Energy and Water Balance

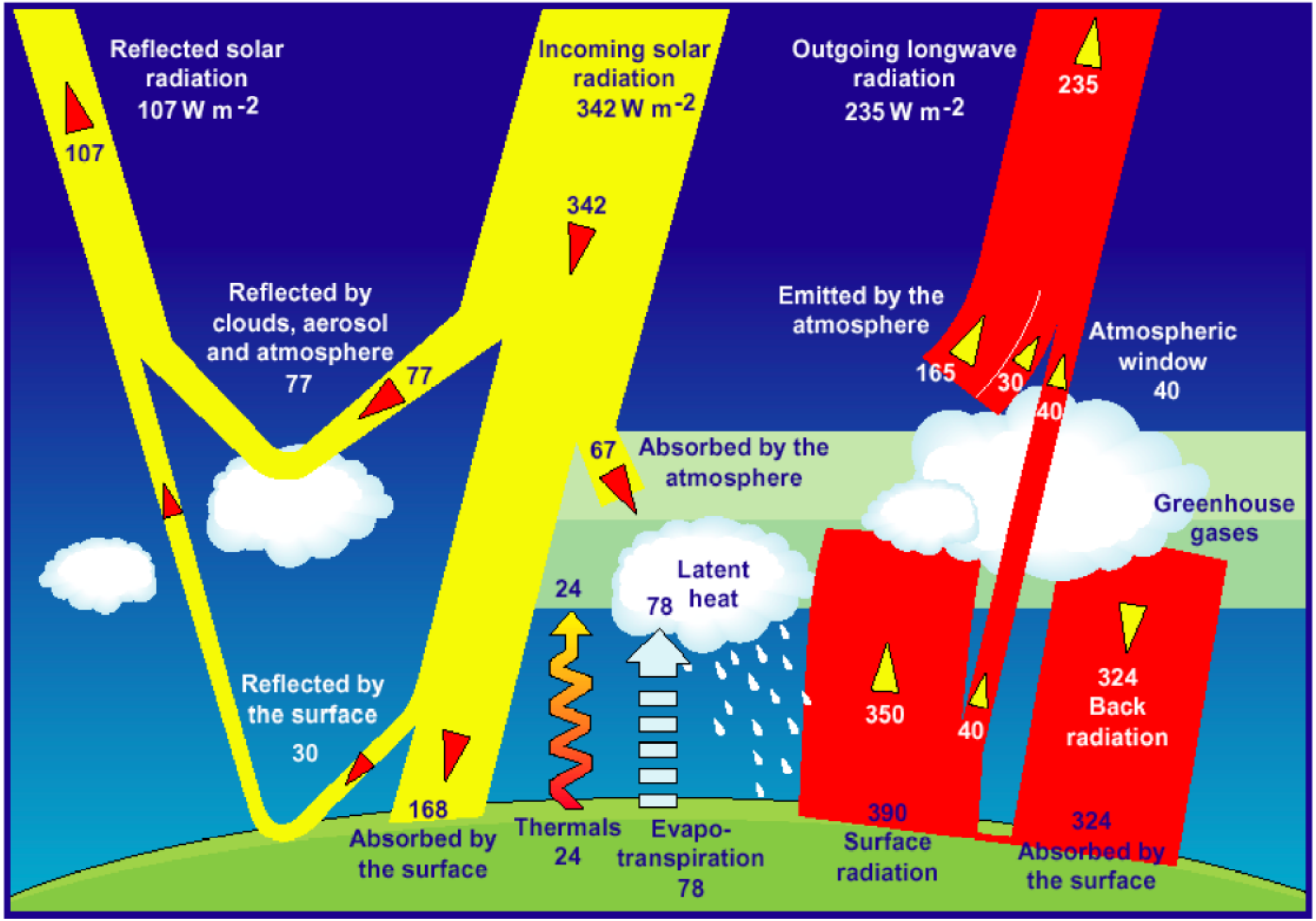
September 17, 2019

Pre-class ice breaker → write down your answer

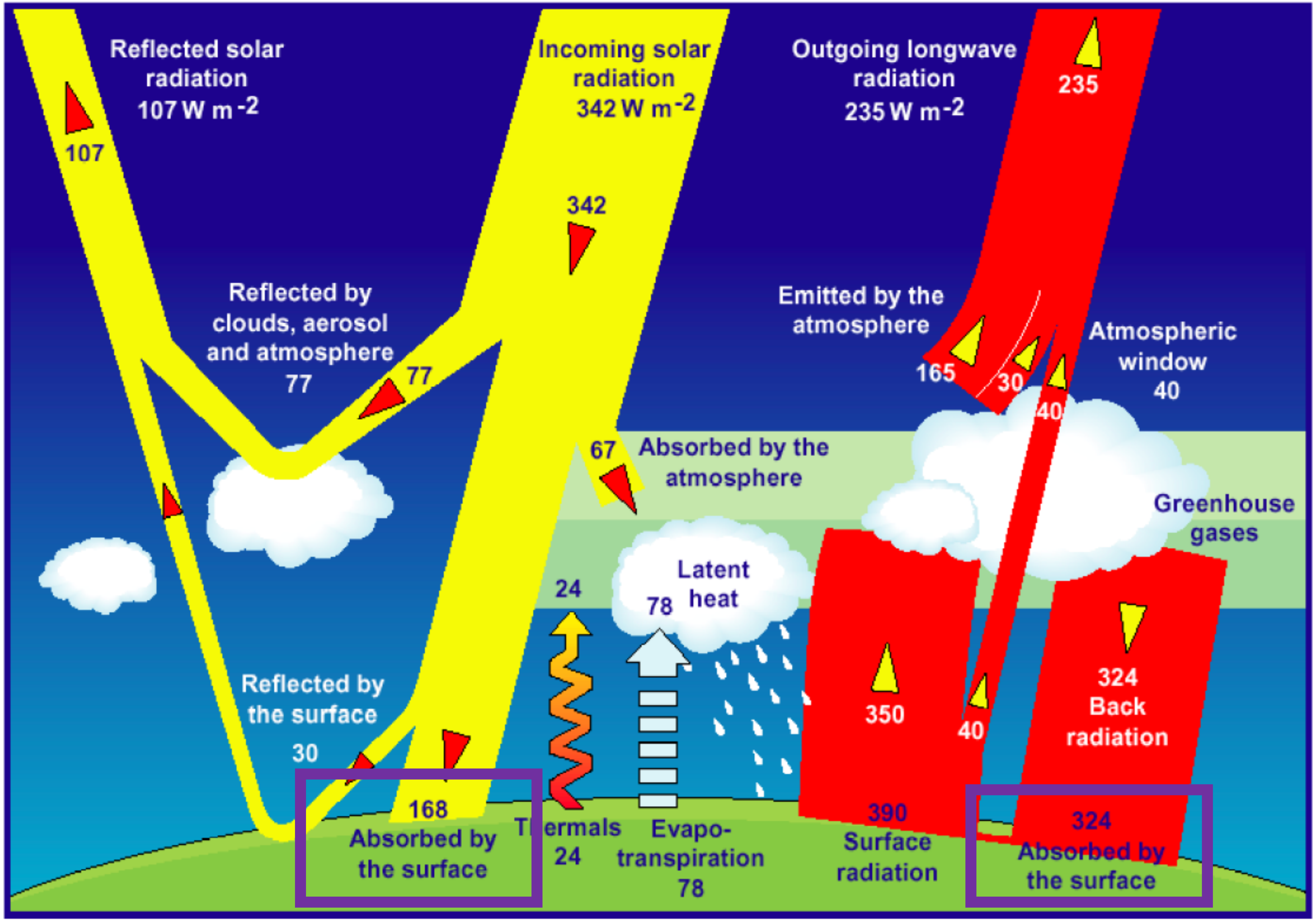
a. Are urban areas cooler than close-by rural areas? Why or why not?
b. Why are polar areas warming at a faster rate than equatorial areas?
c. Why are greenhouse gases warming the Earth?

The surface energy budget

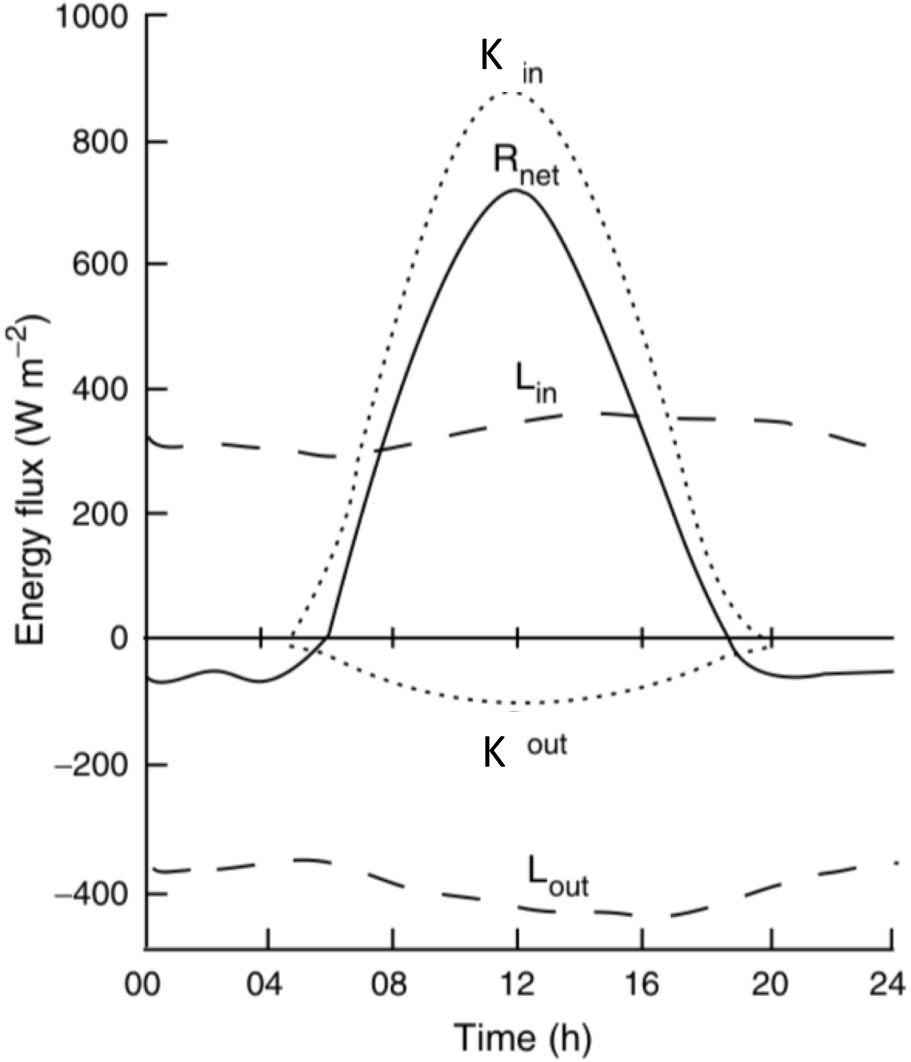
Climate System Energy Balance



Climate System Energy Balance



The net radiation absorbed by a surface is a sum of ingoing and outgoing radiation



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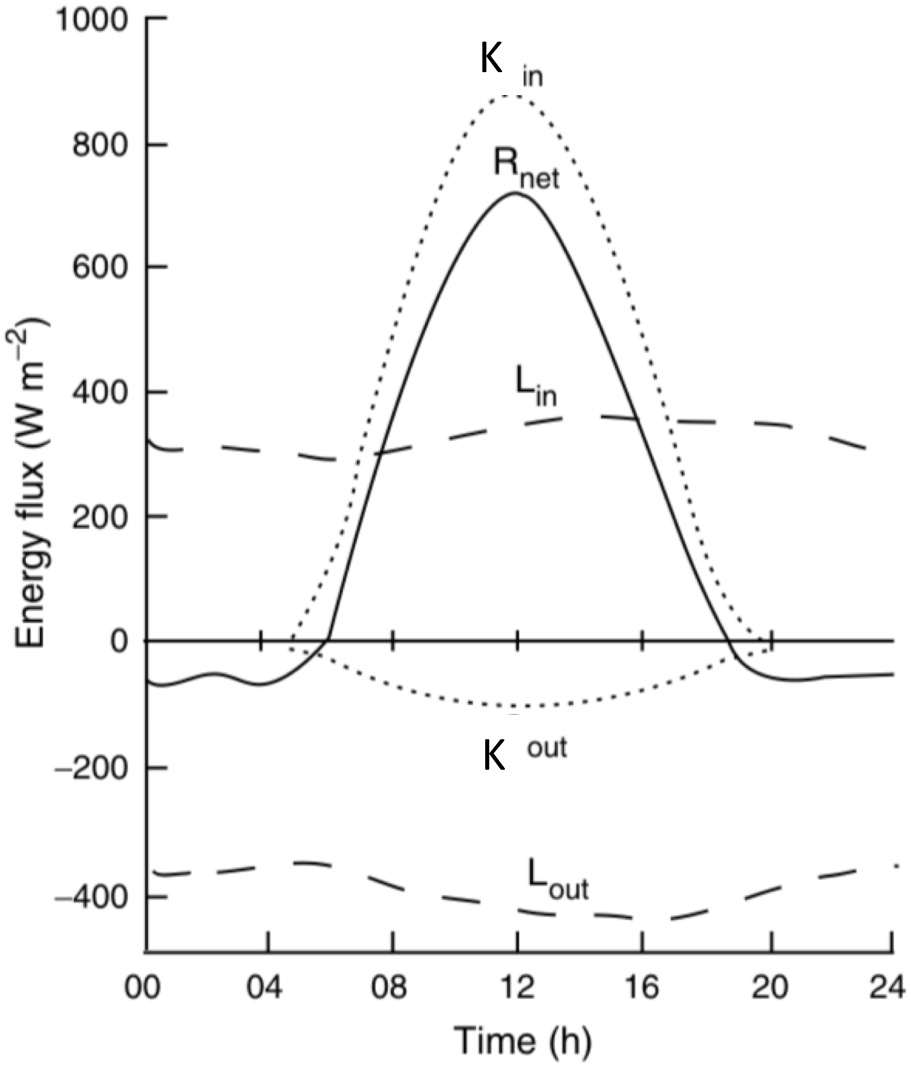
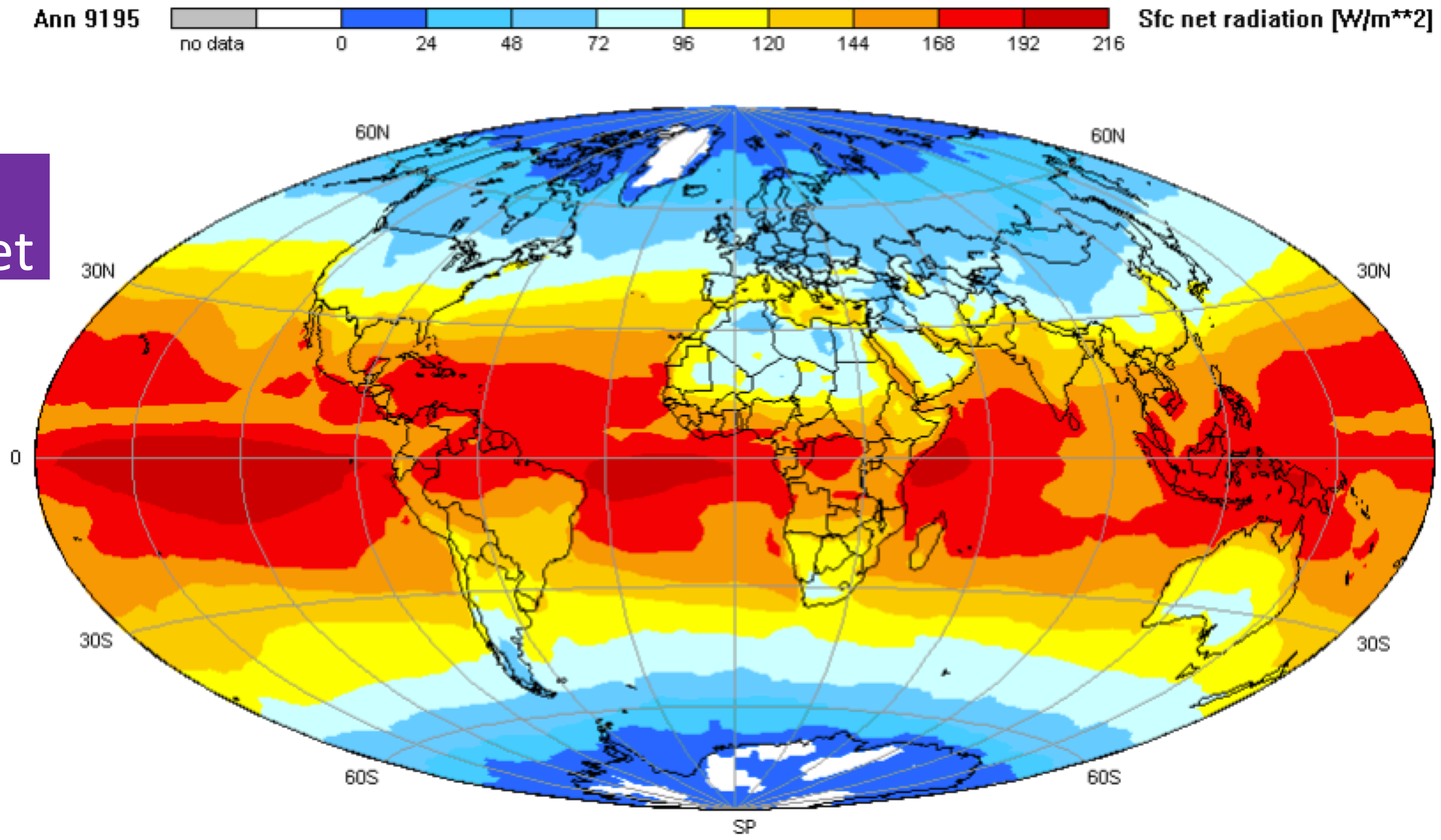


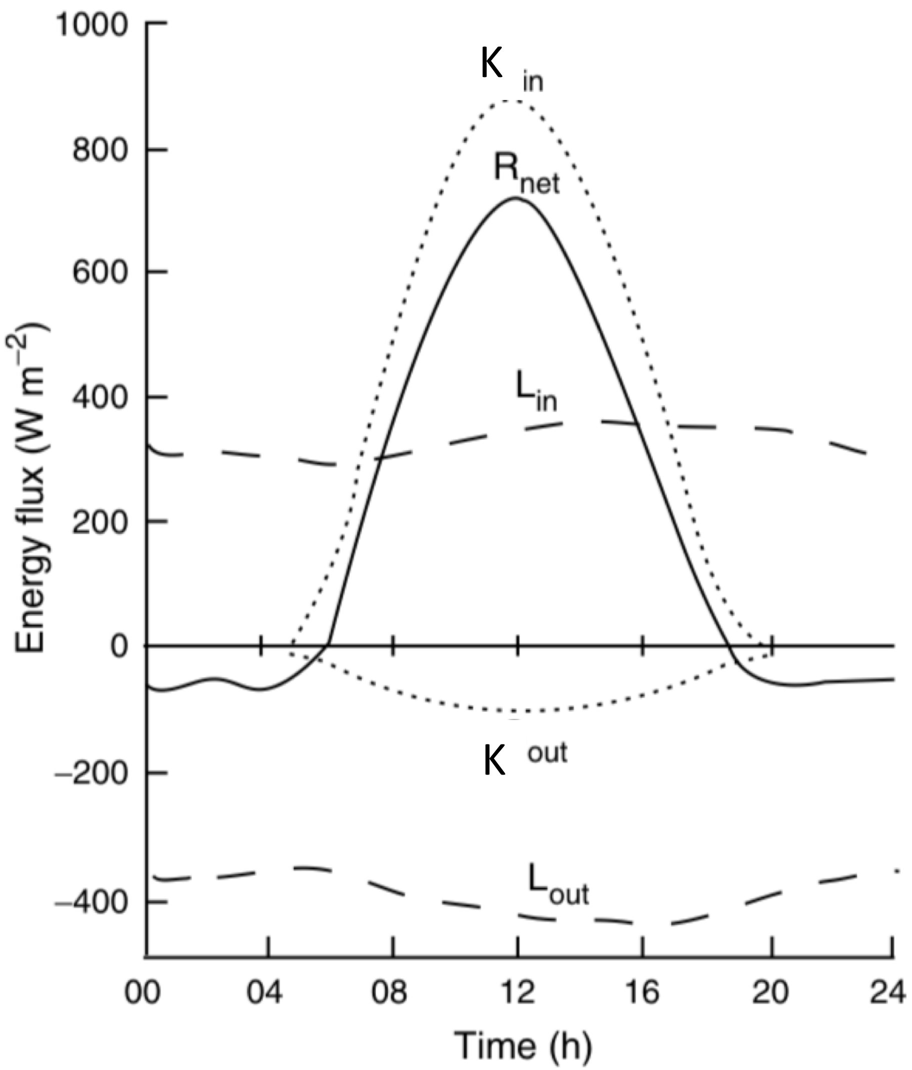
$R_{net} = (K_{in} - K_{out}) + (L_{in} - L_{out})$

R_{net}



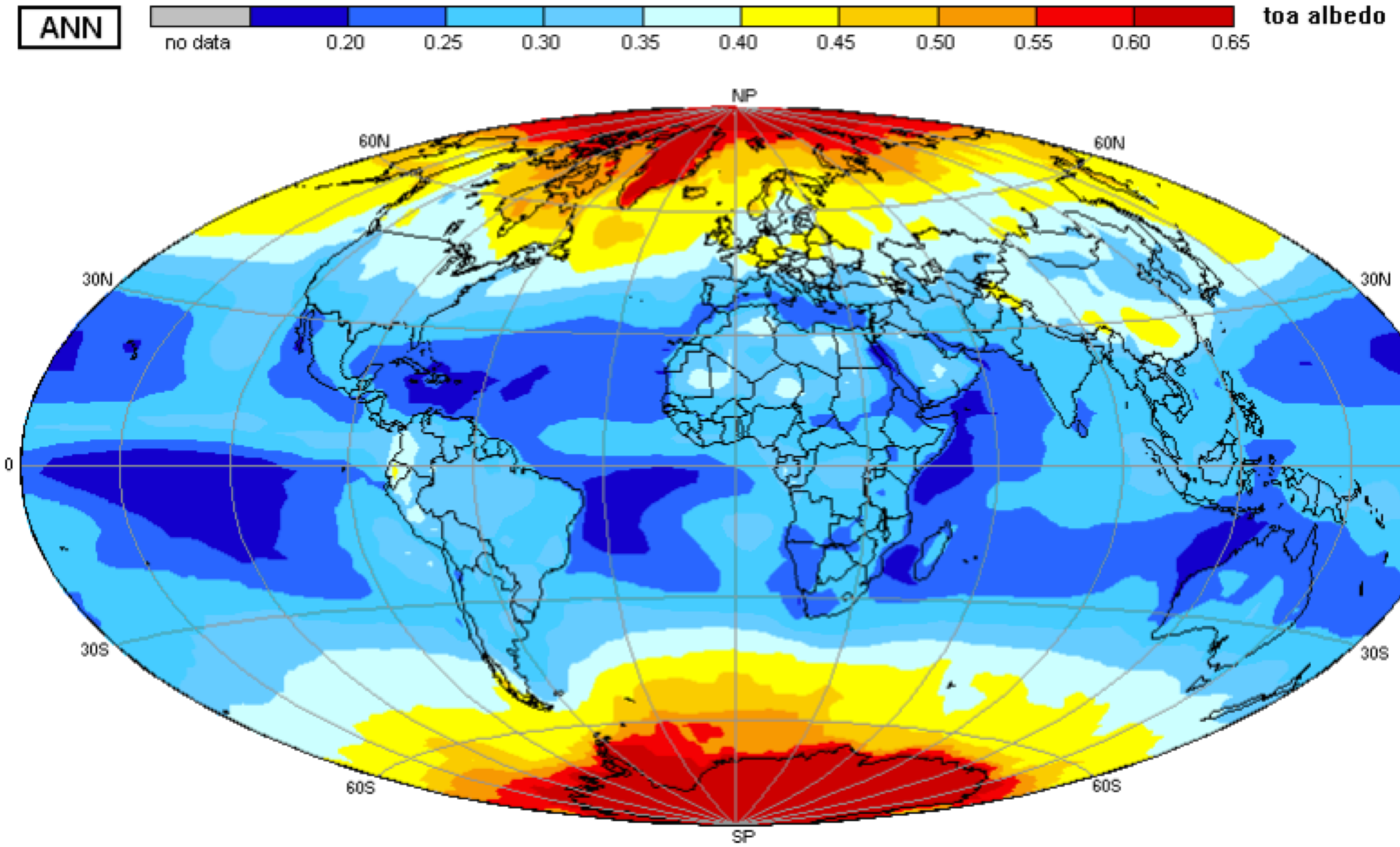
Annual average of the net radiation at the surface during the period 1991-1995 (Raschke&Ohmura 2005)

Shortwave (K) depends on the albedo (α)



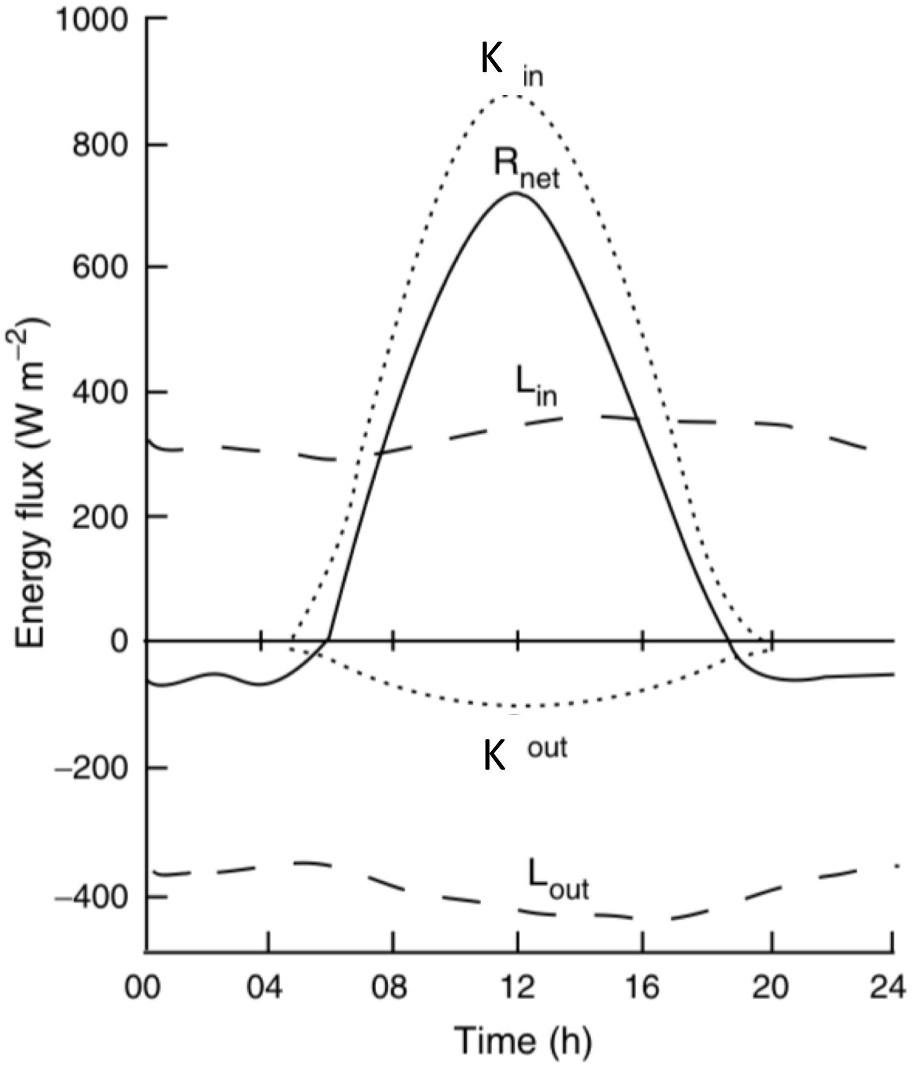
$$R_{net} = (K_{in} - K_{out}) + (L_{in} - L_{out})$$
$$R_{net} = (1 - \alpha)K_{in} + (L_{in} - L_{out})$$

α



Annual average of the albedo of the earth-atmosphere system during the period 1991-1995 (Raschke&Ohmura 2005)

Longwave (L) depends on temperature (T)



$R_{net} = (K_{in} – K_{out}) + (L_{in} – L_{out})$

$R_{net} = (1– \alpha)K_{in} + (L_{in} – L_{out})$

$R_{net} = (1– \alpha)K_{in} + (L_{in} – L_{out})$

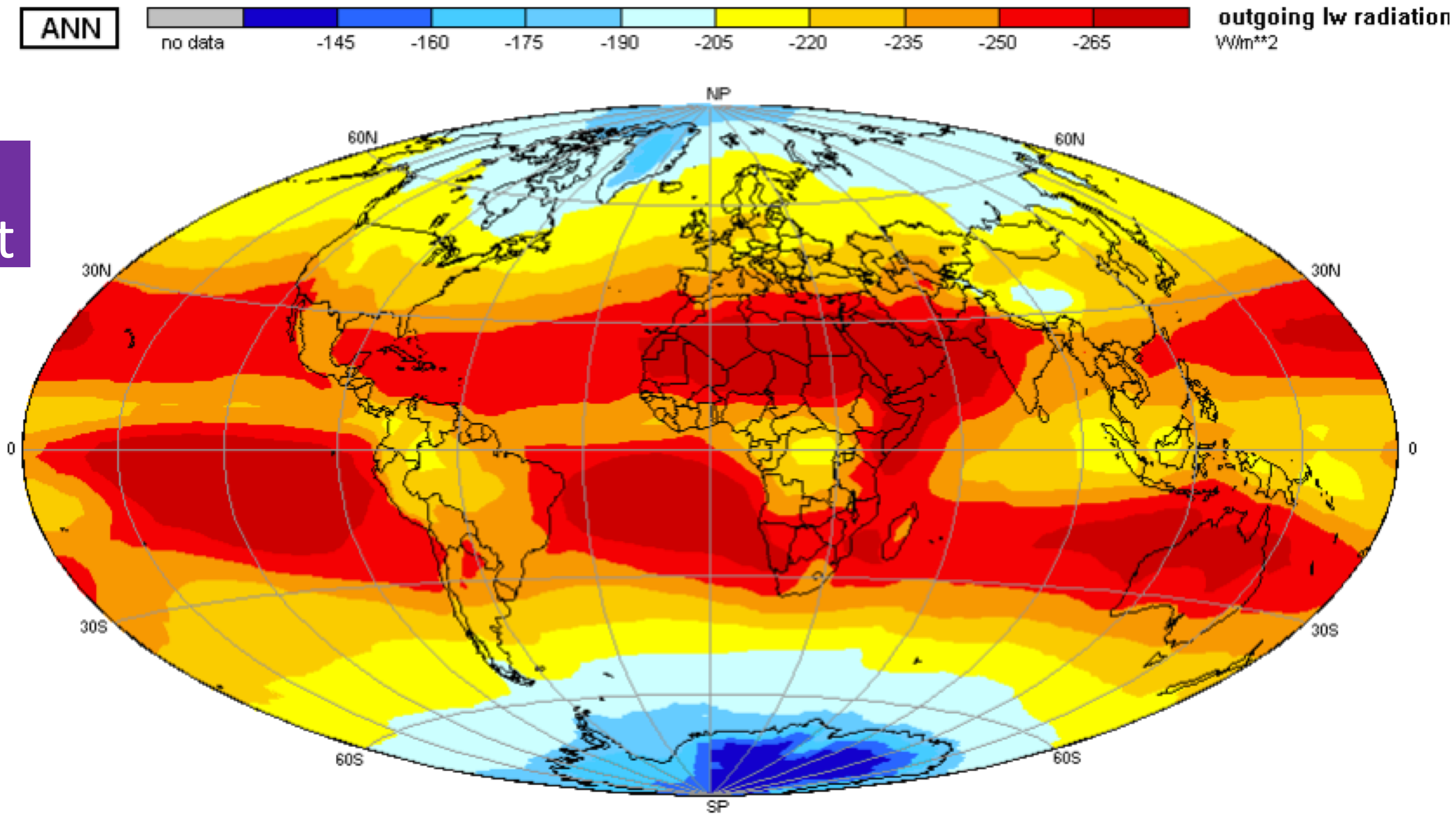
$L_{in} = \sigma\varepsilon_{sky}T_{sky}^{4}$

$L_{out} = \sigma\varepsilon_{surface}T_{surface}^{4}$

ε = emissivity

σ = Stefan-Boltzman constant

L_{out}



Annual average of the terrestrial emission at top of the atmosphere during the period 1991-1995 (Raschke&Ohmura 2005)

Net radiation absorbed is partitioned into non-radiative fluxes

Net radiation (R_{net}) is partitioned into different fluxes at the surface

$$R_{net} = H + LE + G + \Delta S$$

Net radiation (R_{net}) is partitioned into different fluxes at the surface

$$\boxed{R_{net}} = H + LE + G + \Delta S$$

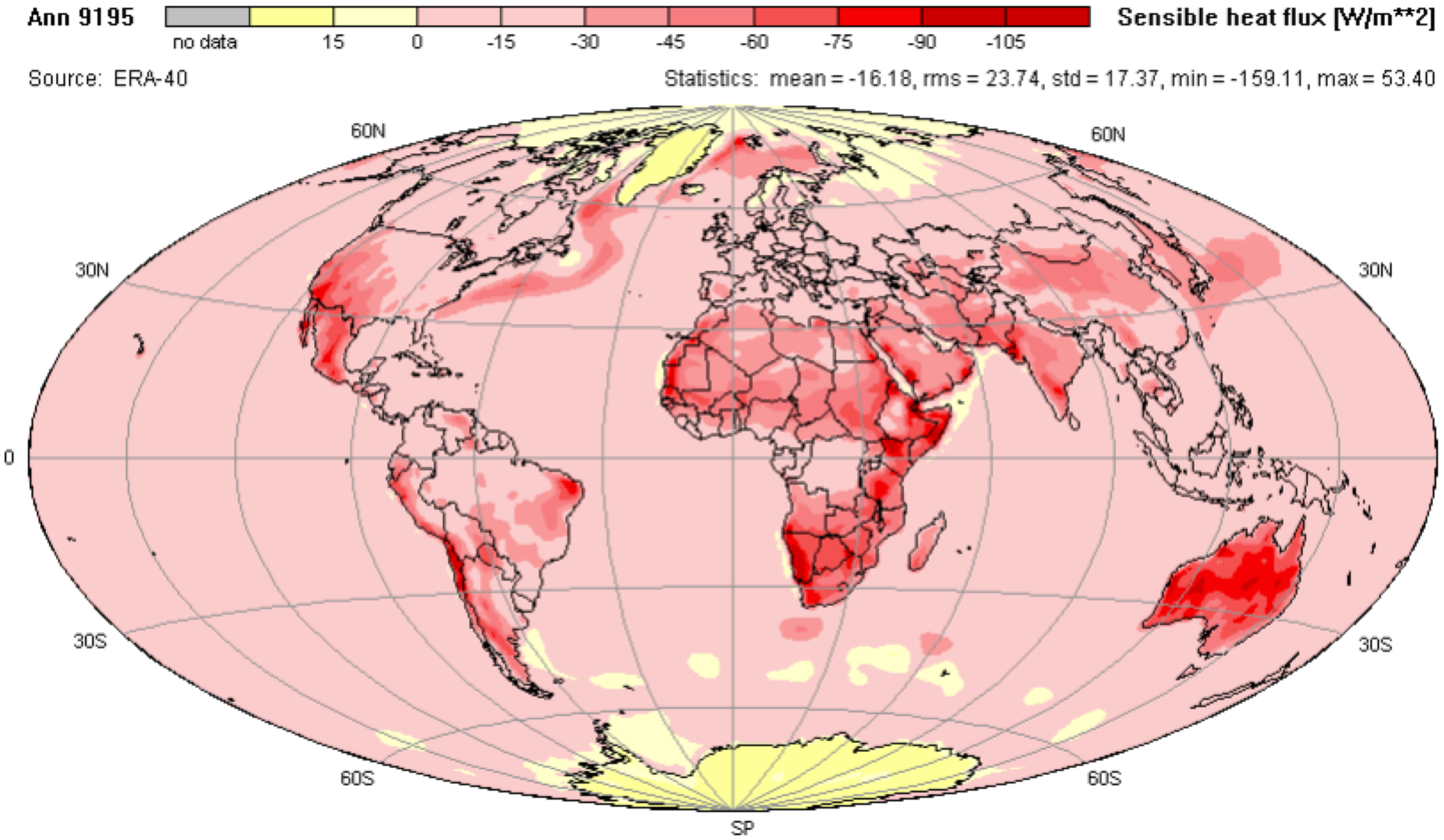
Total radiation absorbed by the surface

Net radiation (R_{net}) is partitioned into different fluxes at the surface

$$R_{net} = \boxed{H} + LE + G + \Delta S$$

Sensible heat flux (heats air)

H



Annual mean distribution of sensible heat fluxes during the period 1991-1995 (Raschke&Ohmura 2005)

Net radiation (R_{net}) is partitioned into different fluxes at the surface

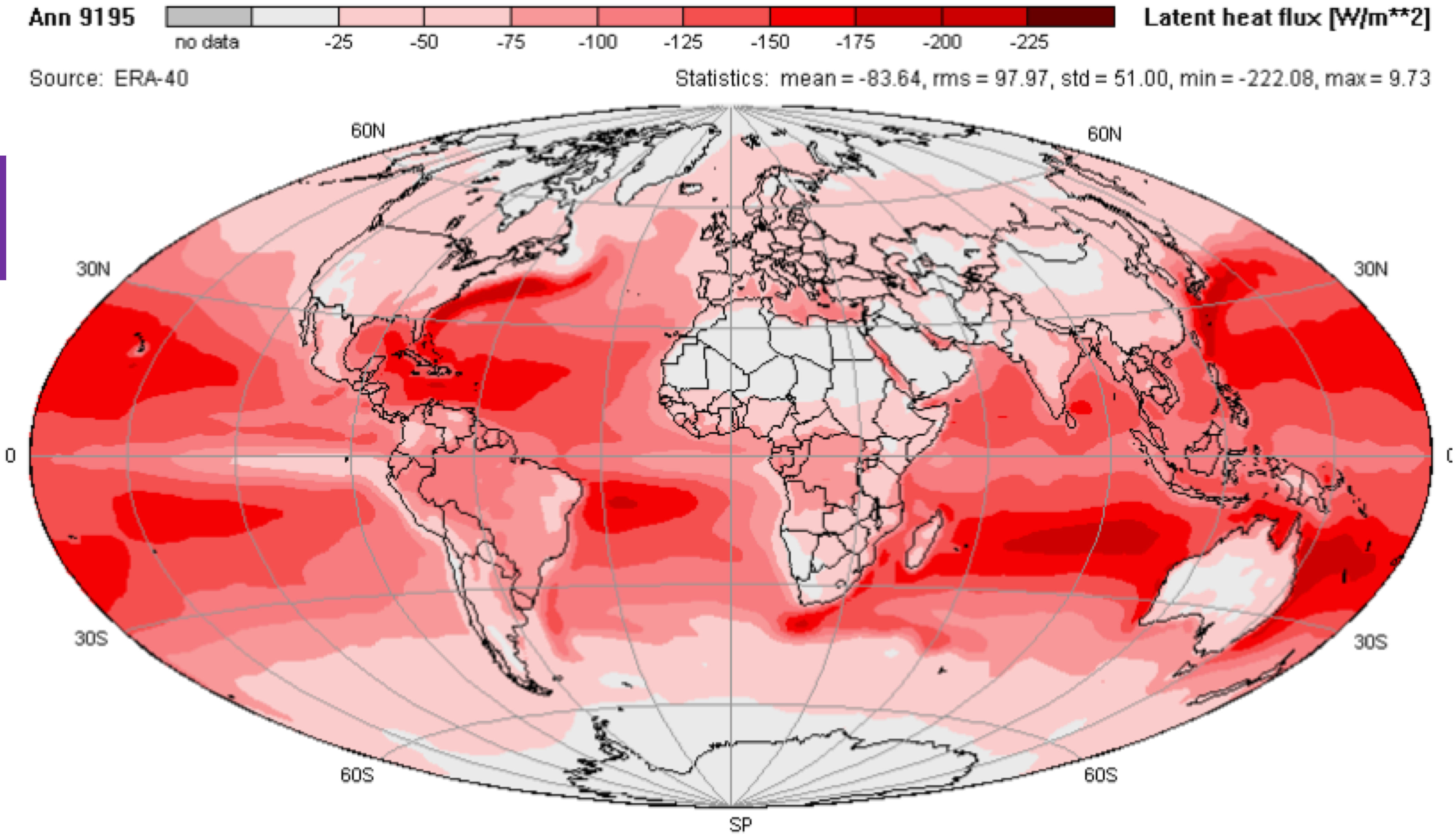
$$R_{net} = H + \boxed{LE} + G + \Delta S$$

Latent heat flux (water evaporation; no T change)

L = latent heat of vaporization (constant)

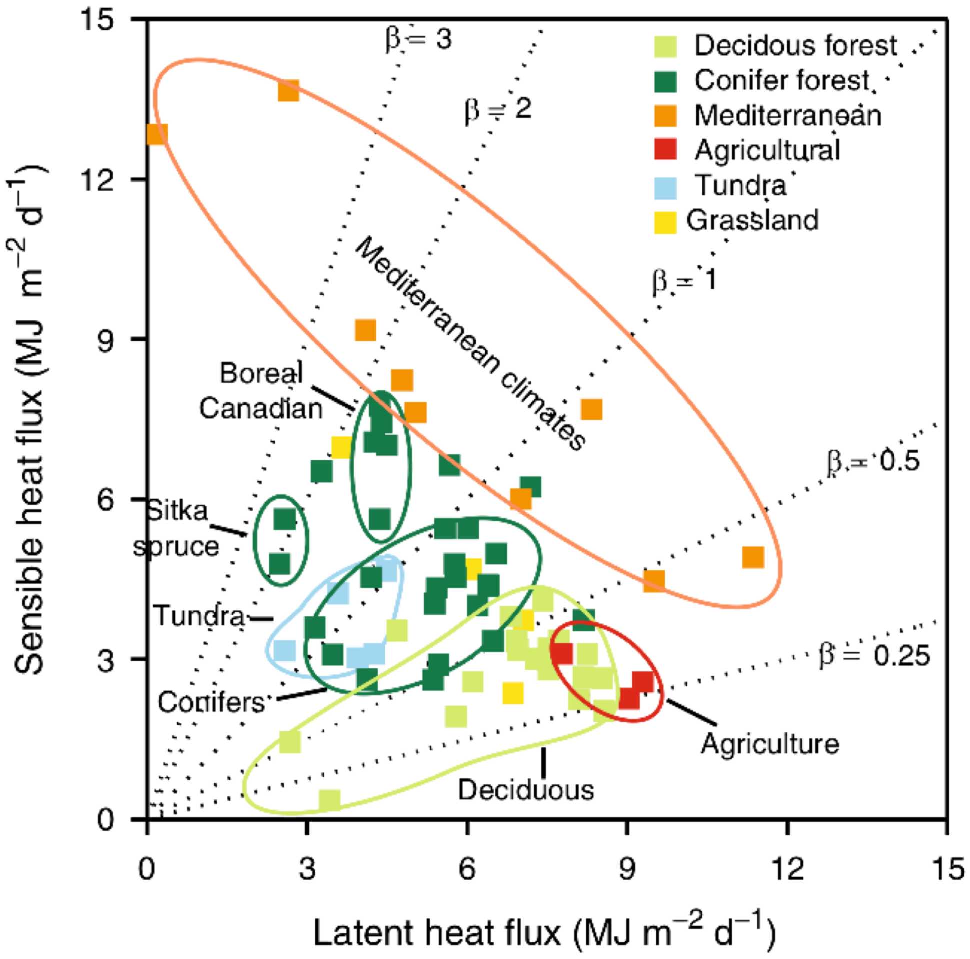
E = evapotranspiration

LE



Annual mean distribution of latent heat fluxes duing the period 1991-1995 (Raschke&Ohmura 2005)

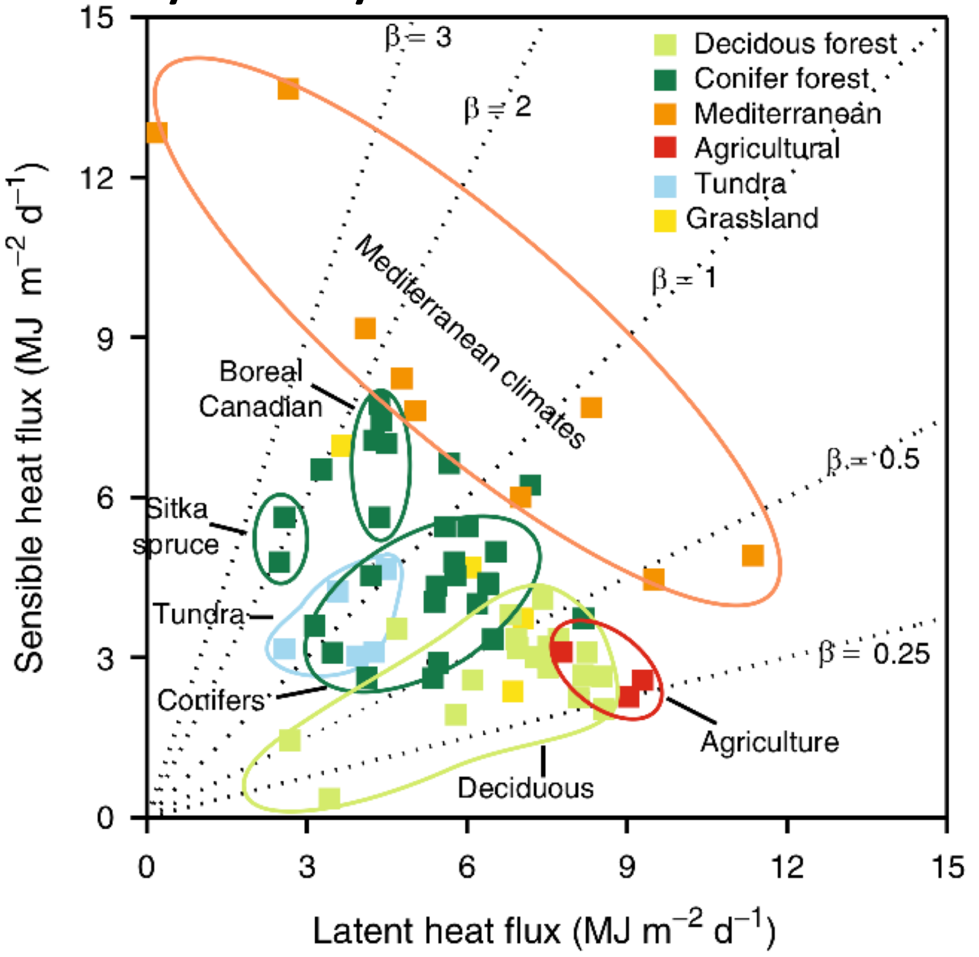
Bowen ratio – ratio of sensible (H) to latent (LE) heat flux (H/LE)



What do you notice from this figure?

Bowen ratio – ratio of sensible (H) to latent (LE) heat flux (H/LE)

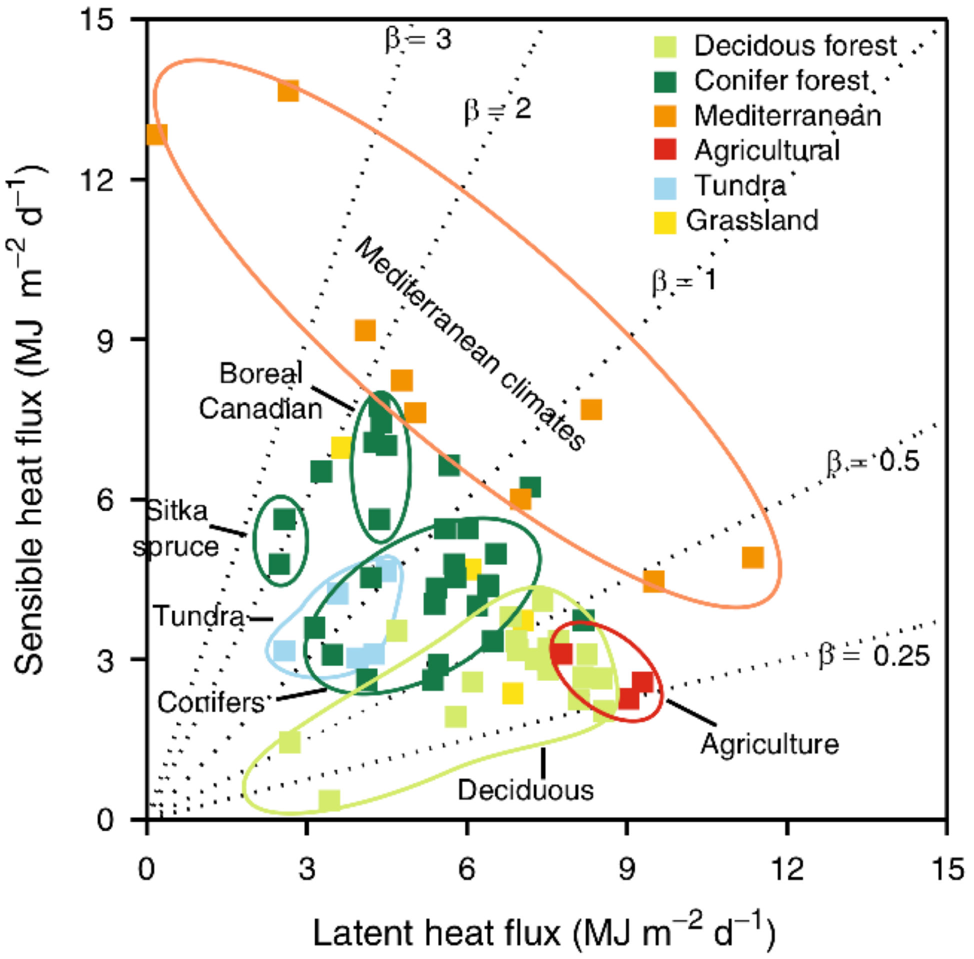
Low transpiration/
Dry ecosystems



High
transpiration/Wet
ecosystems

Bowen ratio – is spatially and temporally variable

Desert - High



Spatial – turbulence within and between ecosystems

Temporal – snowmelt, bud break

Tropical Rainforest – Low

Tight linkage of energy and water budgets

Areas with high Bowen ratios tend to have higher air temperatures for a given amount of R_{net}

Net radiation (R_{net}) is partitioned into different fluxes at the surface

$$R_{net} = H + LE + \boxed{G} + \Delta S$$

Ground heat flux (heats ground; typically small)

Net radiation (R_{net}) is partitioned into different fluxes at the surface

$$R_{net} = H + LE + G + \boxed{\Delta S}$$

Storage

Class activity → turn in for participation point

- Answer the beginning of class questions using the energy budget equations:
  1. Are urban areas cooler than close-by rural areas? Why or why not?
  2. Why are polar areas warming at a faster rate than equatorial areas?
  3. Why are greenhouse gases warming the Earth?

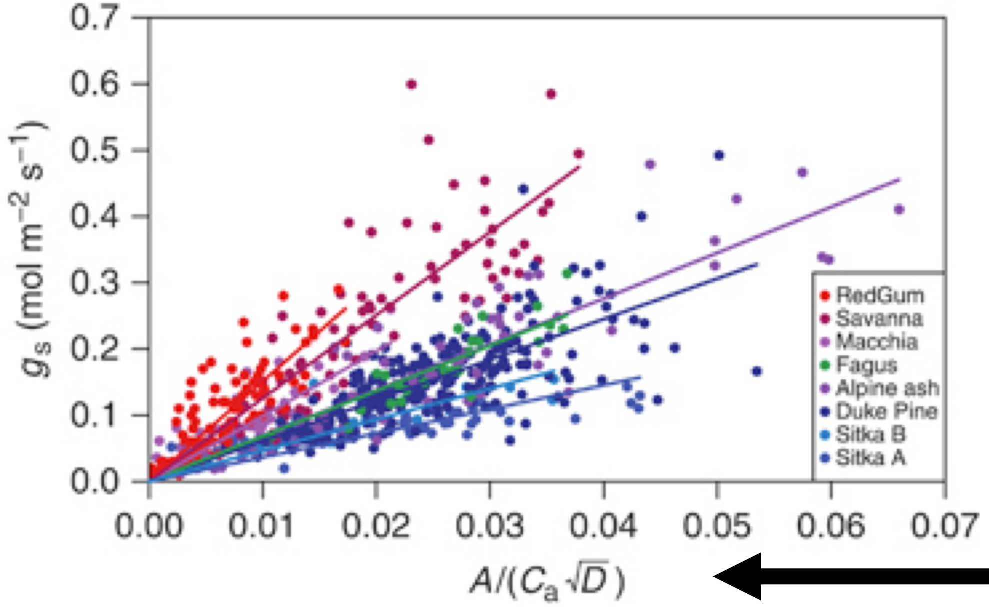
Surface energy budget recap

- Important biological characteristics
  - Albedo
  - Transpiration (latent heat flux)
- Coupling with terrestrial water cycles
  - Influences atmospheric water demand
  - Influences atmospheric water storage

Half-baked climate solutions!

- Idea: open up stomata to crank up photosynthesis to increase carbon uptake
- Would this impact climate?

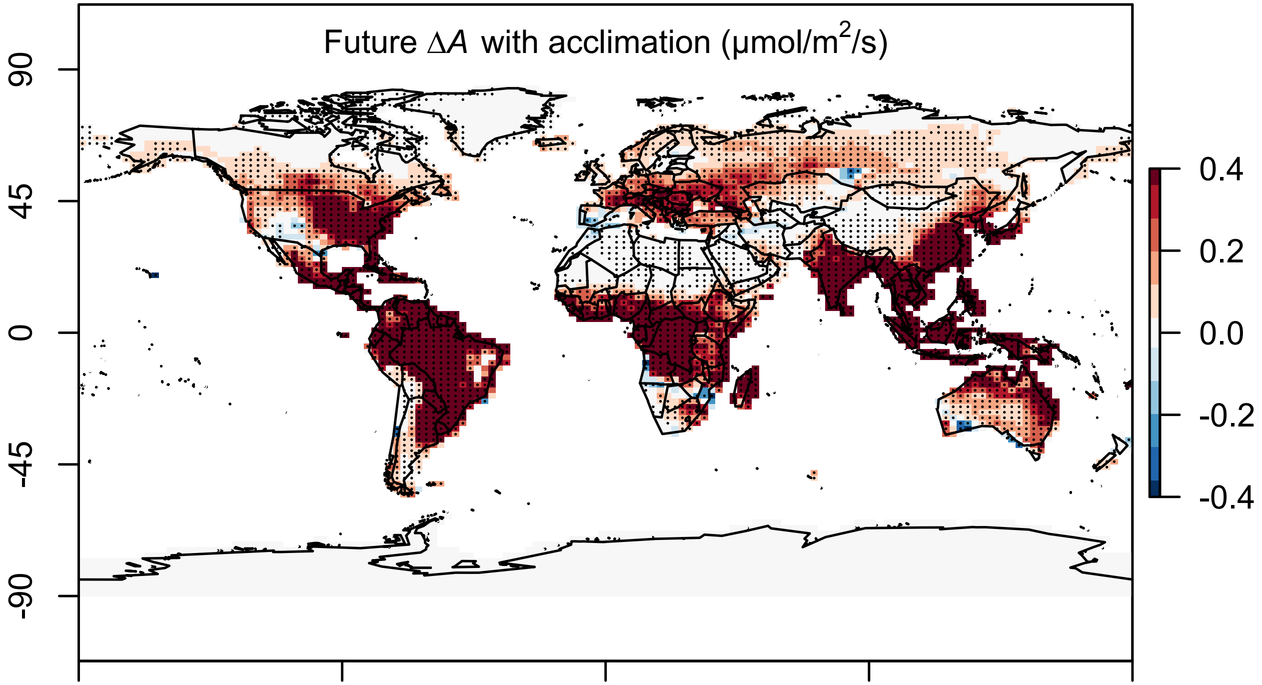
Openness of stomata



Photosynthesis

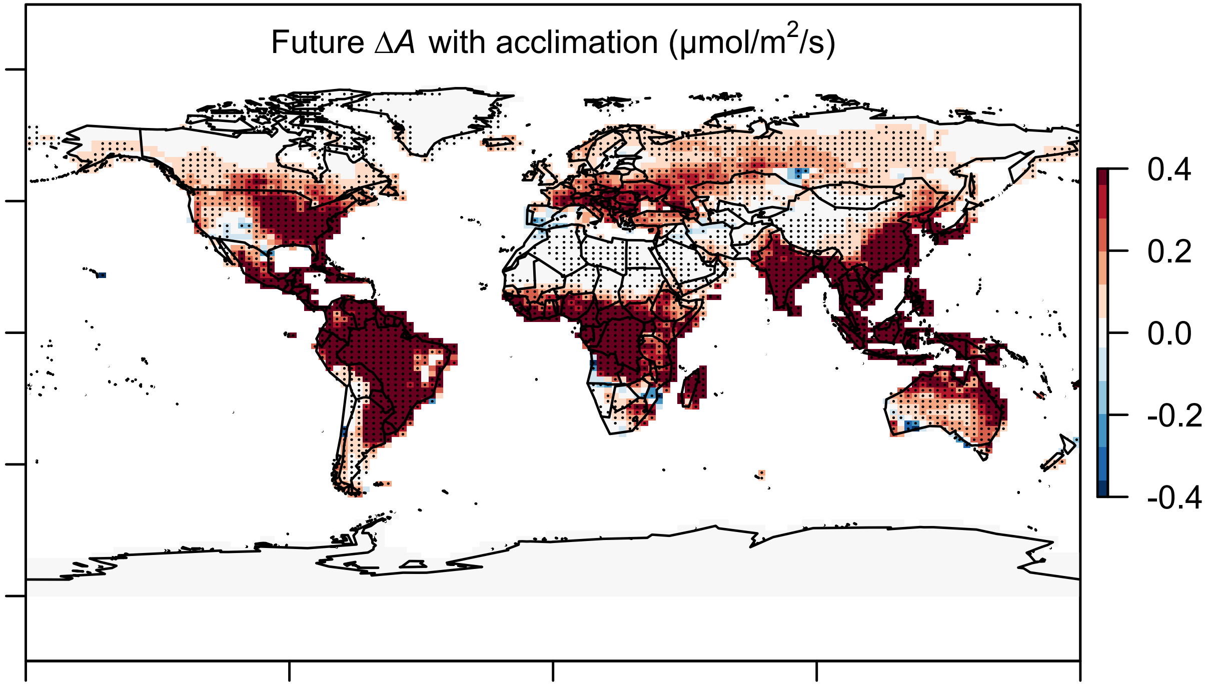
Medlyn et al. (2011)

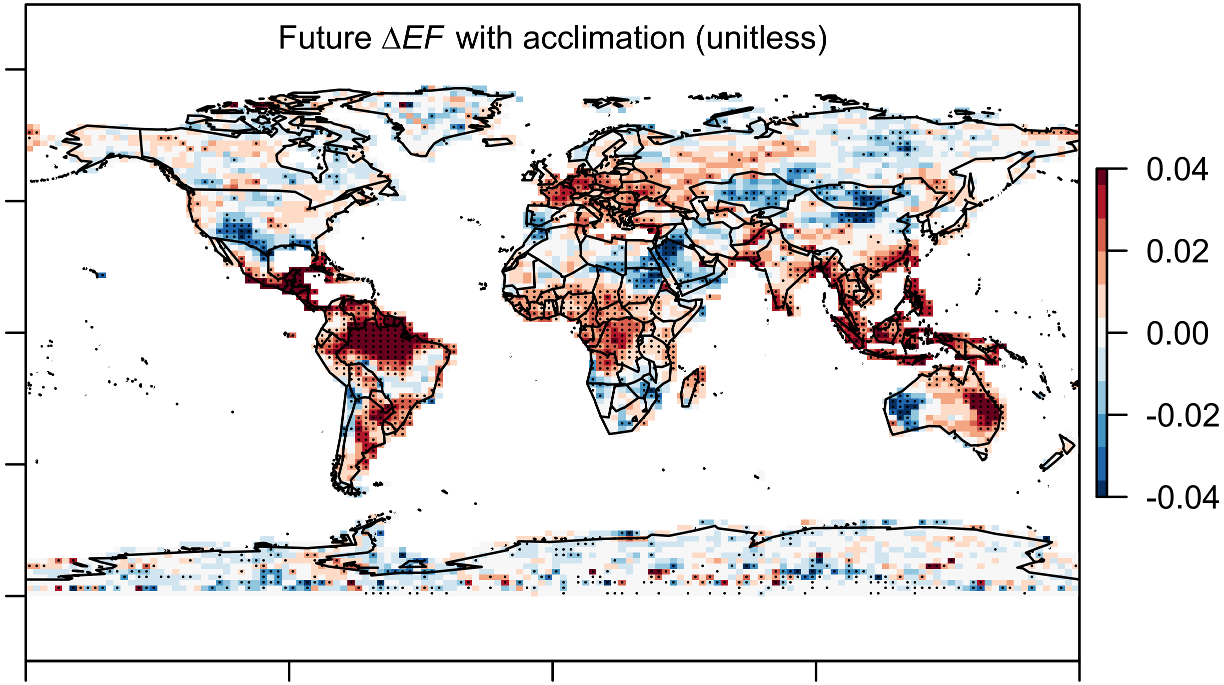
Higher photosynthesis



Smith et al. (2017)

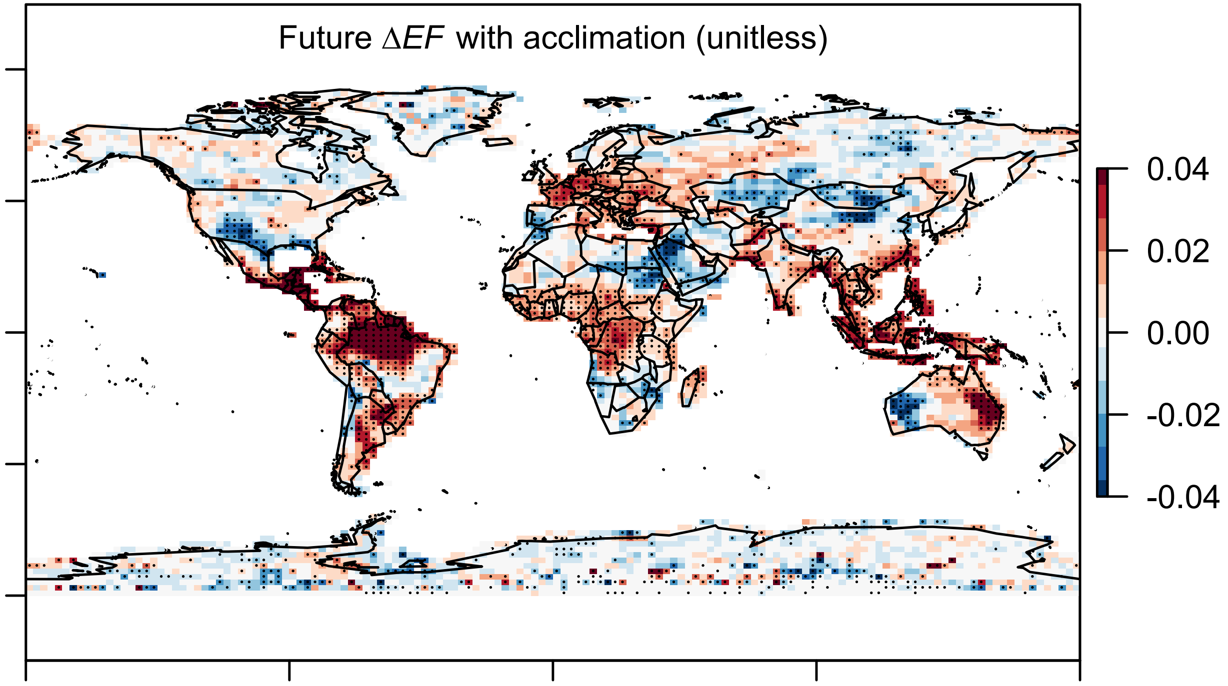
Higher photosynthesis → More latent heat flux

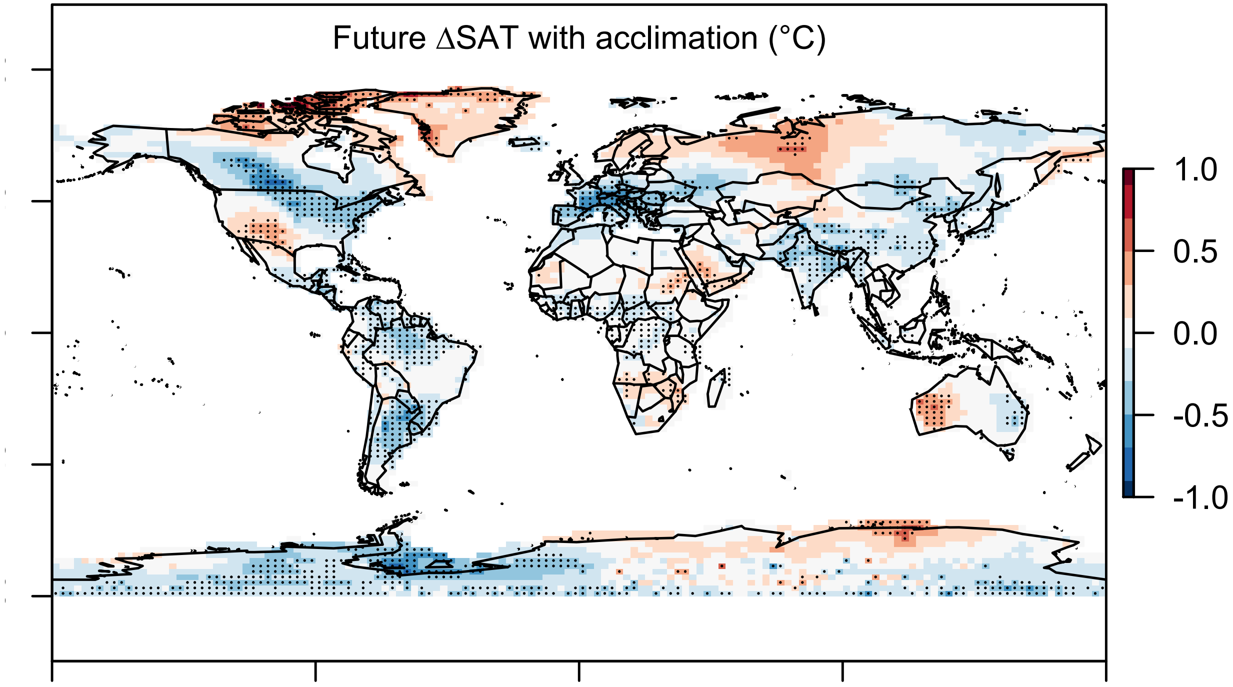




Smith et al. (2017)

More latent heat flux → Local cooling



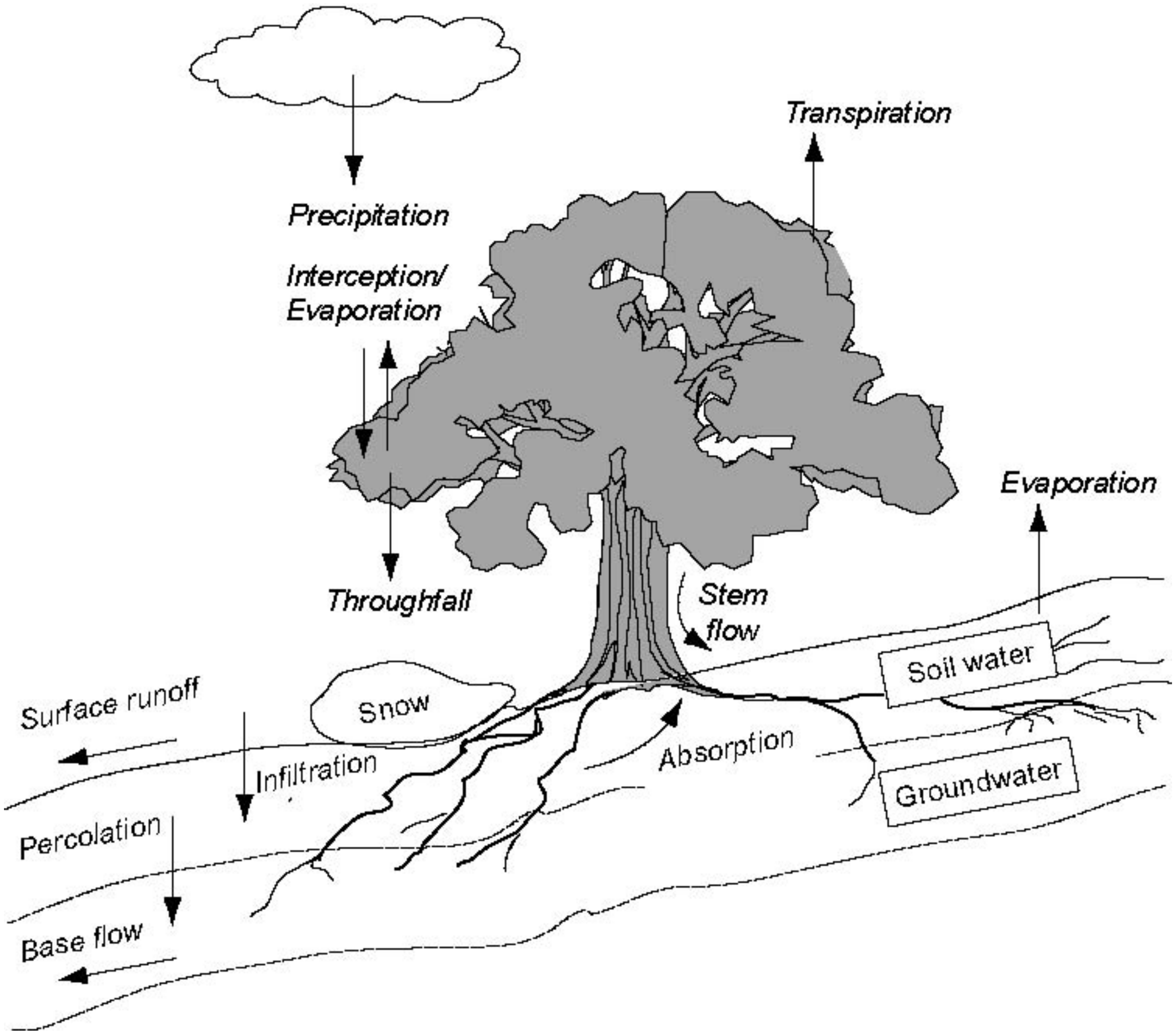


Smith et al. (2017)

Water budget

Questions

- How does water enter a terrestrial ecosystem?
- Where does it go?
  - Outputs
  - Storage



Transpiration
Precipitation
Interception/
Evaporation
Evaporation
Throughfall
Stem
flow
Soil water
Surface runoff
Snow
Infiltration
Absorption
Groundwater
Percolation
Base flow

The Water Budget

Precipitation +/- Storage = Evapotranspiration + Runoff

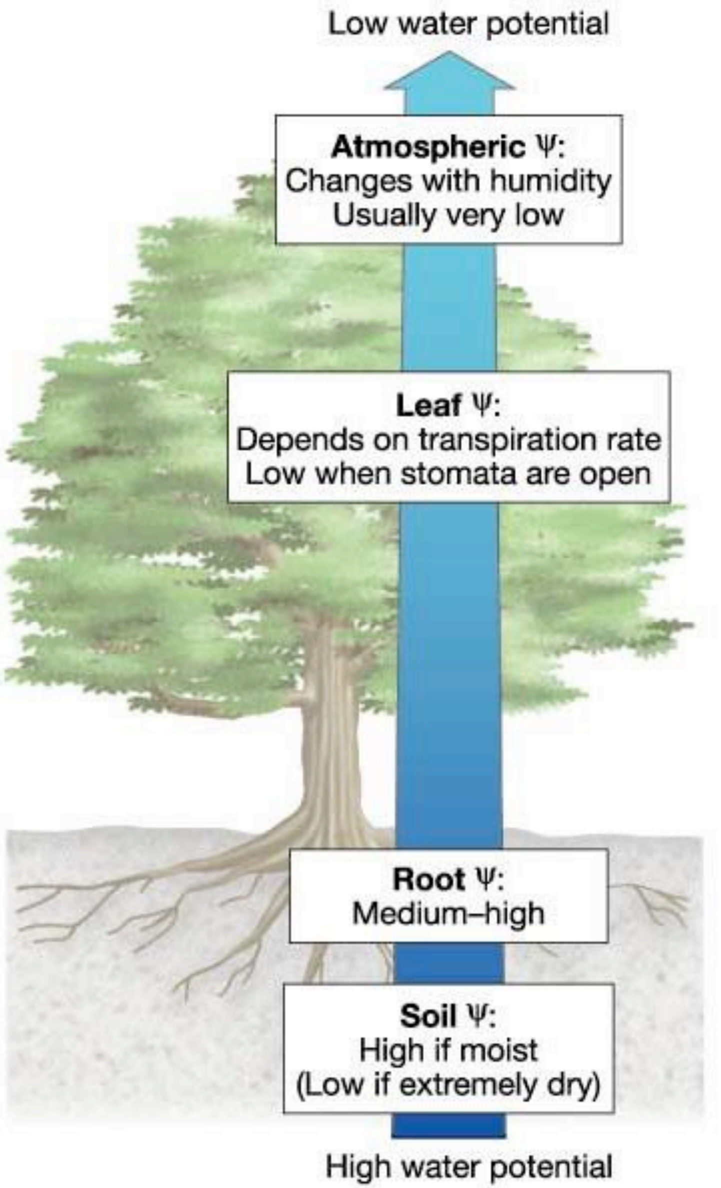
The Water Budget

$$P \pm \Delta S = E + R$$

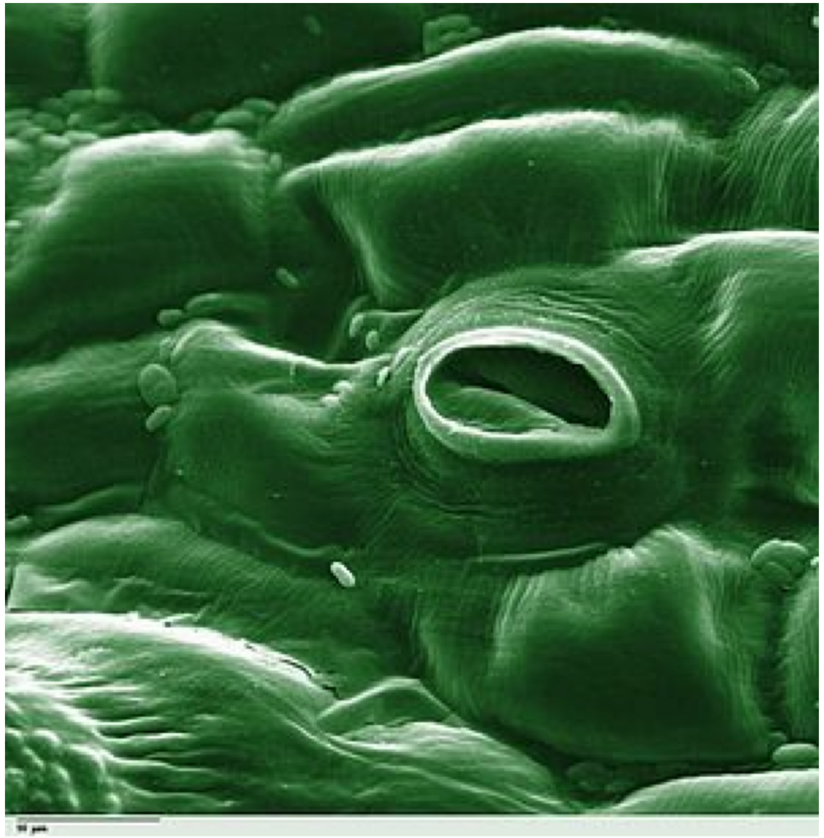
The Water Budget

$$P = E + R +/- \Delta S$$

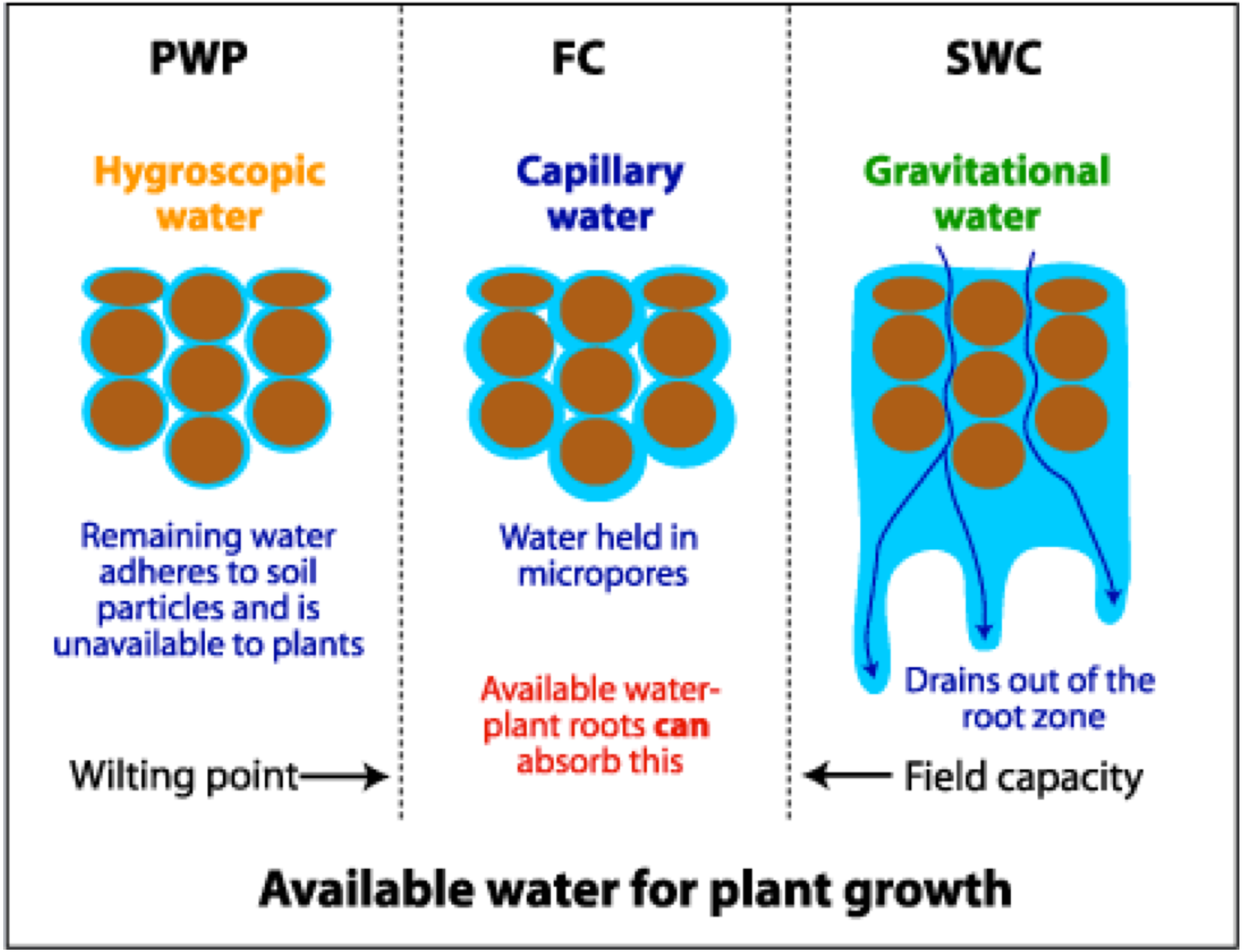
Water moves through ecosystems via potential gradients

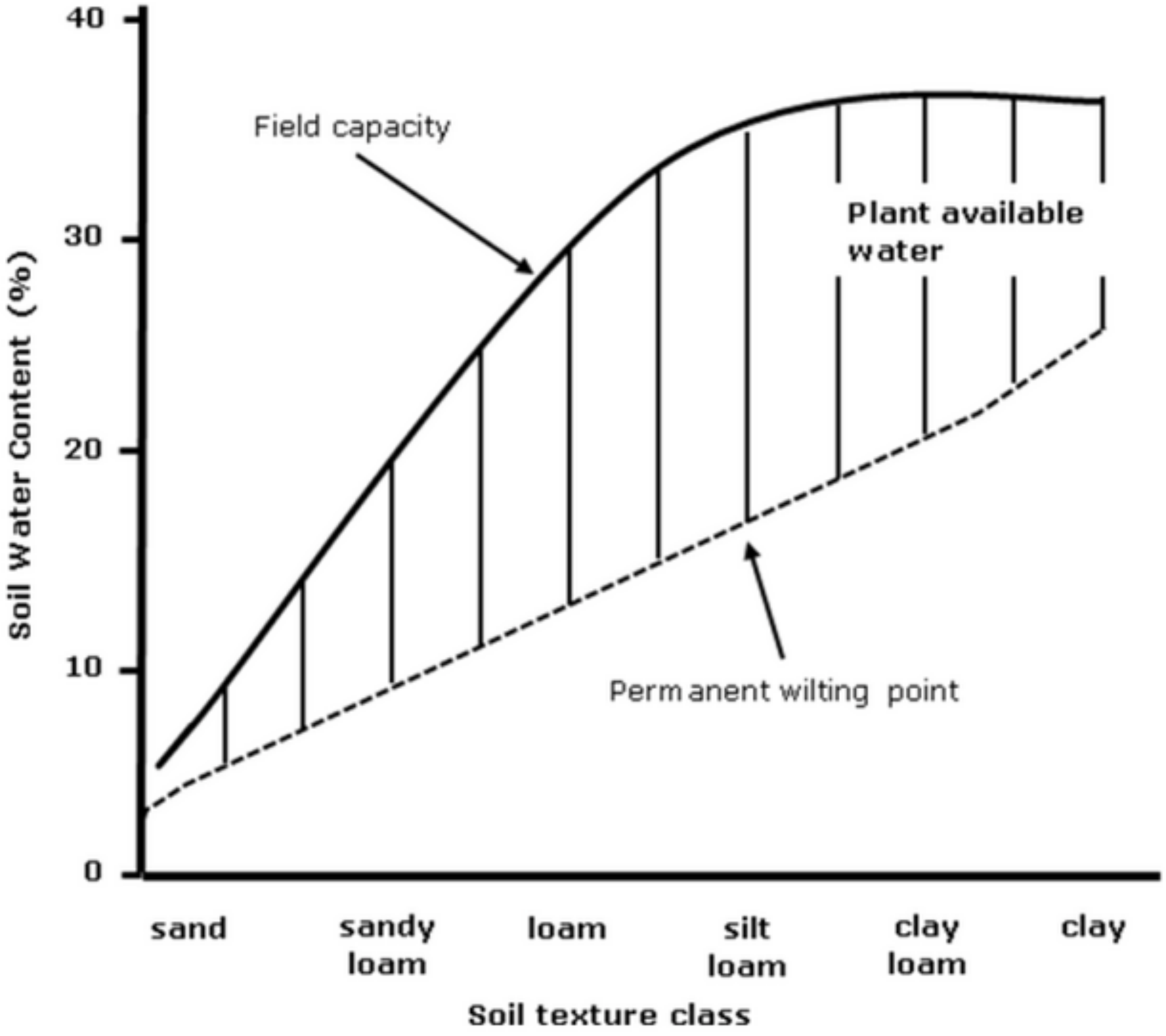


Water moves from high water potential to low water potential via a continuous water column/film



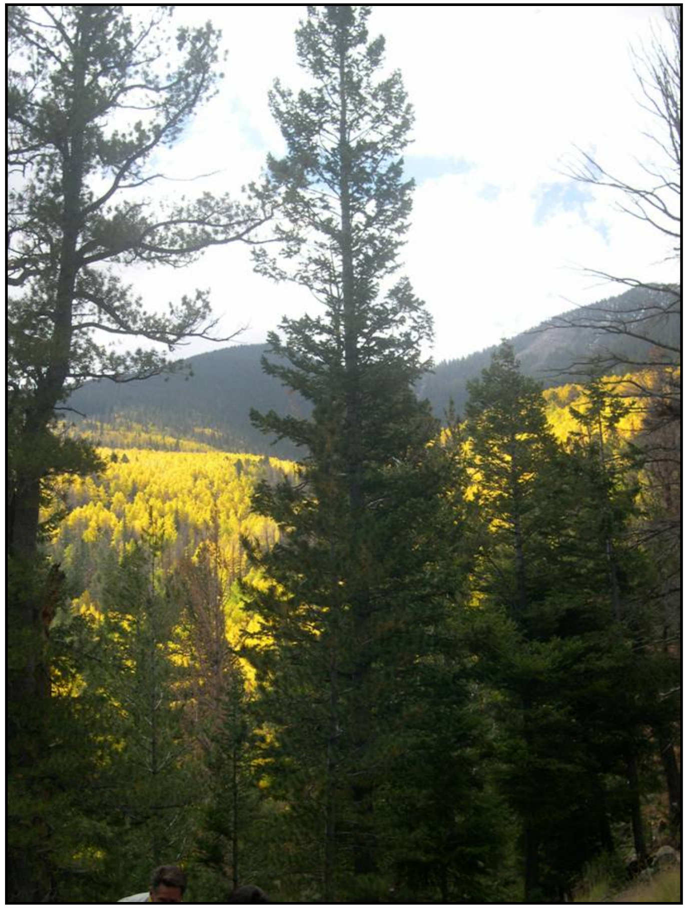
Remember: soil water potential depends on soil texture

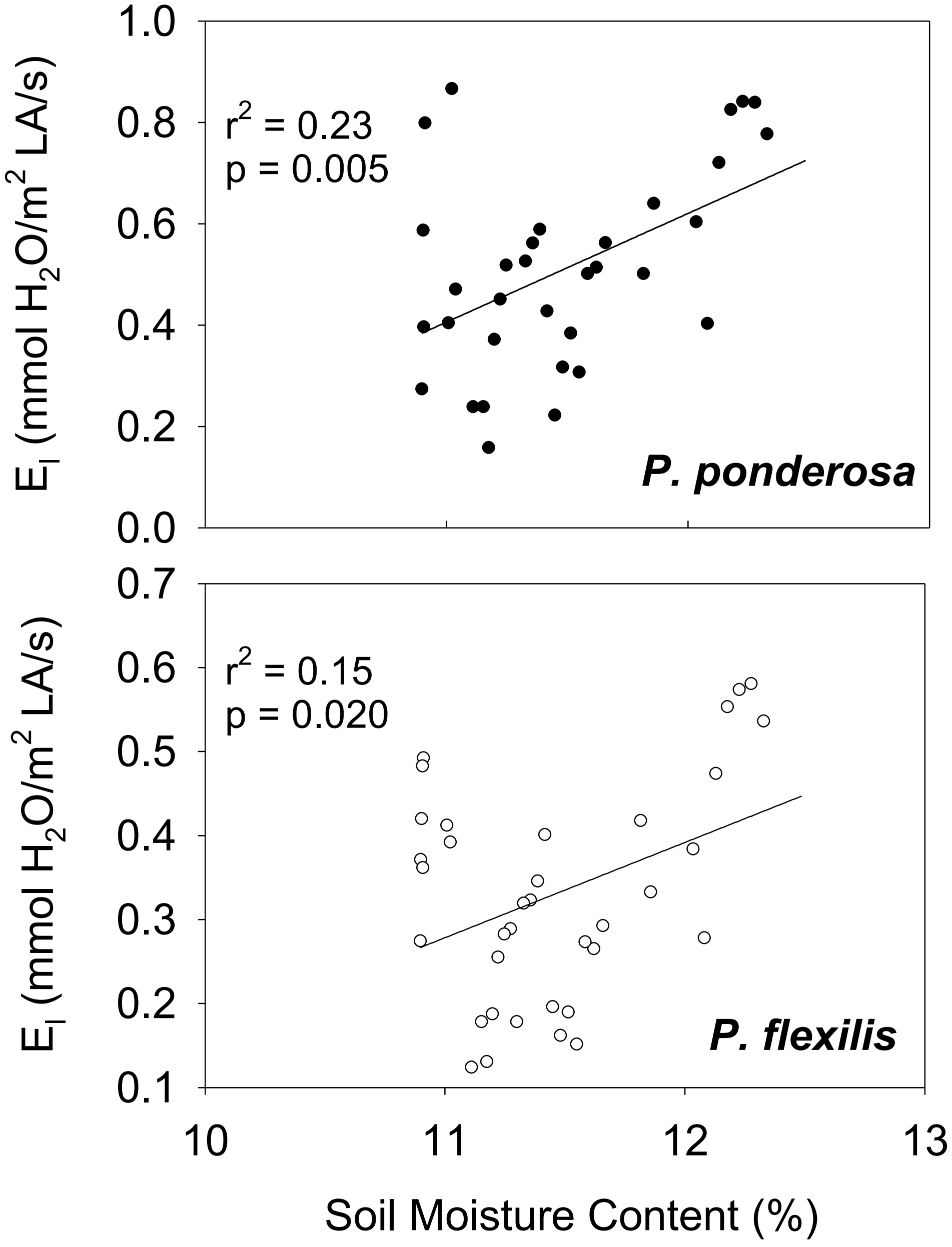

PWP
FC
SWC
Hygroscopic water
Capillary water
Gravitational water
Remaining water adheres to soil particles and is unavailable to plants
Water held in micropores
Drains out of the root zone
Available water- plant roots can absorb this
Wilting point
Field capacity
Available water for plant growth


40
30
20
10
0
Soil Water Content (%)
Field capacity
Plant available water
Permanent wilting point
sand
sandy loam
loam
silt loam
clay loam
clay
Soil texture class

Coupling to the energy budget: Transpiration

Transpiration is positively related to soil water availability…





(Fischer et al. 2003 Tree Phys.)

…and stomatal opening…

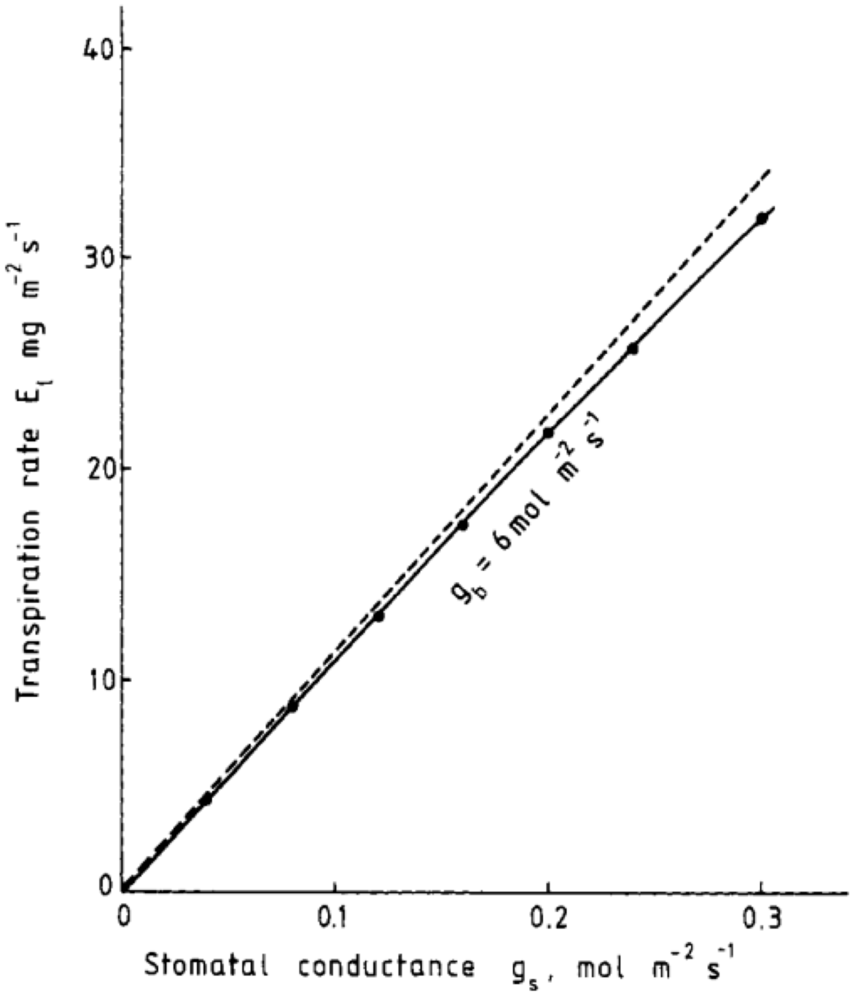
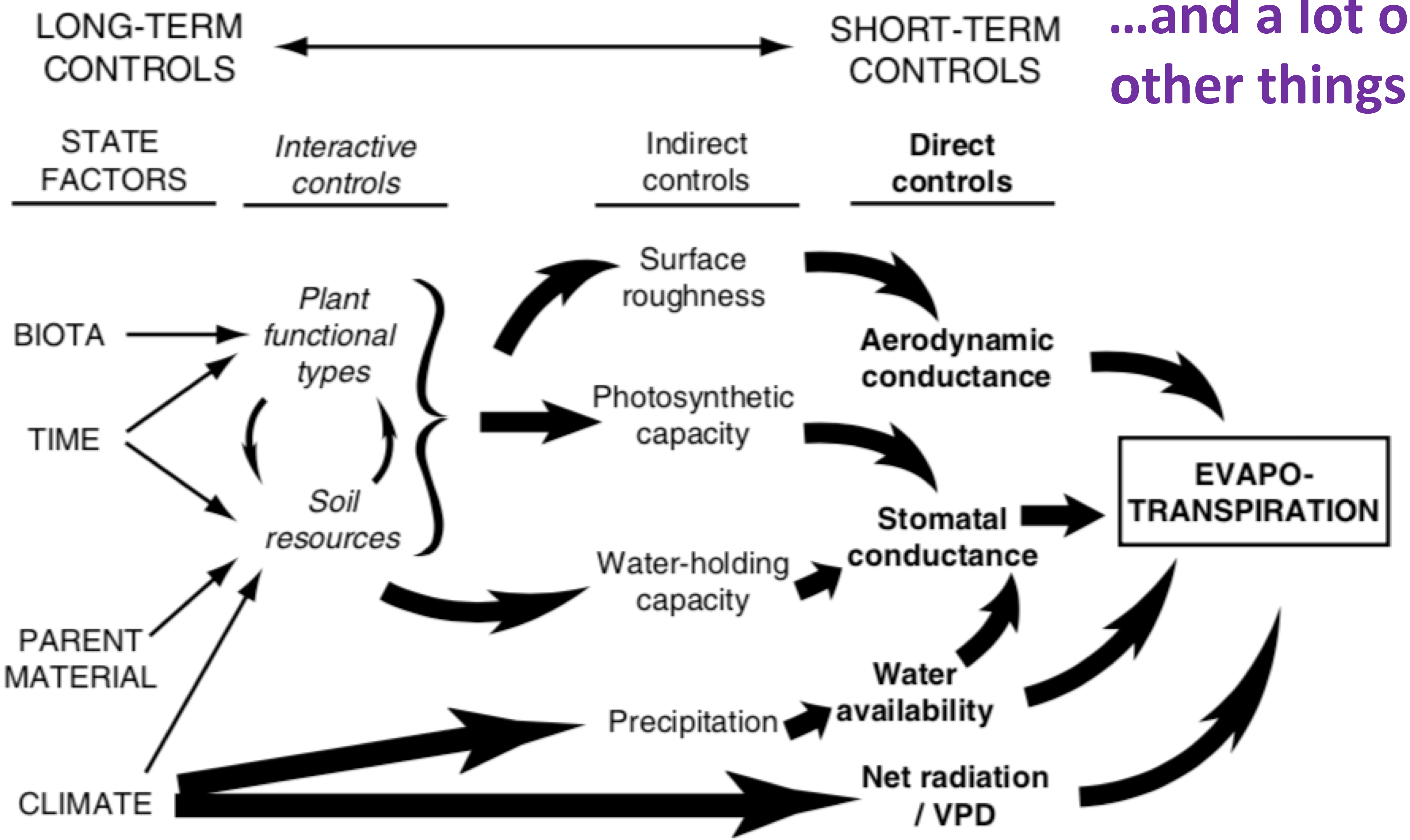
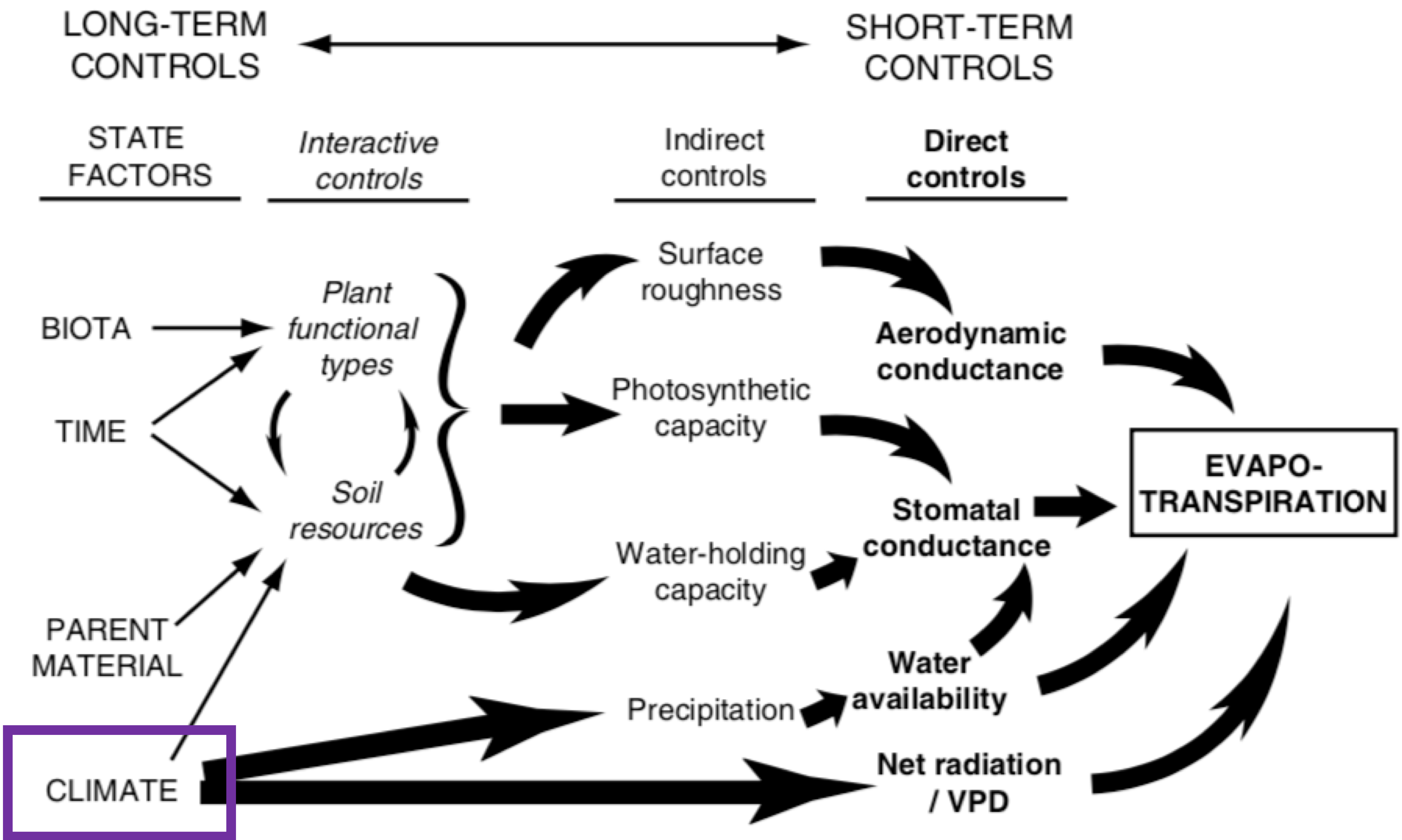


Fig. 1. The relationship between transpiration rate and stomatal conductance of a Sitka spruce shoot measured in a well-stirred cuvette with a constant saturation deficit of 6 millibars at 20°C. The dashed line is the line of zero leaf boundary layer resistance.

Jarvis and McNaughton (1986)

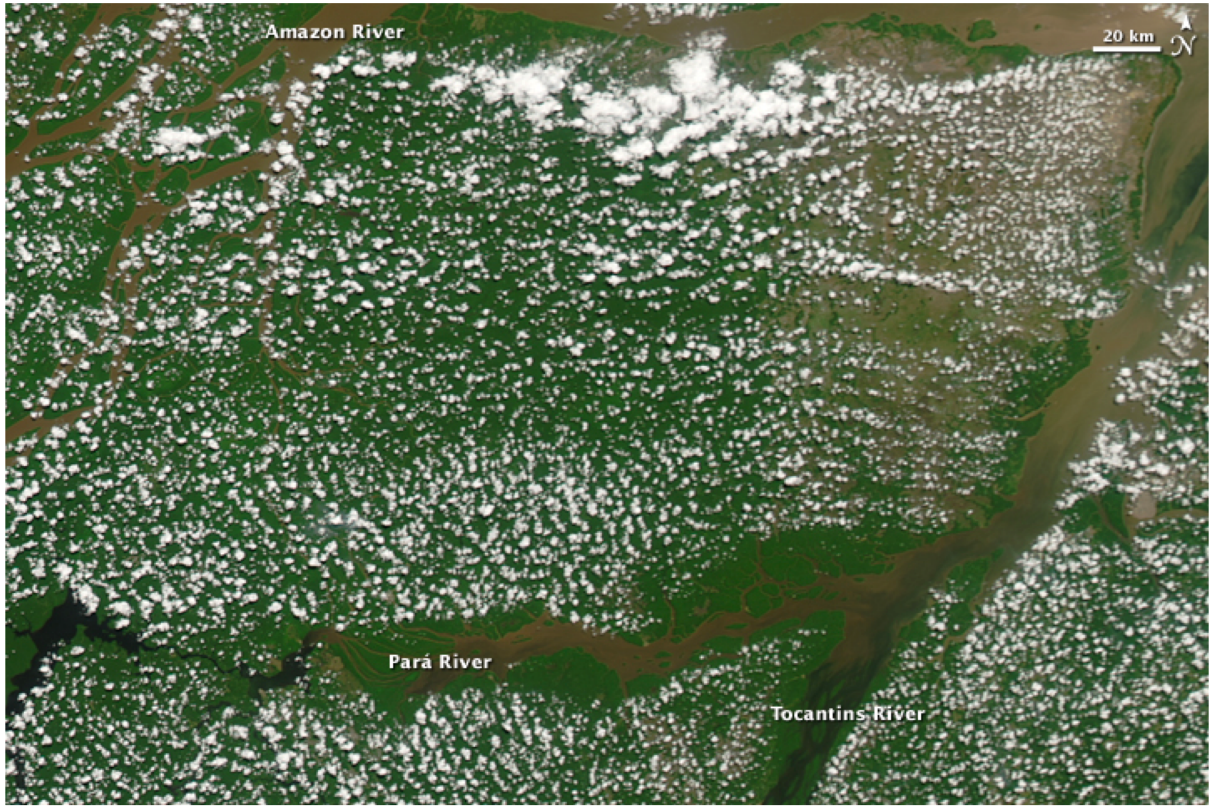


...and a lot of other things!

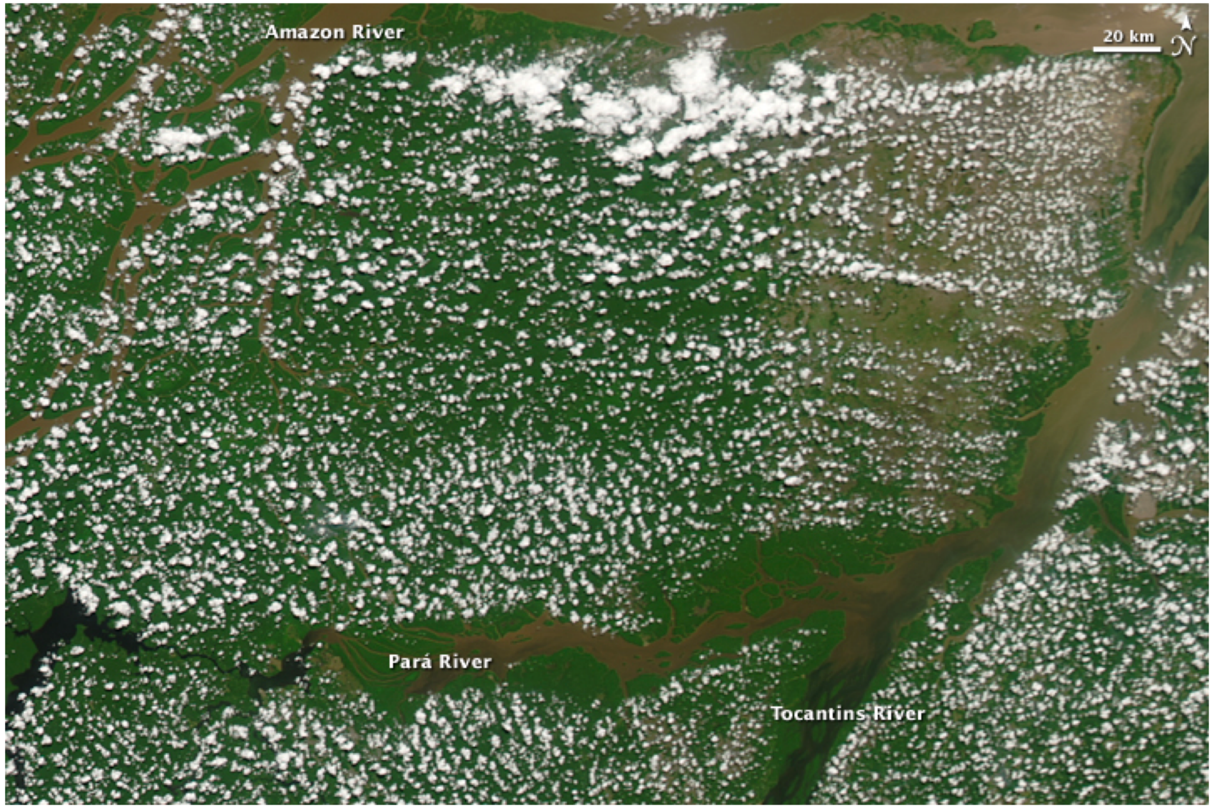

LONG-TERM CONTROLS
SHORT-TERM CONTROLS
STATE FACTORS
Interactive controls
Indirect controls
Direct controls
BIOTA
TIME
PARENT MATERIAL
CLIMATE
Plant functional types
Soil resources
Surface roughness
Photosynthetic capacity
Water-holding capacity
Precipitation
Aerodynamic conductance
Stomatal conductance
Water availability
Net radiation / VPD
EVAPO-TRANSPIRATION

How does transpiration respond to…

- Higher temperatures?
- Reduced humidity?
- Higher light?
- Higher CO_2?



Side bar: Why are there more clouds over the vegetation?



Plant water movement varies by ecosystem due to differential species responses: Isohydry

Isohydry

Isohydric species are sensitive to changes in water availability, quickly closing their stomata in response to drought

- Drought avoiders
- Maintain high Ψ

Anisohydric species tend to respond more slowly to drought

- Drought tolerators
- Tolerate low Ψ

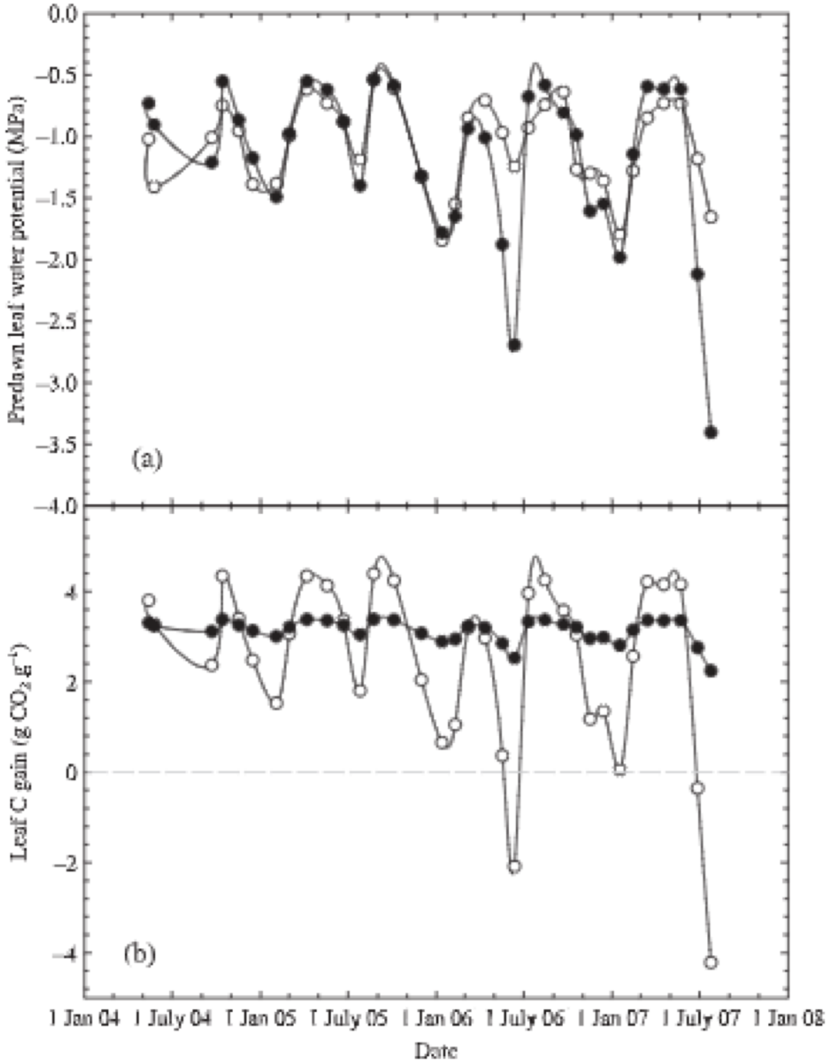
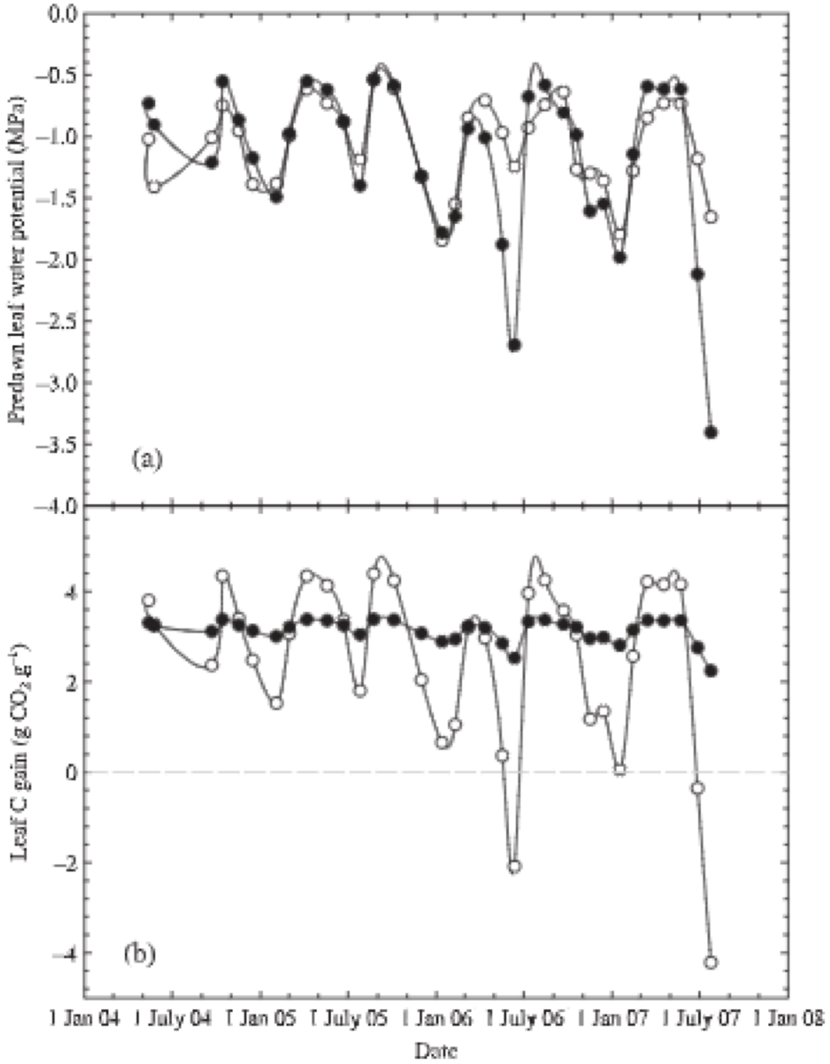


Fig. 11 (a) Three years of monthly observations of predawn water potential of piñon (open circles) and juniper (closed circles) from Mesita del Buey, Los Alamos, New Mexico. Twigs were sampled at least 20 min before sunrise and kept in plastic bags until measurement, which took place within 1 h of collection. Samples consisted of two twigs per tree and a minimum of five trees per species per time period. (b) Seasonal leaf carbon gain for piñon and juniper modeled using Barnes (1986) and the predawn water potentials from (a).

McDowell et al. (2008)



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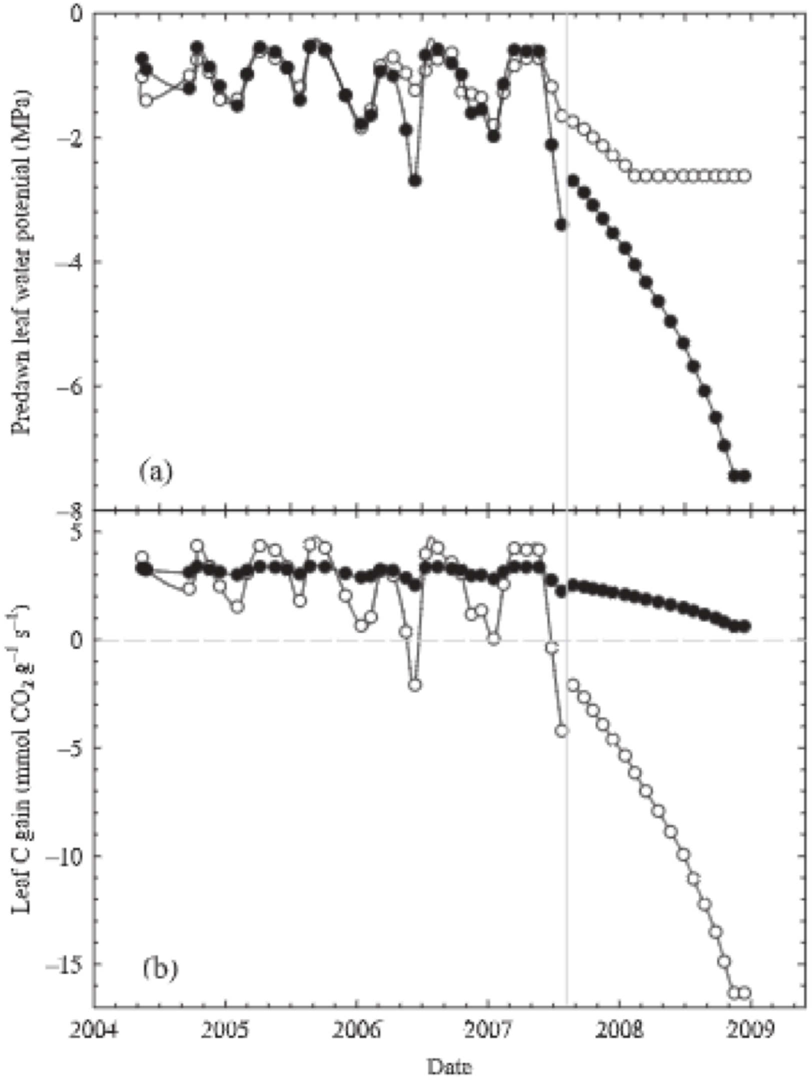


Fig. 13 (a) To the left of the gray bar are 3 yr of monthly observations of predawn water potential for piñon (open circles) and juniper (closed circles) as from Fig. 11(a), and to the right of the gray baris a simulation of the water potential response to a severe drought. A description of the simulation is given in the text. (b) Seasonal leaf carbon gain modeled as per Fig. 11(b) using values of juniper predawn water potential as observed between 2004 and 2007 (left of gray bar) or simulated for 2007–2009 (right of gray bar).

McDowell et al. (2008)

How would isohydry strategy influence the water cycle?

The Water Budget

Precipitation +/- Storage = Evapotranspiration + Runoff

The Water Budget

Precipitation +/- Storage = Evapotranspiration + Runoff

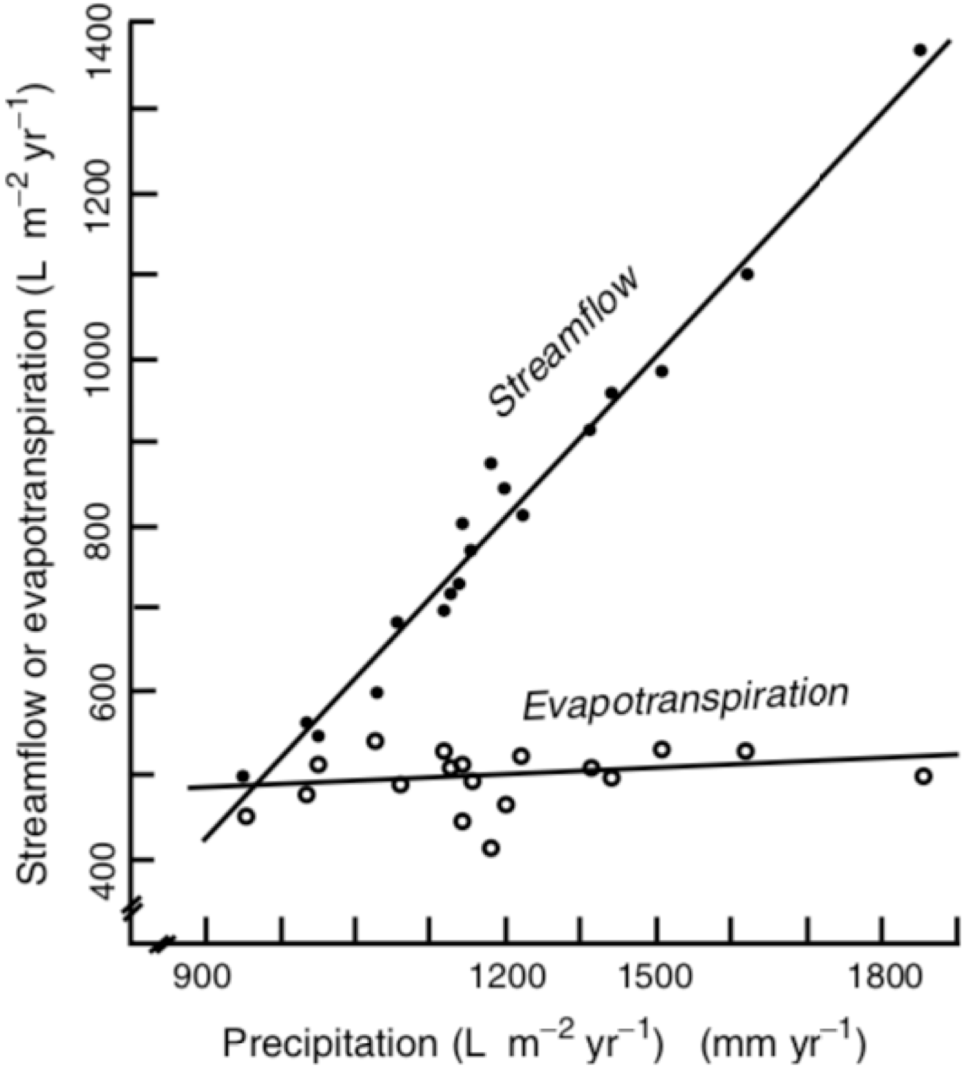
P $\pm$ ΔS = E + R

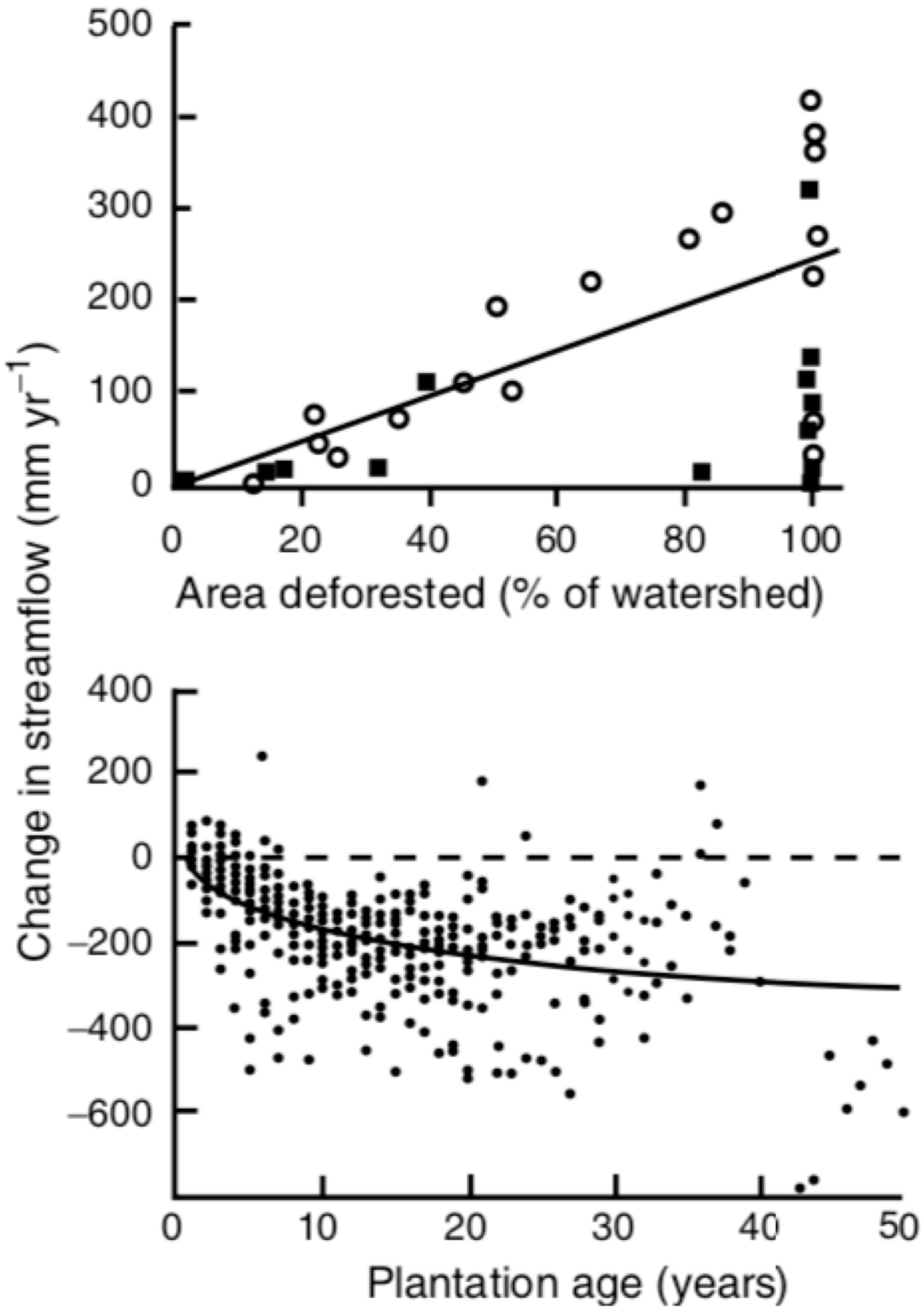
P = Precipitation

S = Storage

E = Evapotranspiration

R = Runoff (streamflow)





What’s happening here?

Final point: you cannot disentangle energy balance from water balance

Final point: you cannot disentangle energy balance from water balance, the combination determines the climate of an ecosystem