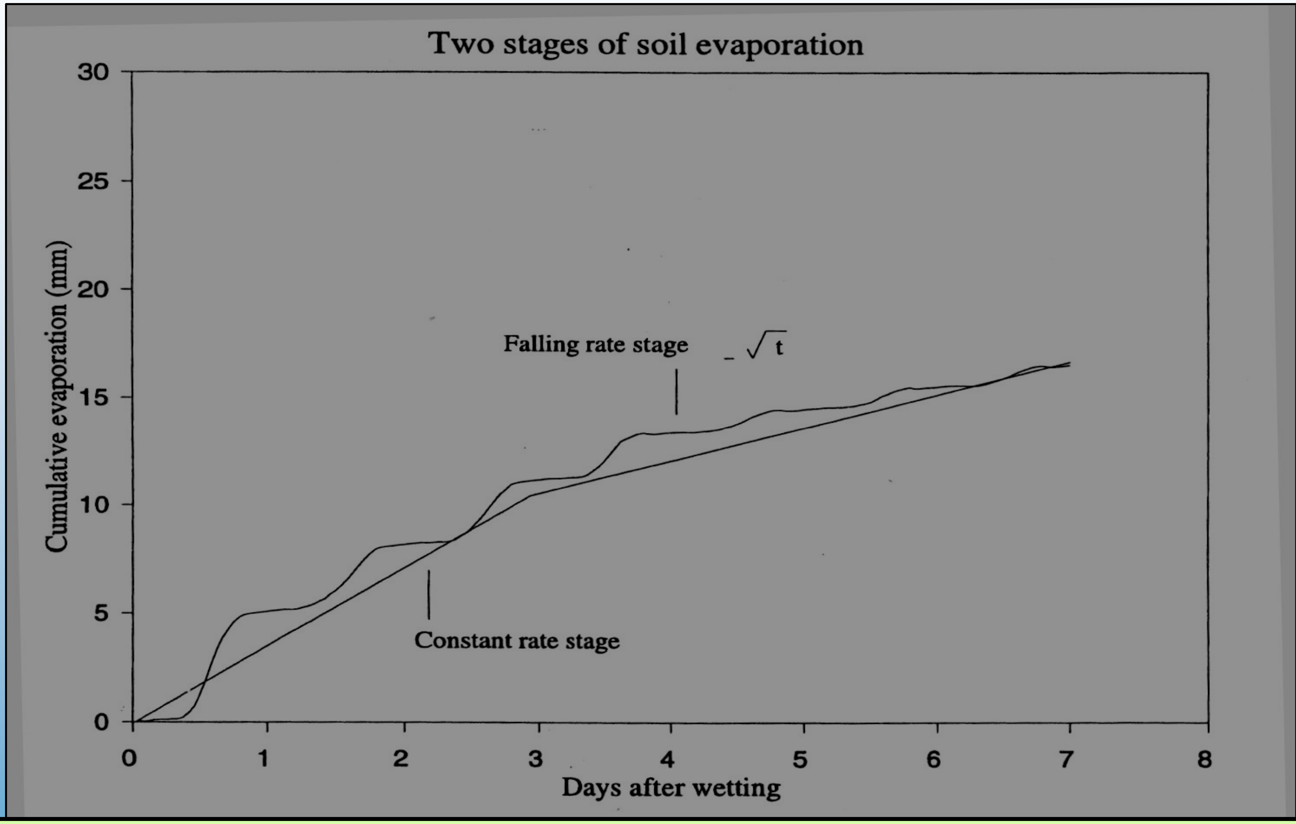
- The infinite variability of soils – homogeneity exists only in theory
- Applied soil physics has been hampered by a lack of characterisation and mathematical description of preferential flow (e.g. wetting fronts as straight lines)
- Many simple guidelines can help e.g.
  - Relation between bulk density, pore space and saturated water content is well described
  - As a first approximation, PAW for most agronomically useable soils is 0.13

Soils

- Characterisation of soil properties for water and plants

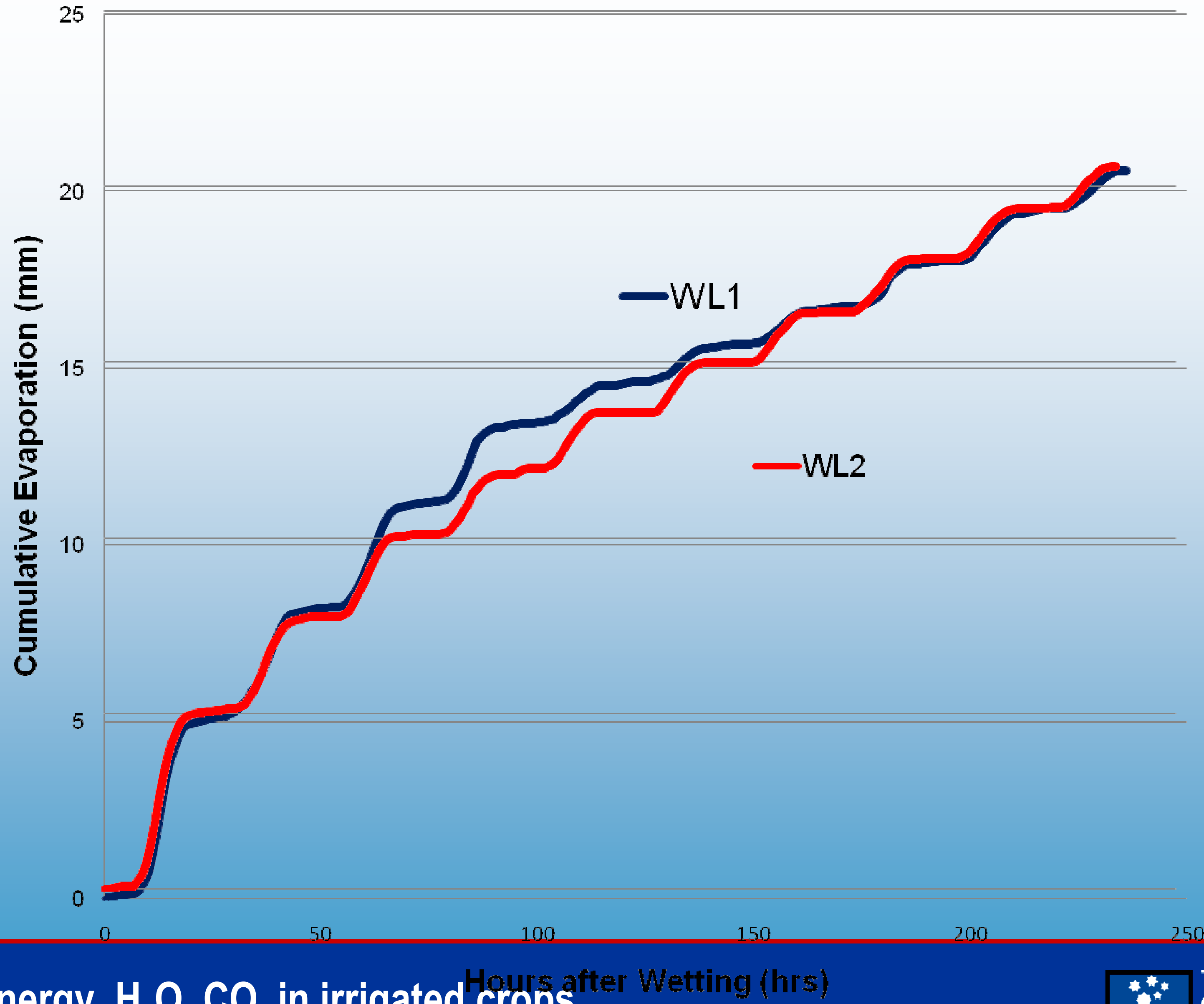
Soil layer thickness (m)	Lower limit (θv)	Drained upper limit (θv)	Saturated water content (θv)	Weighting for roots (0 to 1)	Bulk density (g/cm^3)
0.05	0.08	0.29	0.44	0.75	1.3
0.10	0.11	0.31	0.38	0.75	1.5
0.10	0.20	0.36	0.40	0.50	1.56
0.10	0.27	0.36	0.38	0.50	1.55
0.10	0.25	0.41	0.43	0.35	1.38

Water - estimation of soil evaporation



Σ(First stage evaporation) = f (soil type), $5 < E_{s1} < 12$mm
Second stage evaporation ~ 3.4 (√t)

Cultivated Soil (15/02/94 - 24/02/94)



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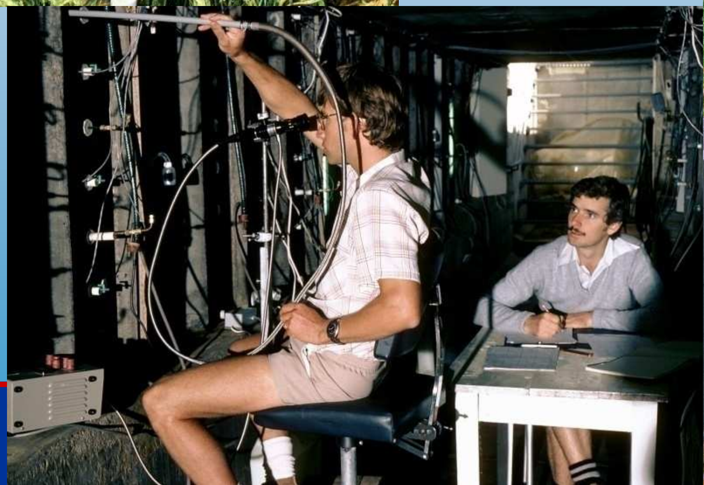
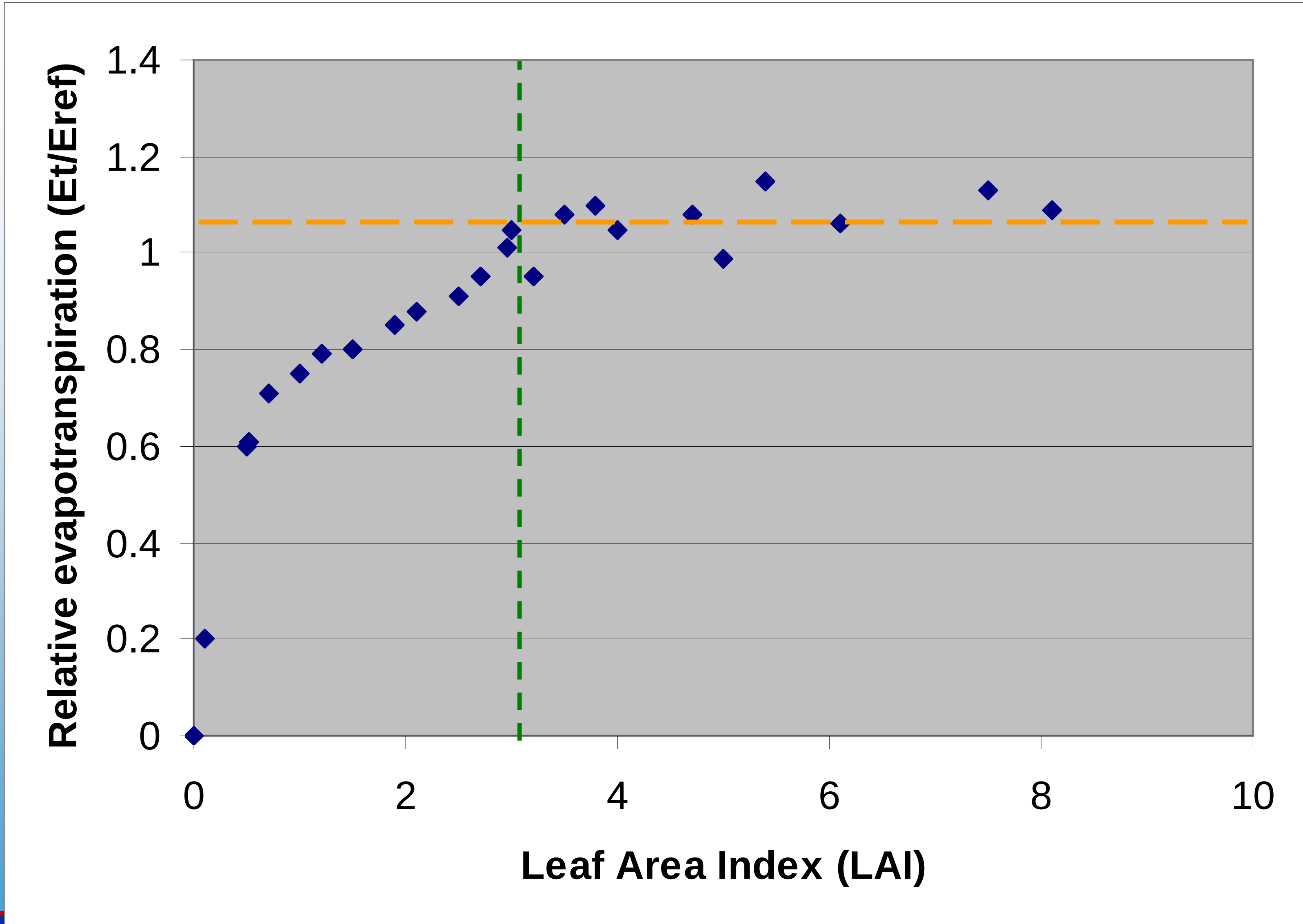
Plants





1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
2
4
6
8
10
Relative evapotranspiration (Et/Eref)
Leaf Area Index (LAI)

Plants

- Canopy water relations
  - Importance of leaf area development (and senescence) for
    - Energy capture
    - Water loss
- Plant water relations
  - Leaf and stem water potentials
  - Growth
  - Stomates
    - Optimisation of CO_2 uptake, H_2O loss
- Roots
  - Optimising water uptake, ion uptake and exclusion
  - Adapting for growth, biologically adjusting the soil environment

Do roots actively “seek” water?

Why do plants transpire?
What is the ecological advantage?