

# Energy and Water Balance

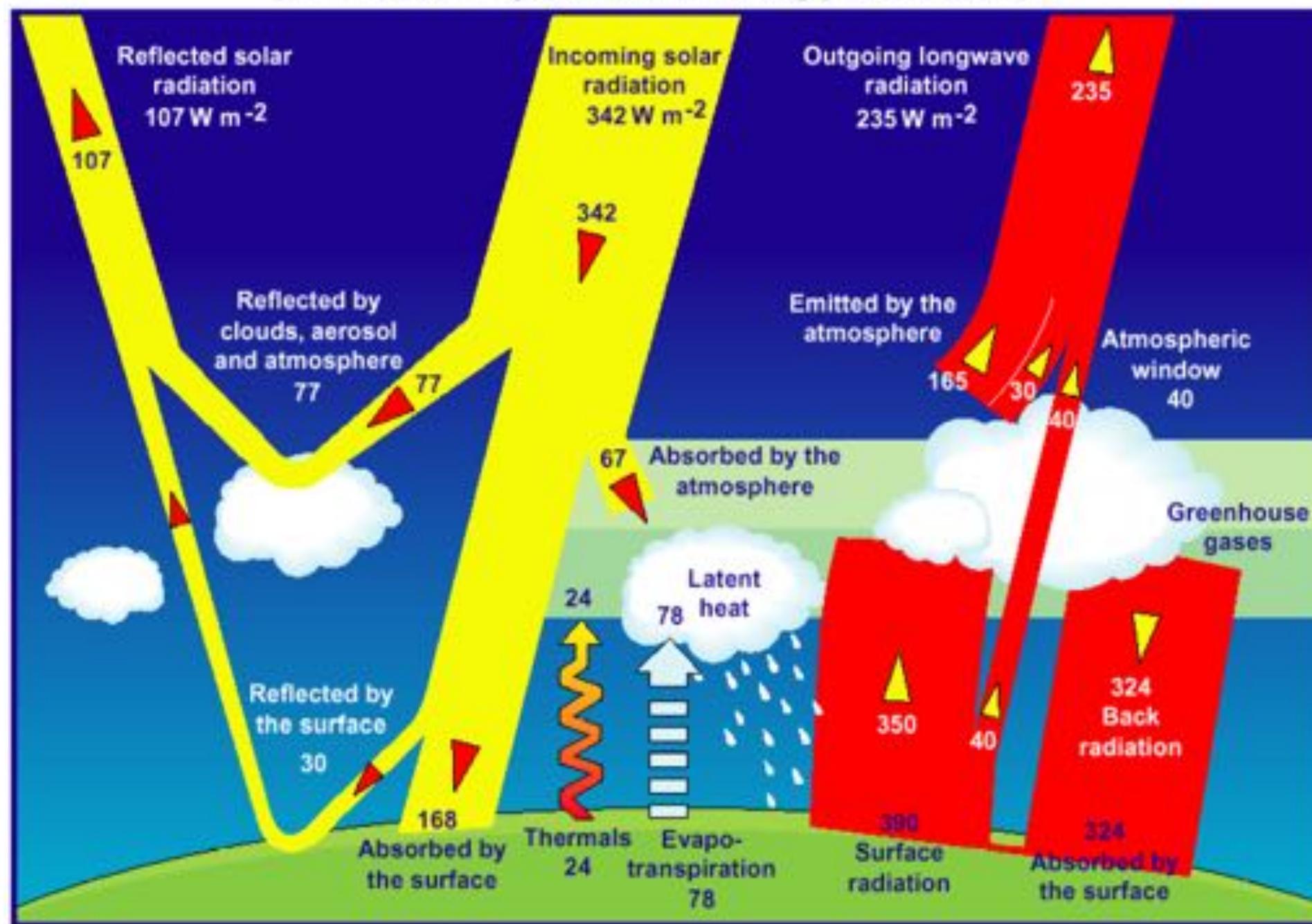
September 17, 2019

Pre-class ice breaker → write down your answer

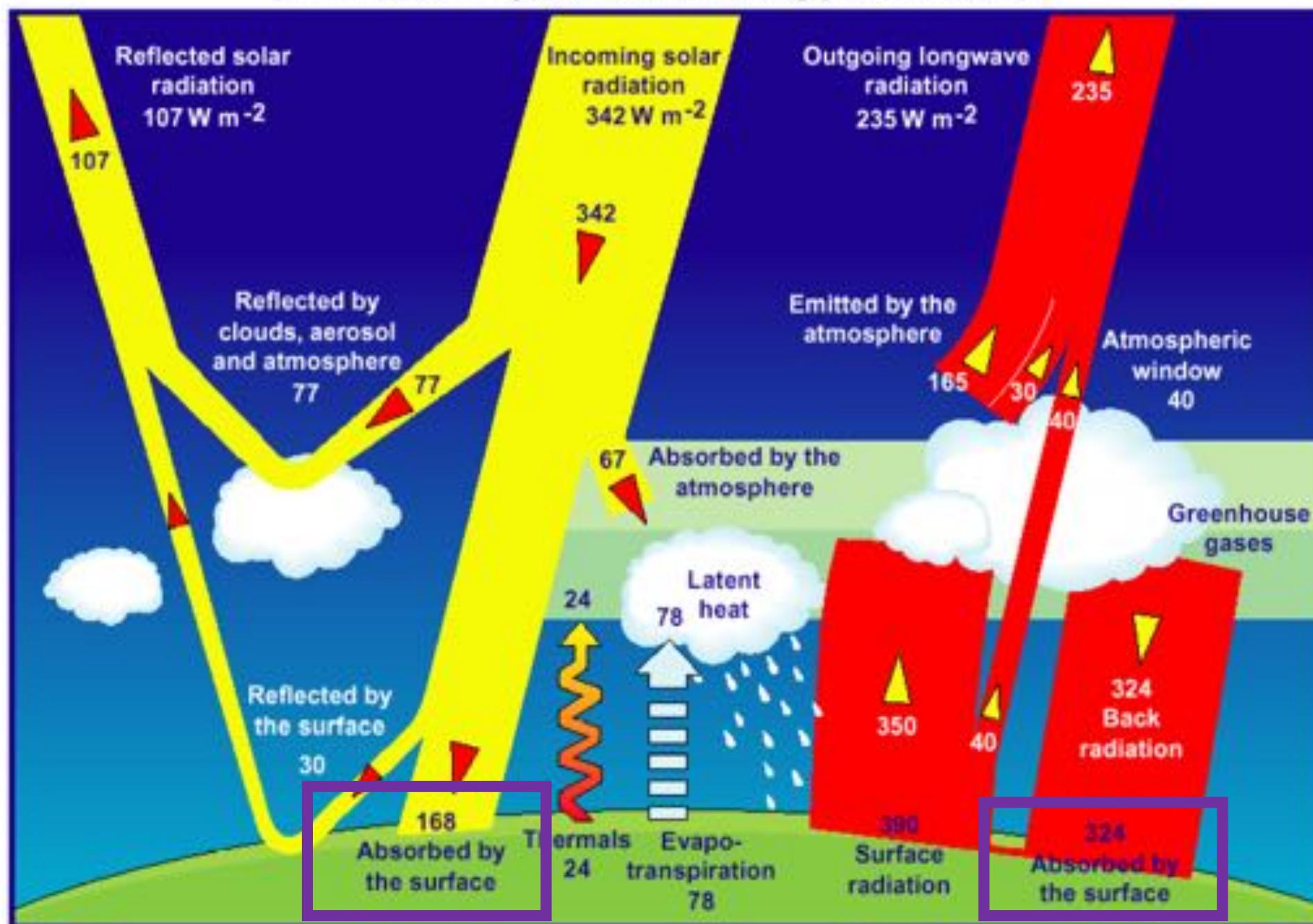
- a. Are urban areas cooler than close-by rural areas? Why or why not?
- b. Why are polar areas warming at a faster rate than equatorial areas?
- c. Why are greenhouse gases warming the Earth?

# The surface energy budget

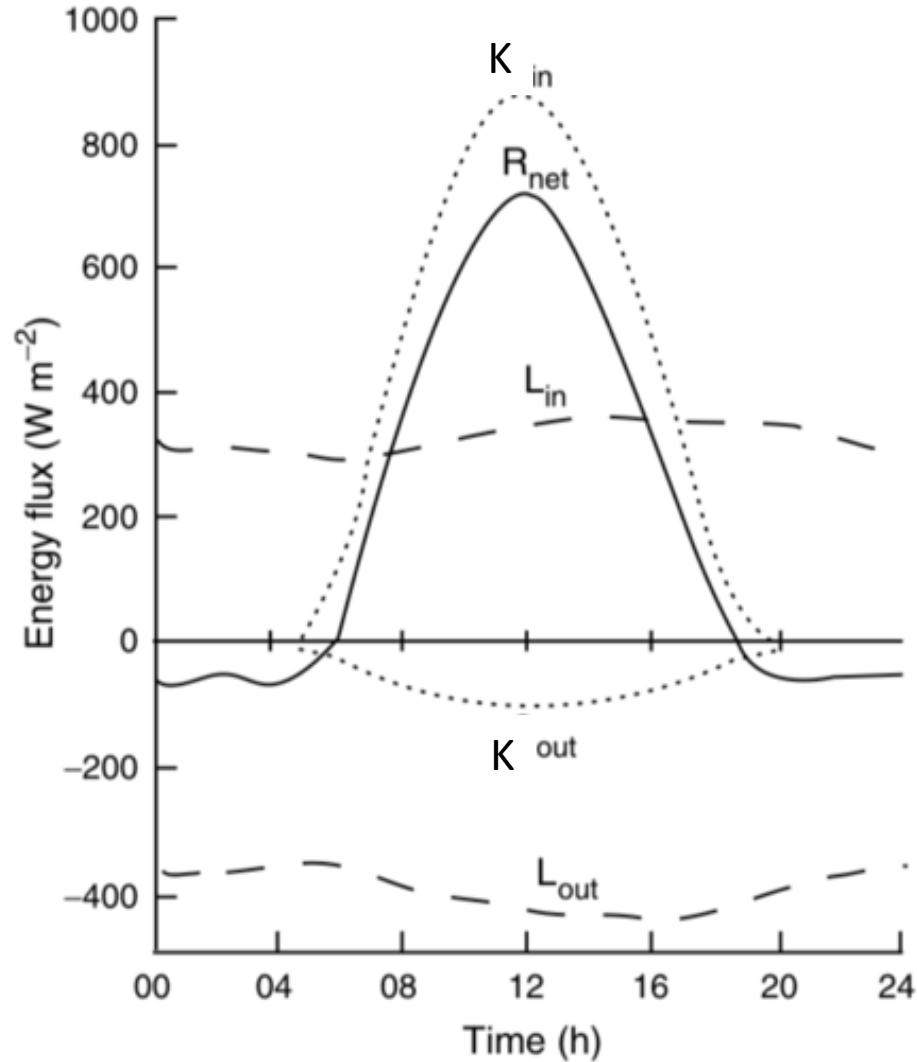
# Climate System Energy Balance



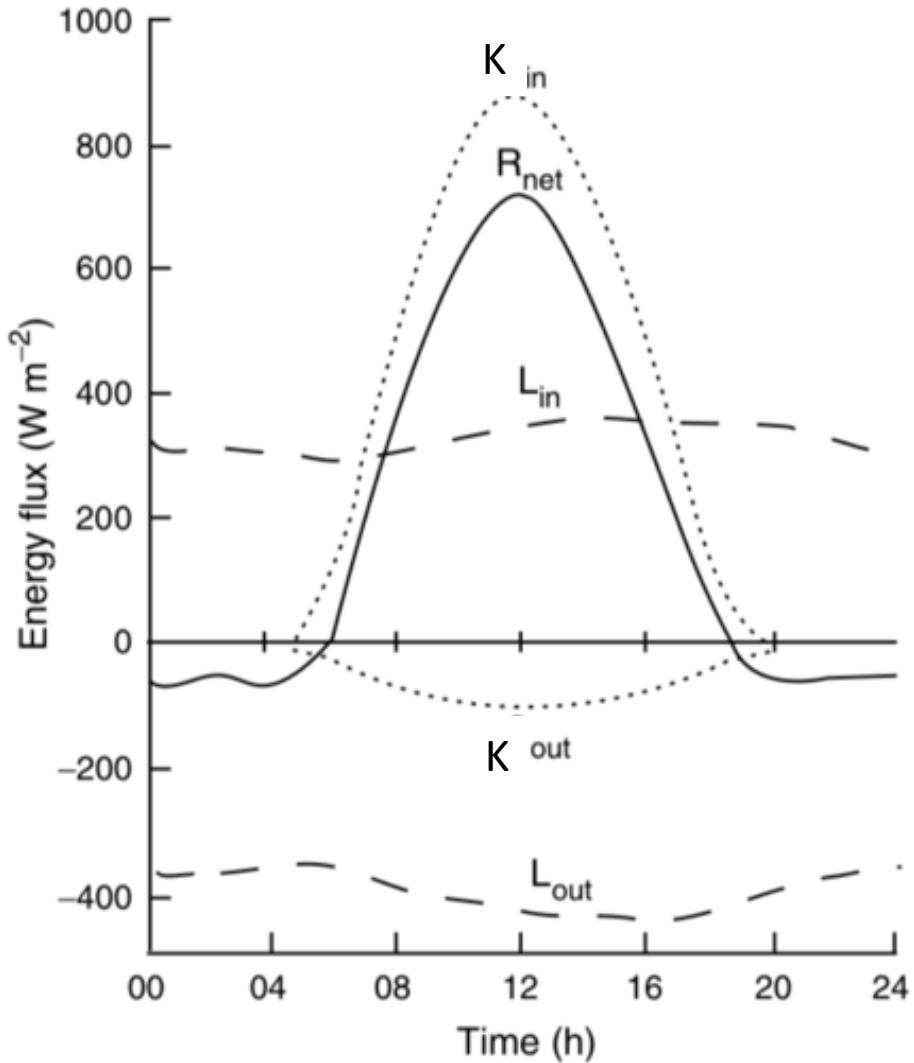
# Climate System Energy Balance



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

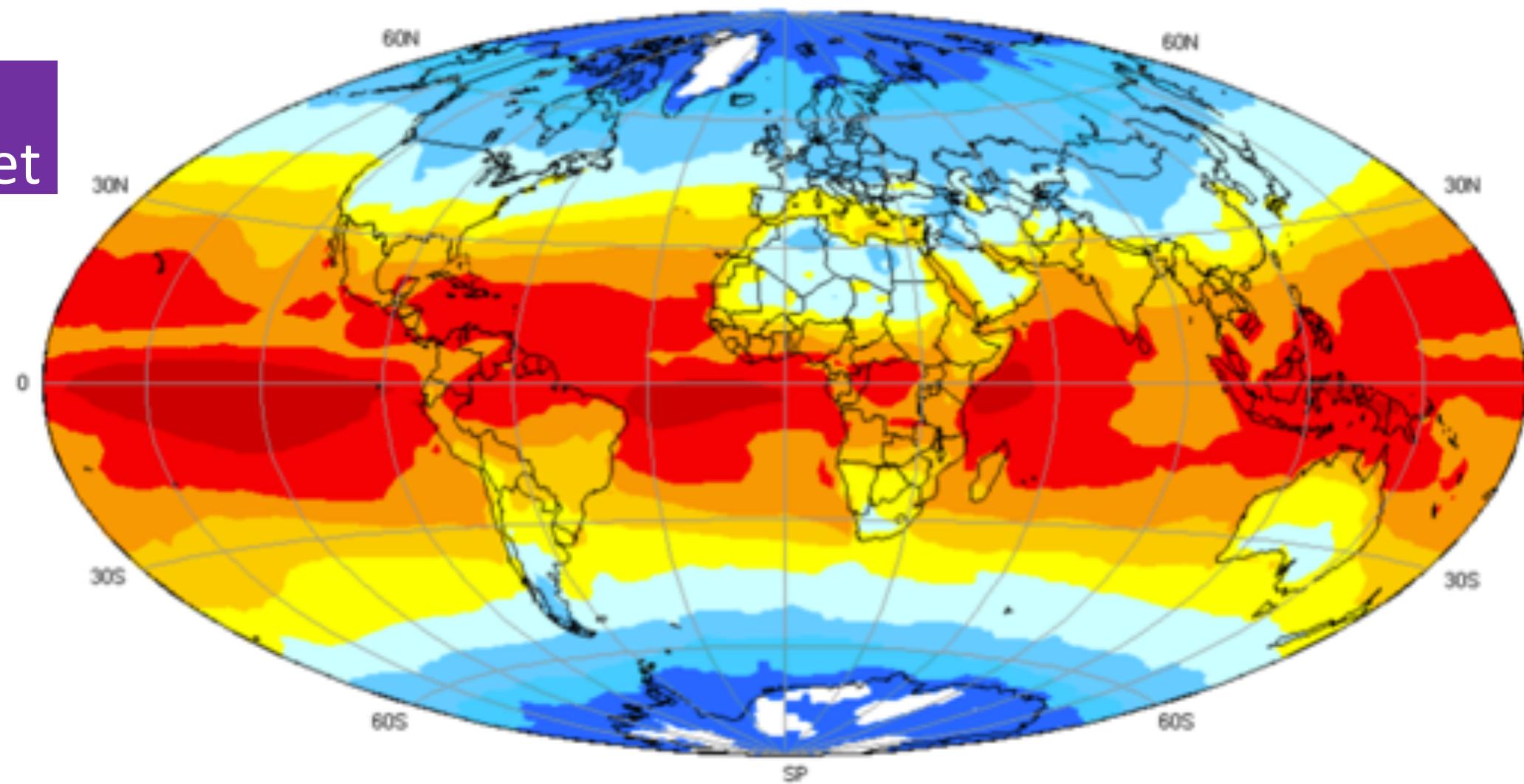


The net radiation absorbed by a surface is a sum of ingoing and outgoing radiation



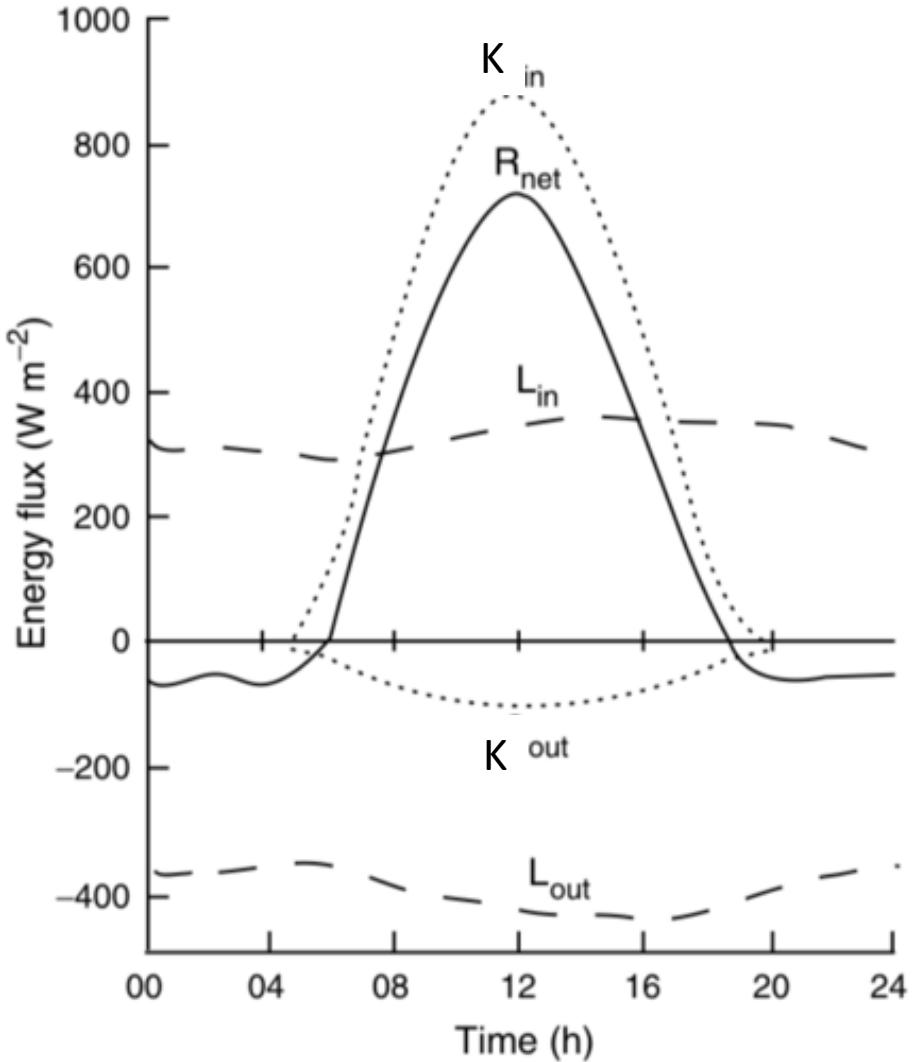
$$R_{\text{net}} = (K_{\text{in}} - K_{\text{out}}) + (L_{\text{in}} - L_{\text{out}})$$

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 $R_{\text{net}}$ 

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

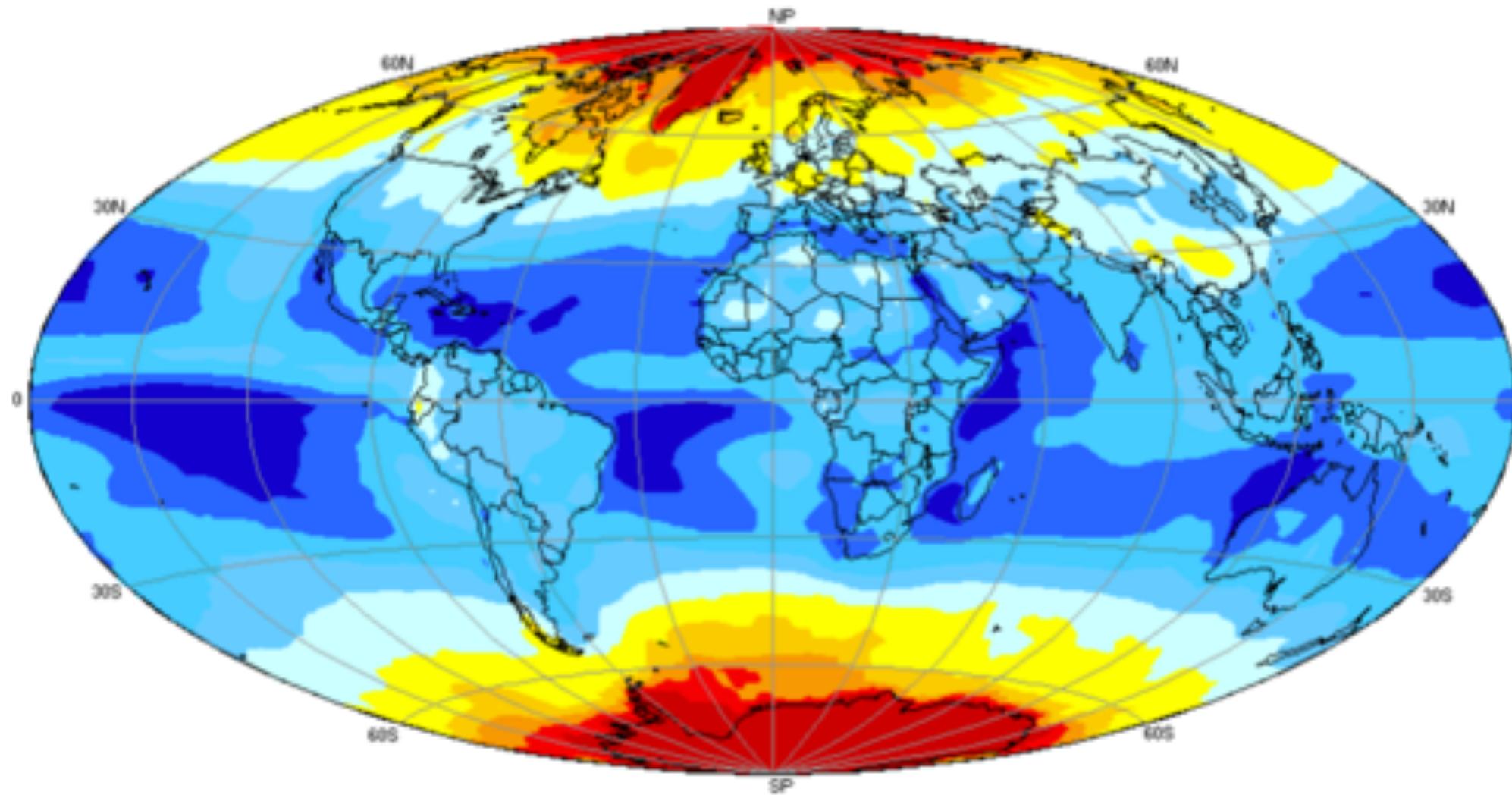
# Shortwave ( $K$ ) depends on the albedo ( $\alpha$ )



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

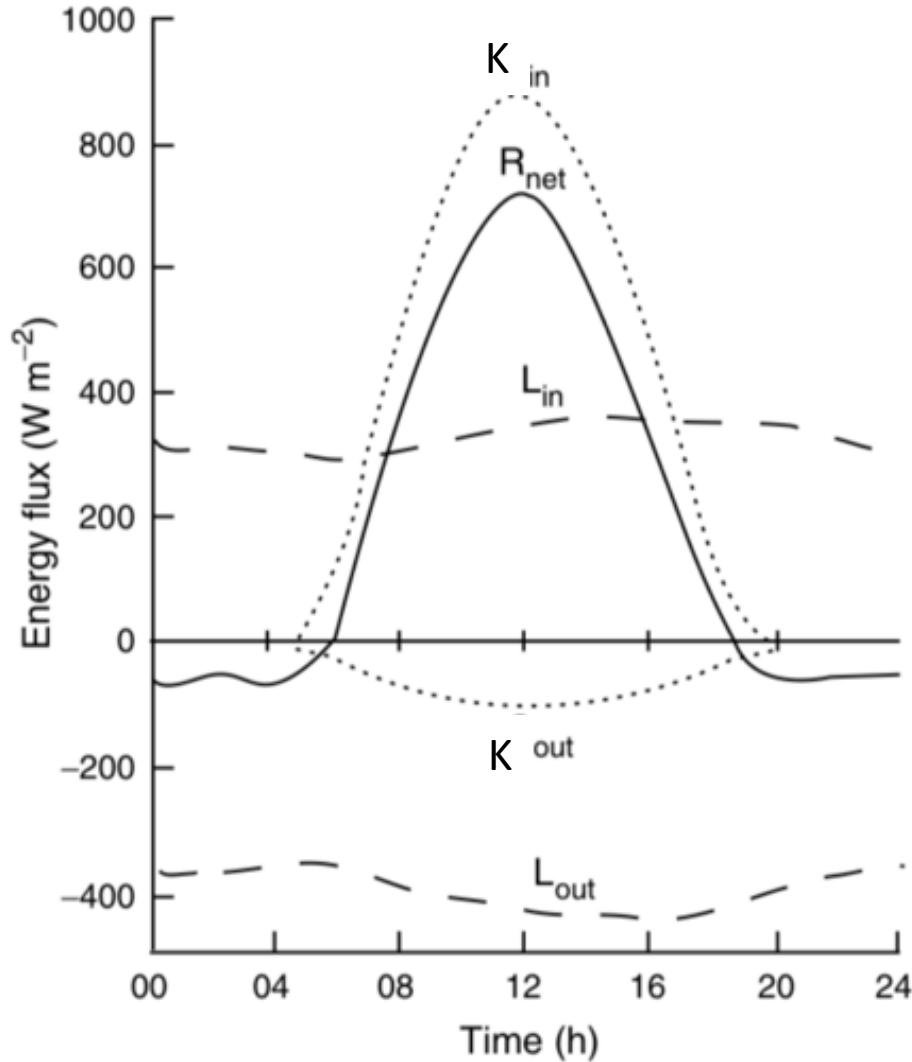


$\alpha$



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

# Longwave (L) depends on temperature (T)



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

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

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

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

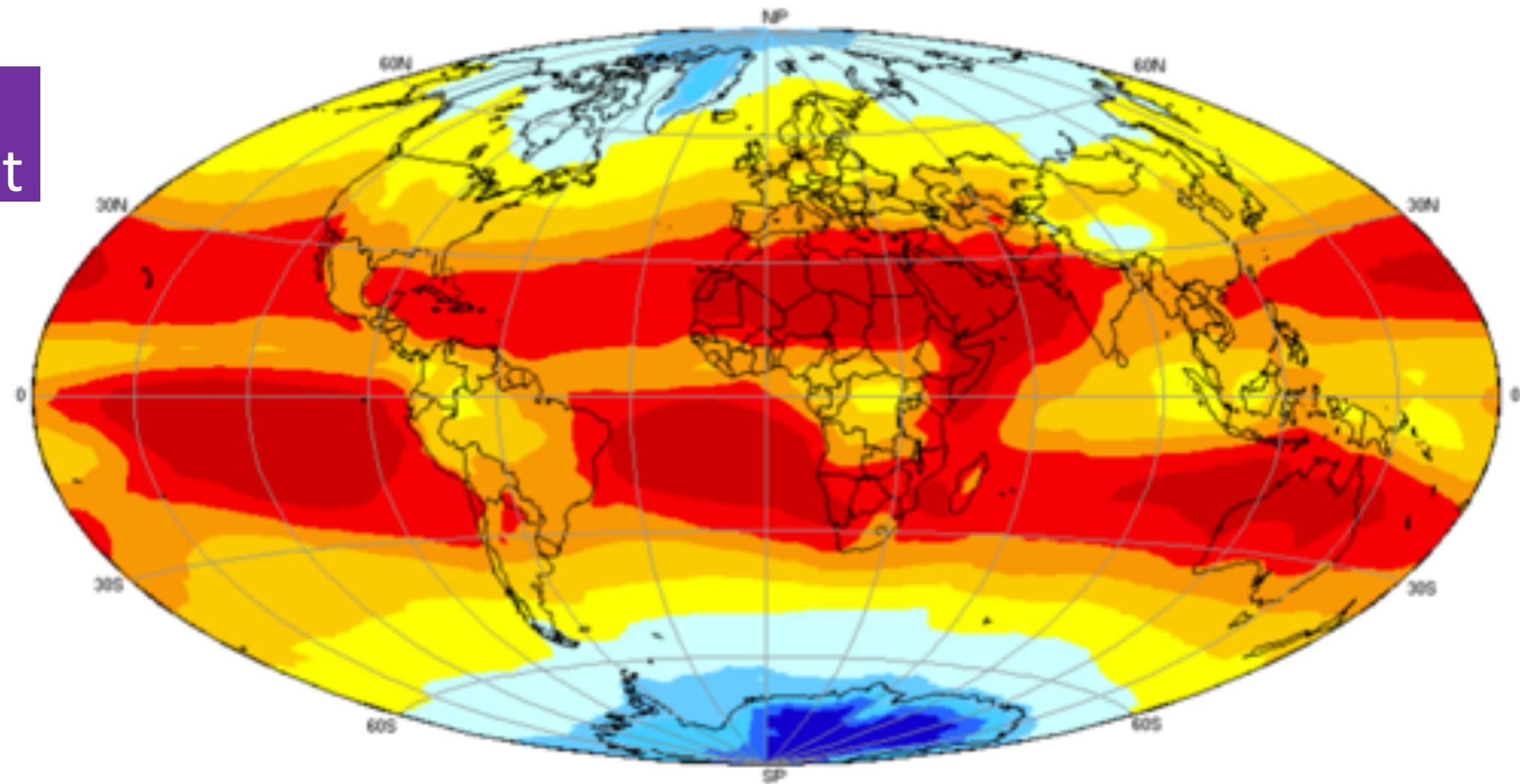
$$L_{out} = \sigma \varepsilon_{surface} T_{surface}^4$$

$\varepsilon$  = emissivity

$\sigma$  = Stefan-Boltzmann constant



L<sub>out</sub>



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 ( $R_{\text{net}}$ ) is partitioned into different fluxes at the surface

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

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

Total radiation absorbed by the surface

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

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

Sensible heat flux (heats air)

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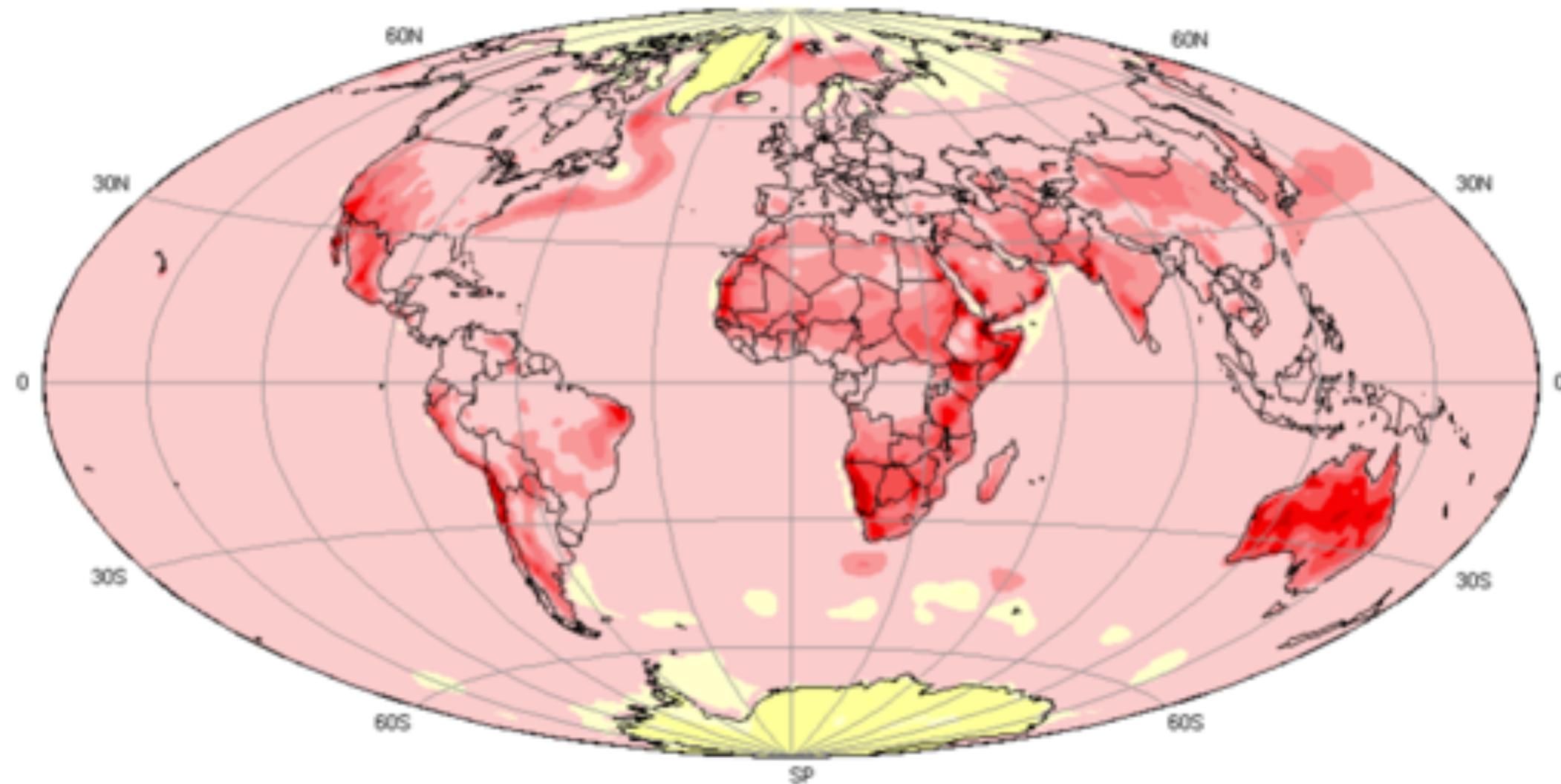


Sensible heat flux [ $\text{W}/\text{m}^{**2}$ ]

Source: ERA-40

Statistics: mean = -16.18, rms = 23.74, std = 17.37, min = -159.11, max = 53.40

H



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

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

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

Latent heat flux (water evaporation; no T change)

L = latent heat of vaporization (constant)

E = evapotranspiration

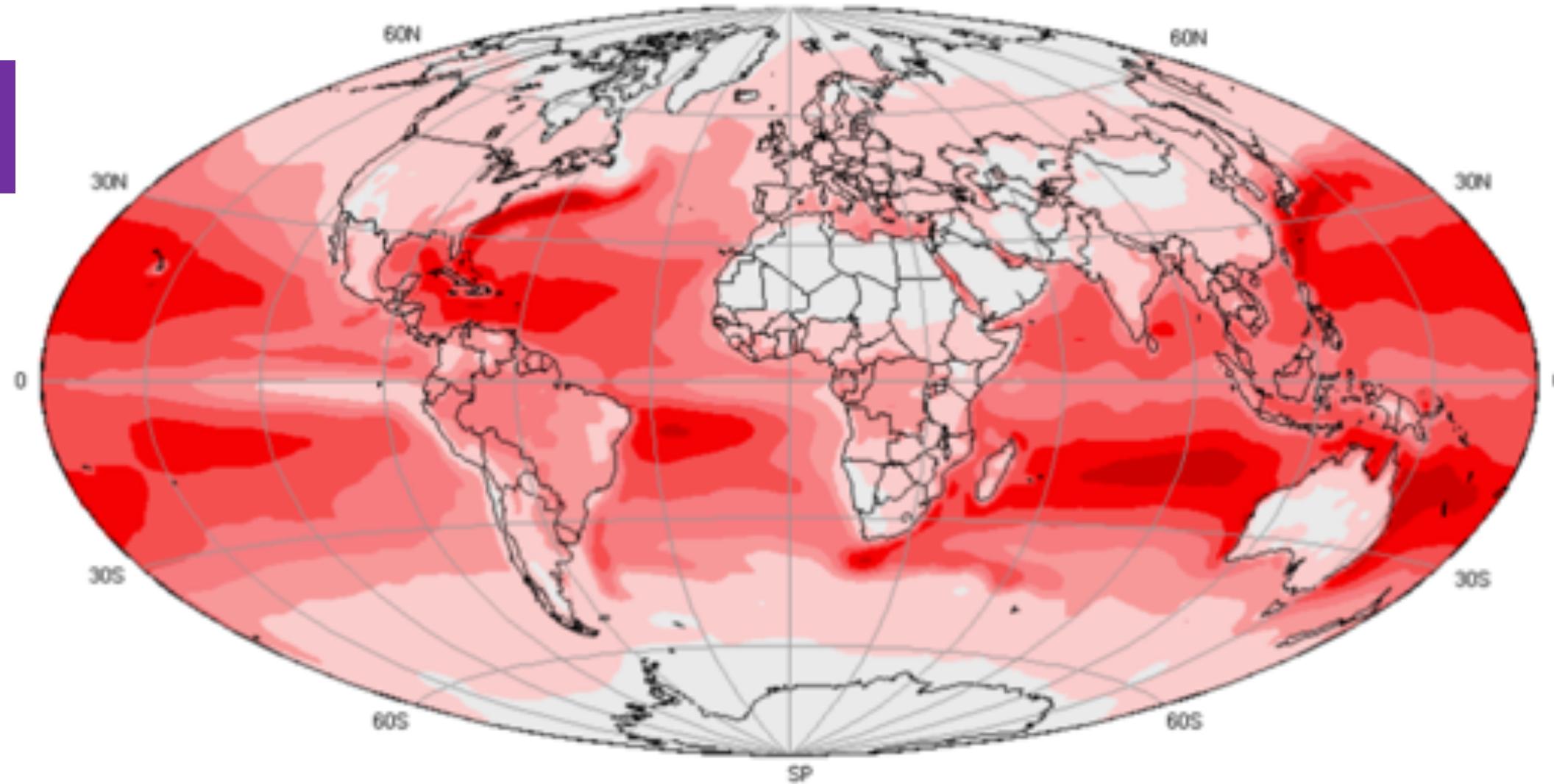
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Source: ERA-40

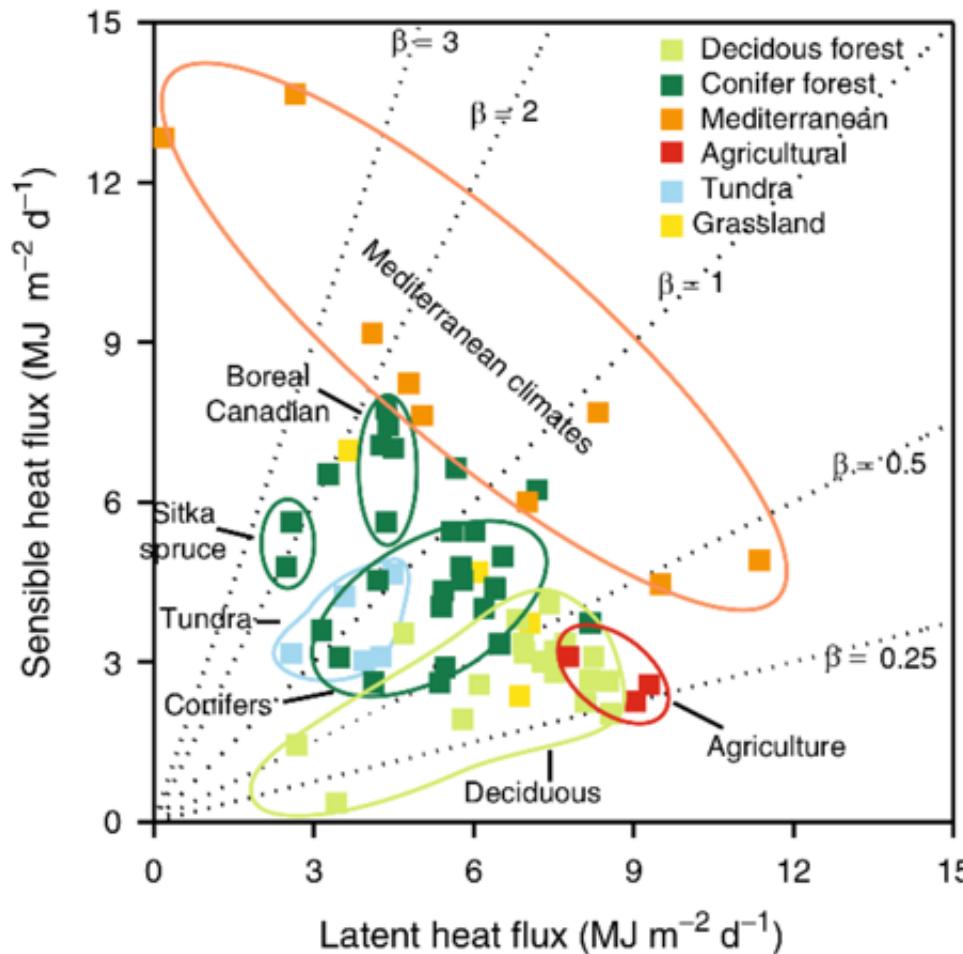
Statistics: mean = -83.64, rms = 97.97, std = 51.00, min = -222.08, max = 9.73

LE



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

# Bowen ratio - ratio of sensible (H) to latent (LE) heat flux ( $H/LE$ )

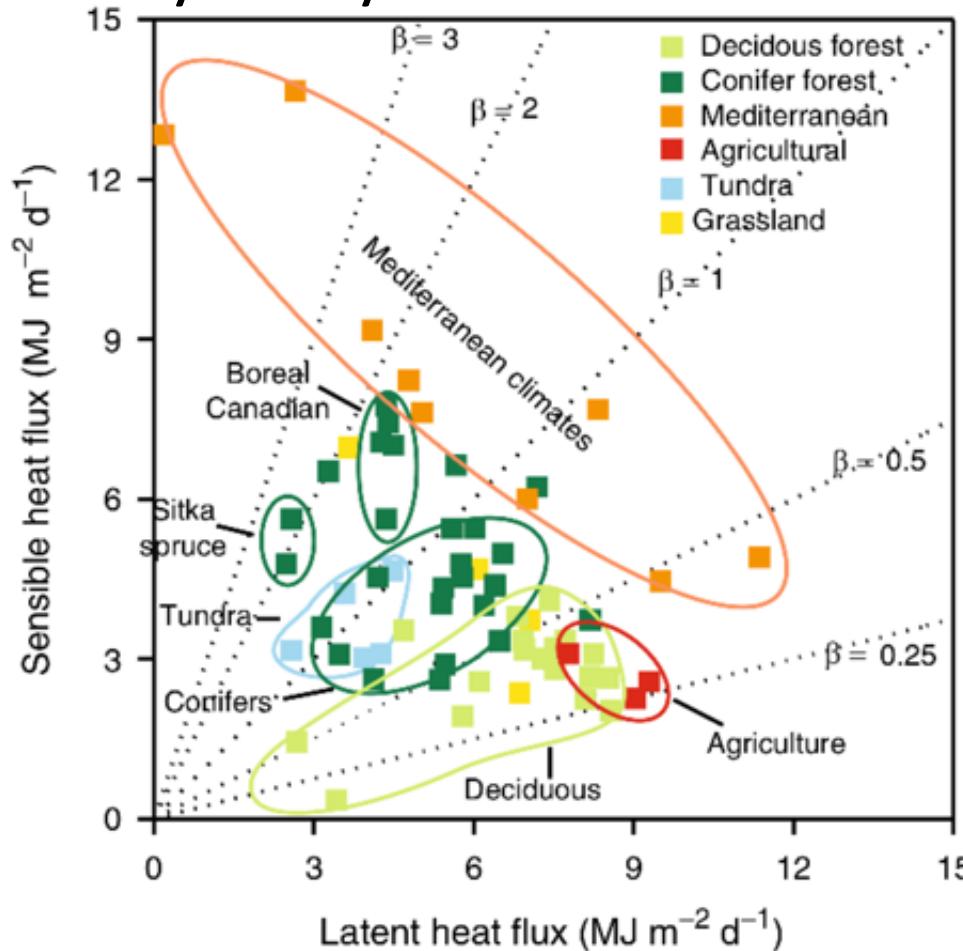


What do you notice  
from this figure?

# Bowen ratio - ratio of sensible (H) to latent (LE) heat flux ( $H/LE$ )

Low transpiration/

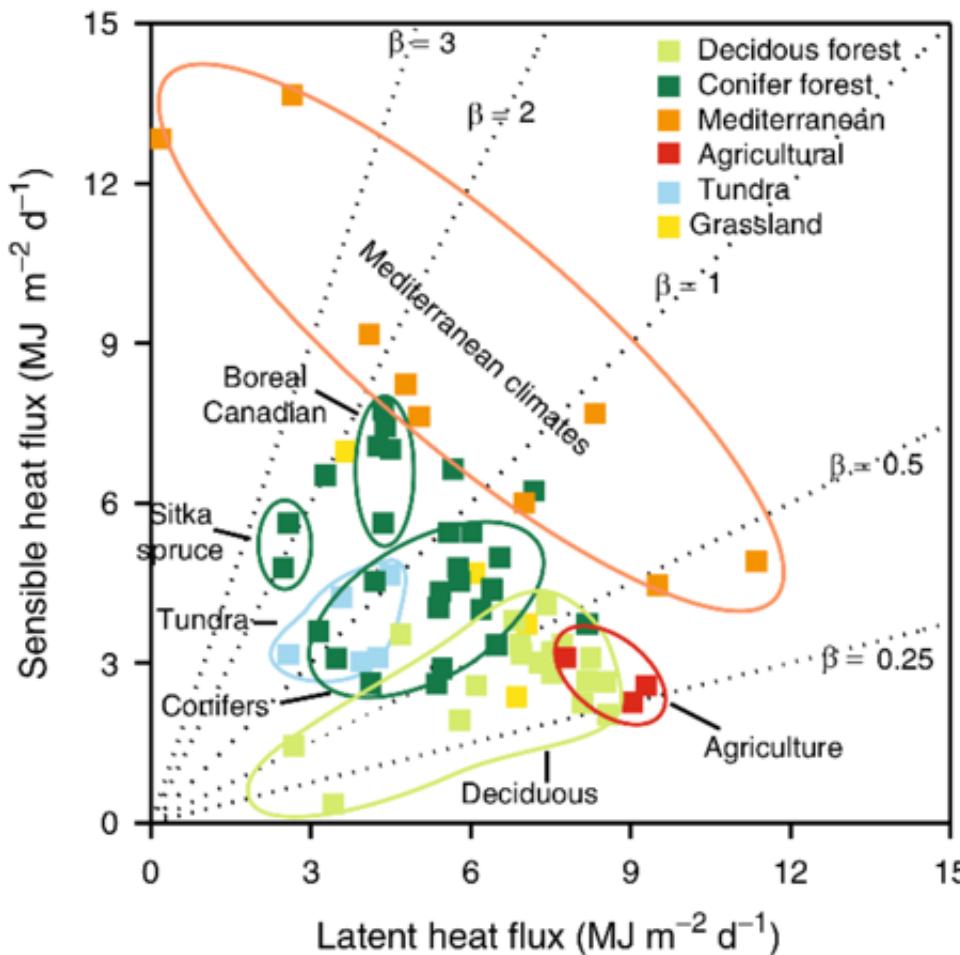
Dry ecosystems



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 ( $R_{\text{net}}$ ) is partitioned into different fluxes at the surface

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

Ground heat flux (heats ground; typically small)

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

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

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?

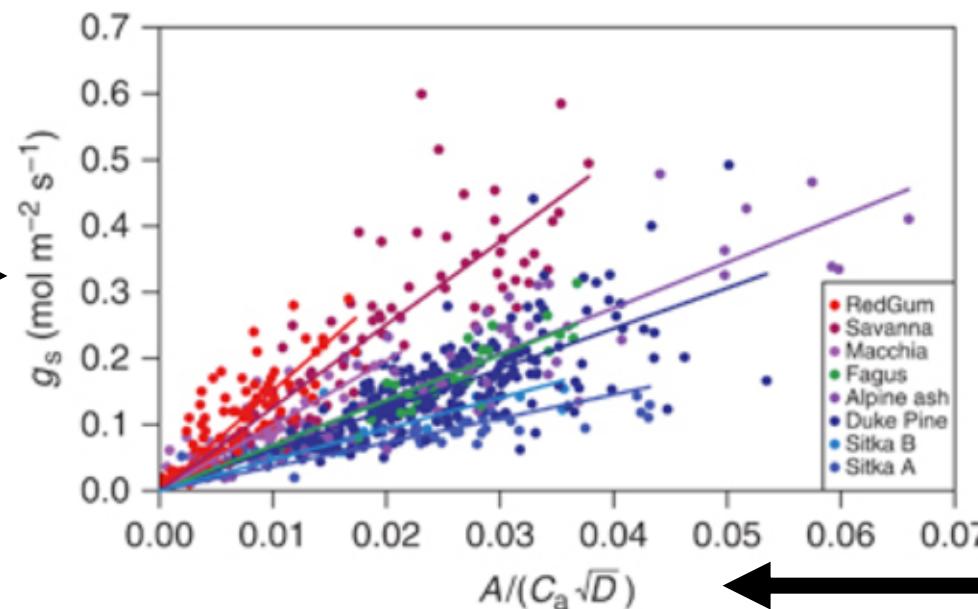
# Surface energy budget recap

- 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!

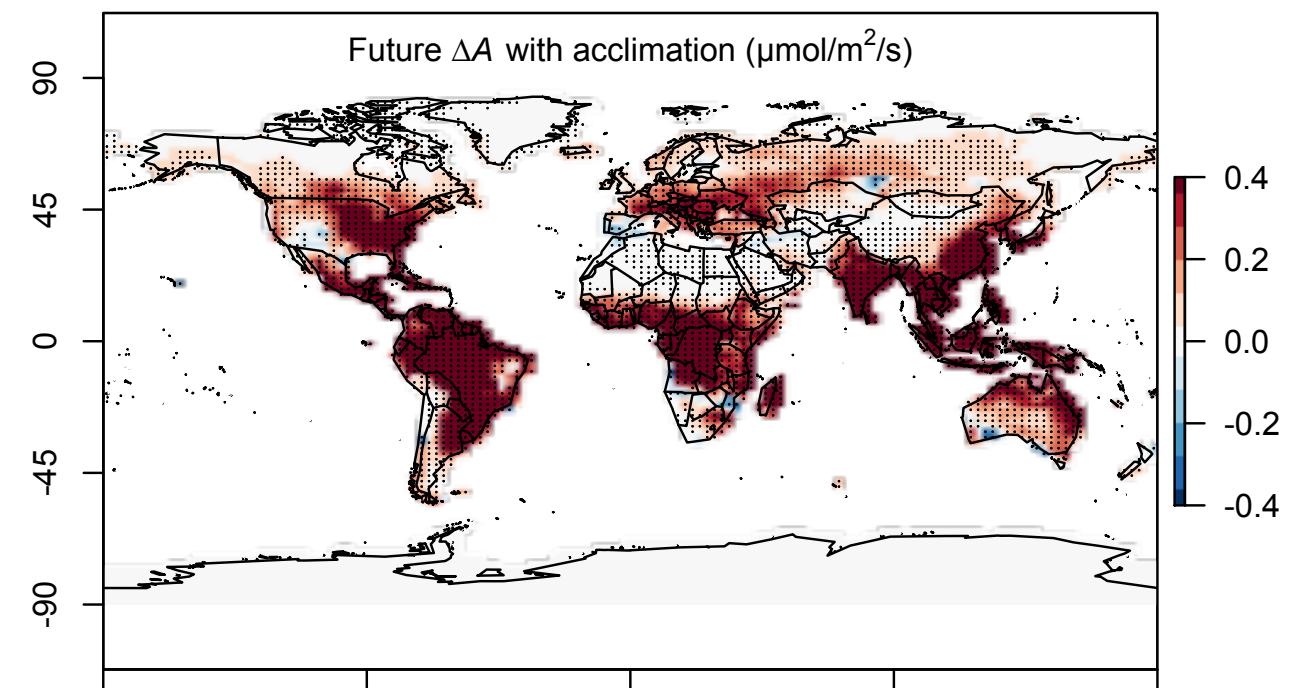
- Idea: open up stomata to crank up photosynthesis to increase carbon uptake
- Would this impact climate?

Openness of  
stomata

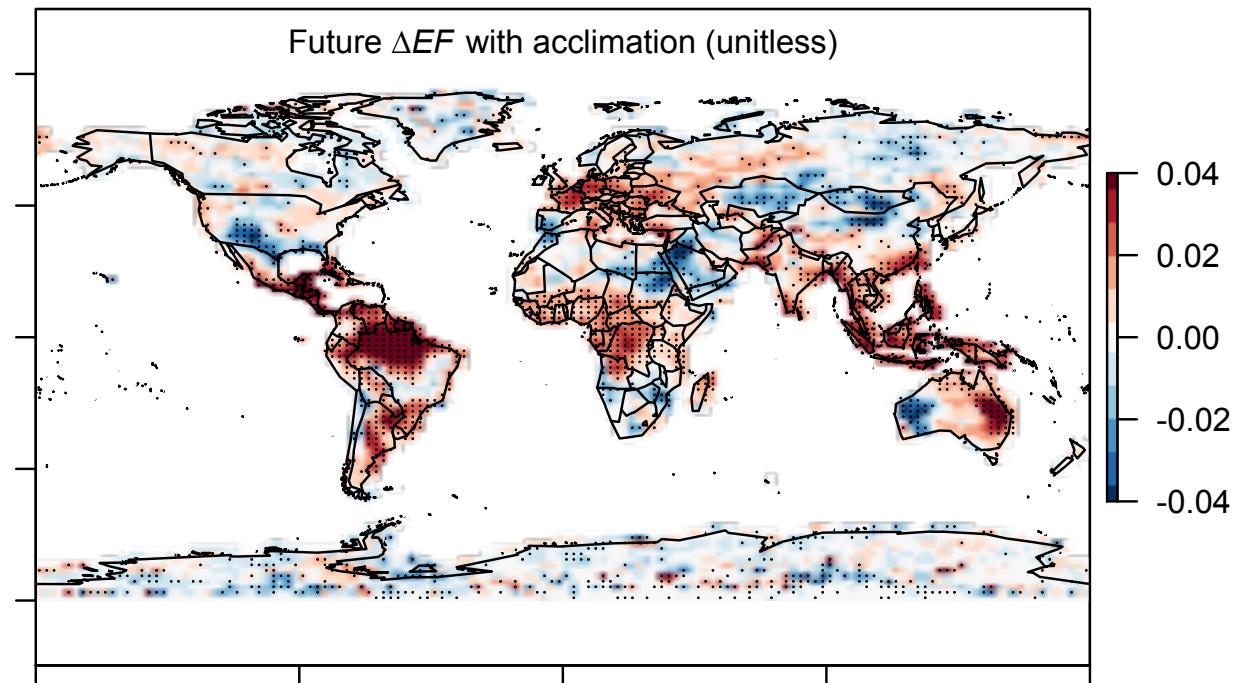
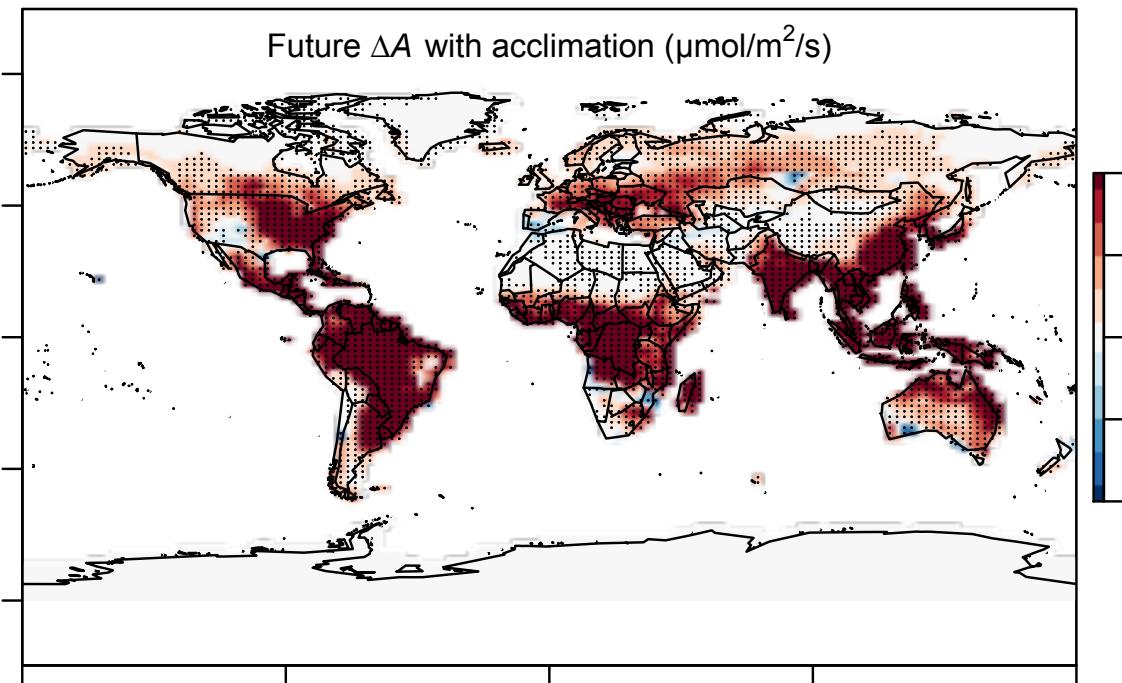


Photosynthesis

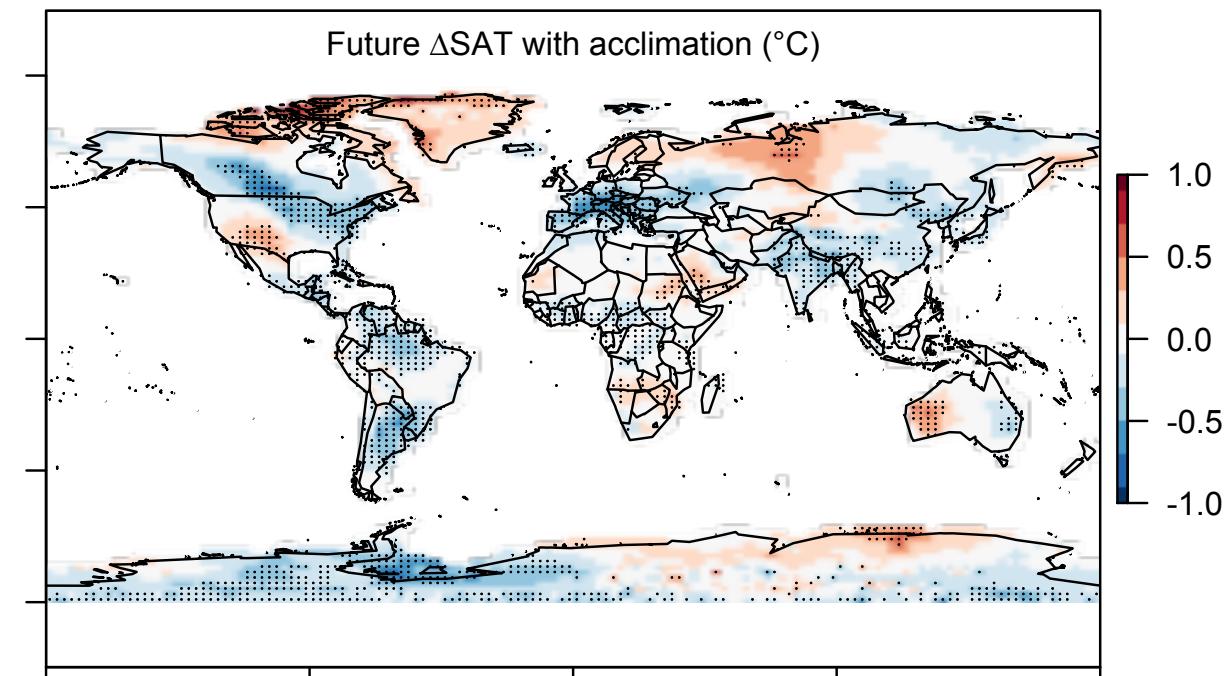
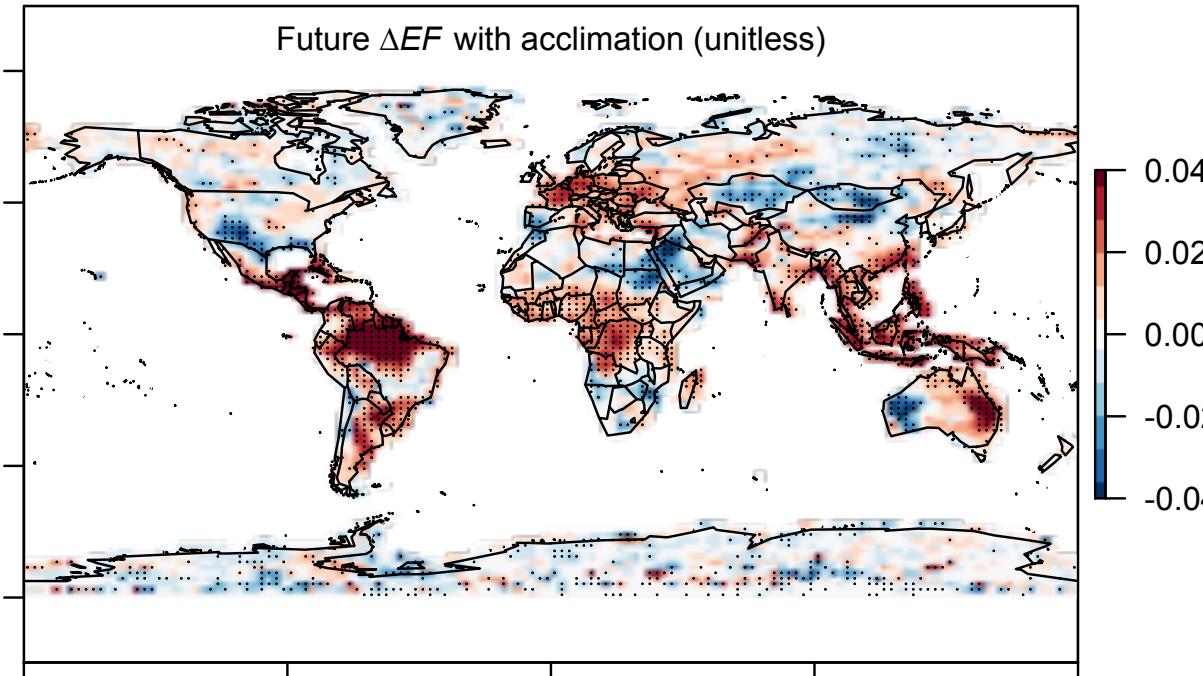
# Higher photosynthesis



Higher photosynthesis → More latent heat flux



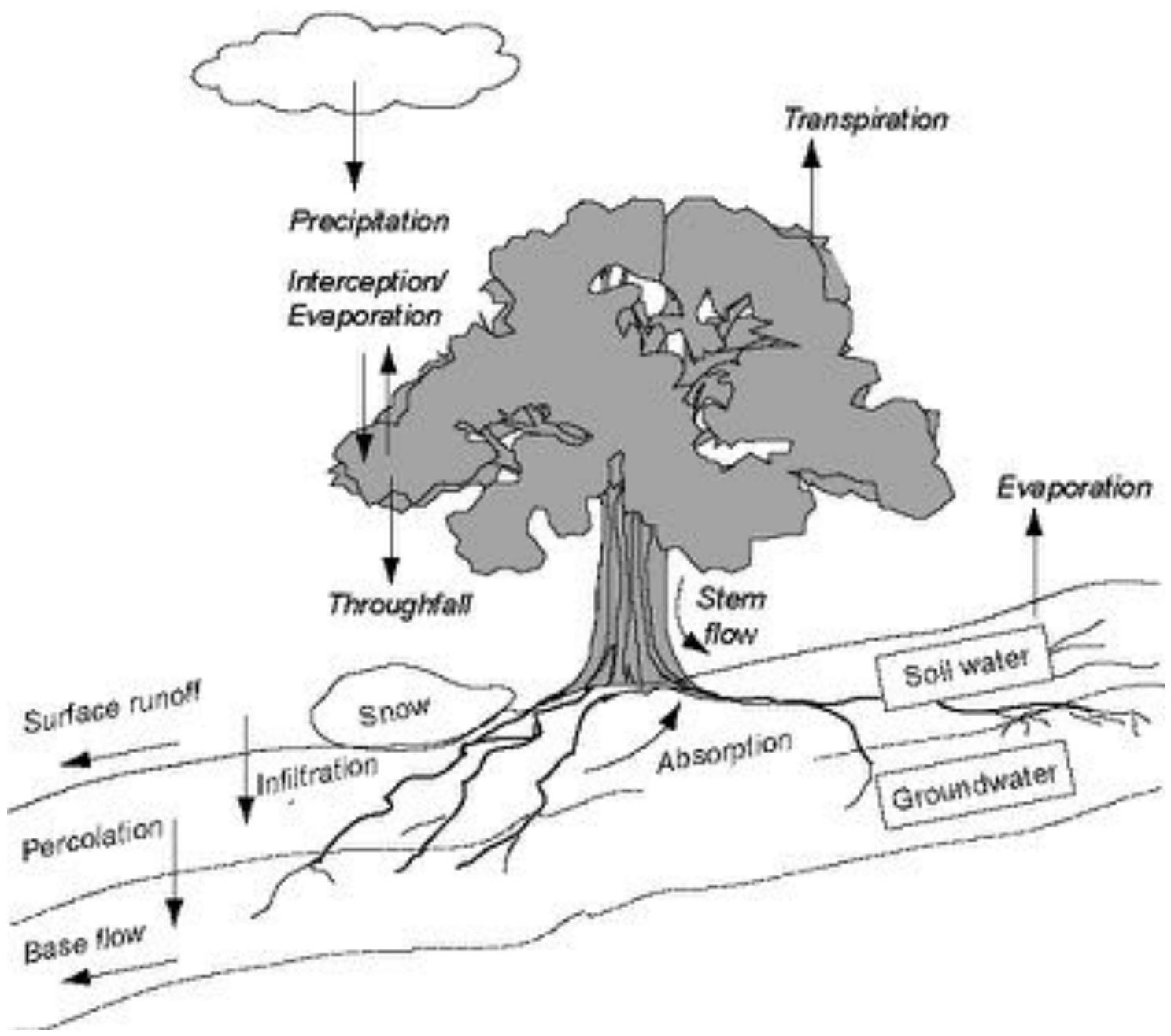
More latent heat flux → Local cooling



# Water budget

# Questions

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



# The Water Budget

Precipitation +/- Storage =  
Evapotranspiration + Runoff

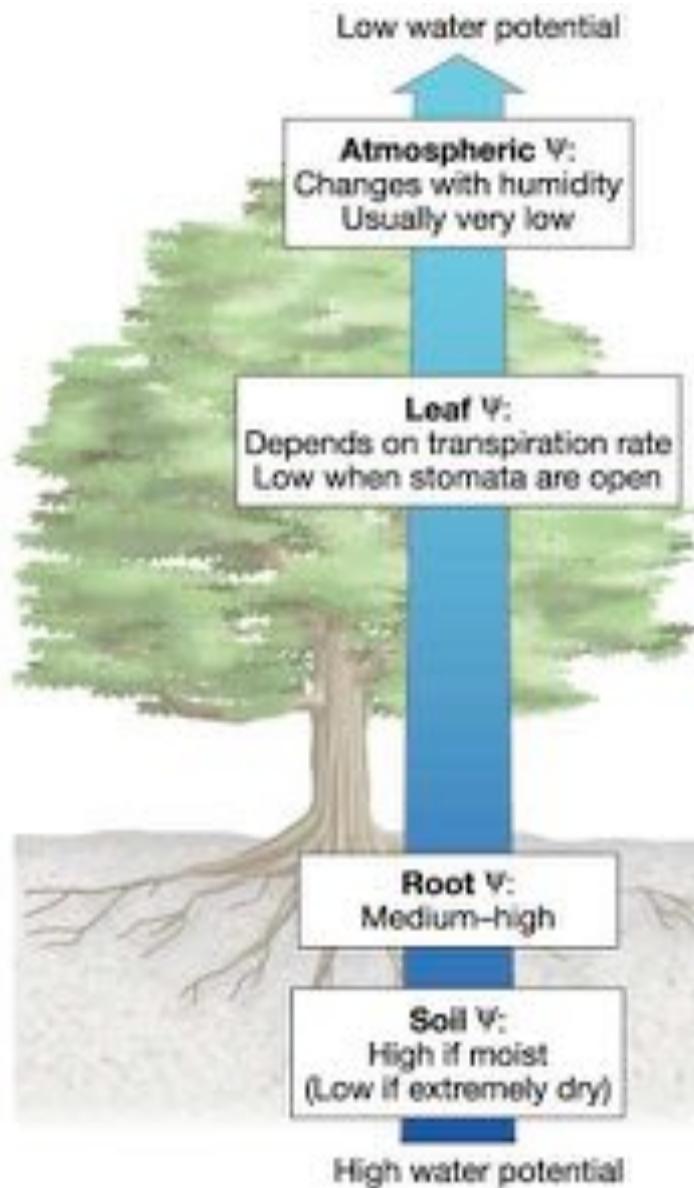
# The Water Budget

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

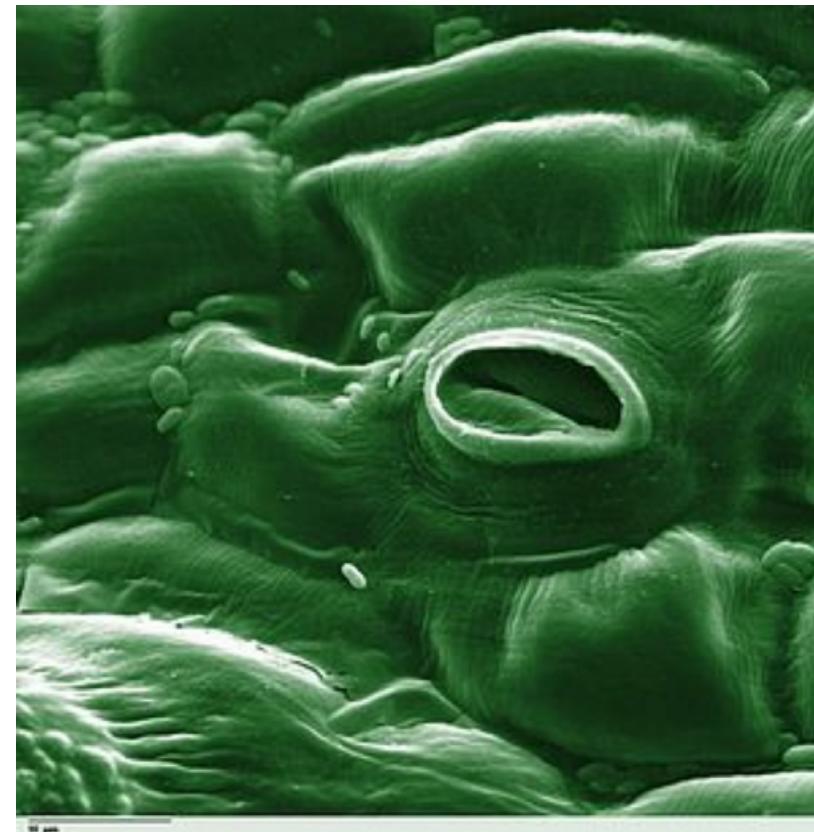
# The Water Budget

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

Water moves through  
ecosystems via potential  
gradients



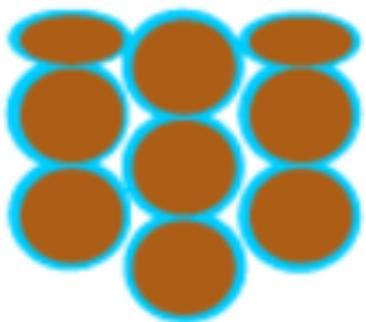
**Water moves from high water potential to low water potential via a continuous water column/film**



Remember: soil water potential  
depends on soil texture

PWP

Hygroscopic  
water

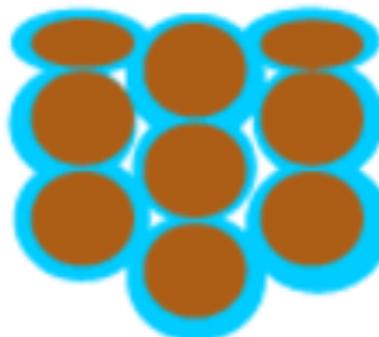


Remaining water  
adheres to soil  
particles and is  
unavailable to plants

Wilting point →

FC

Capillary  
water

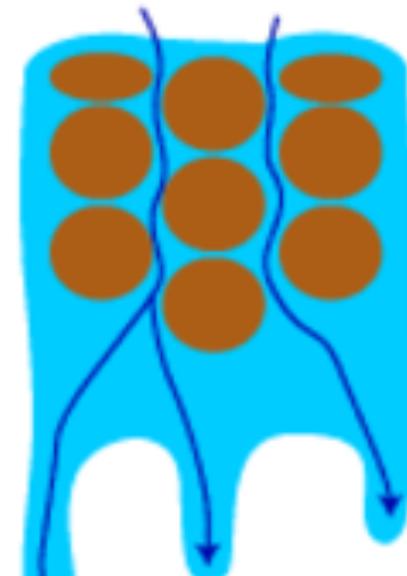


Water held in  
micropores

Available water-  
plant roots **can**  
absorb this

SWC

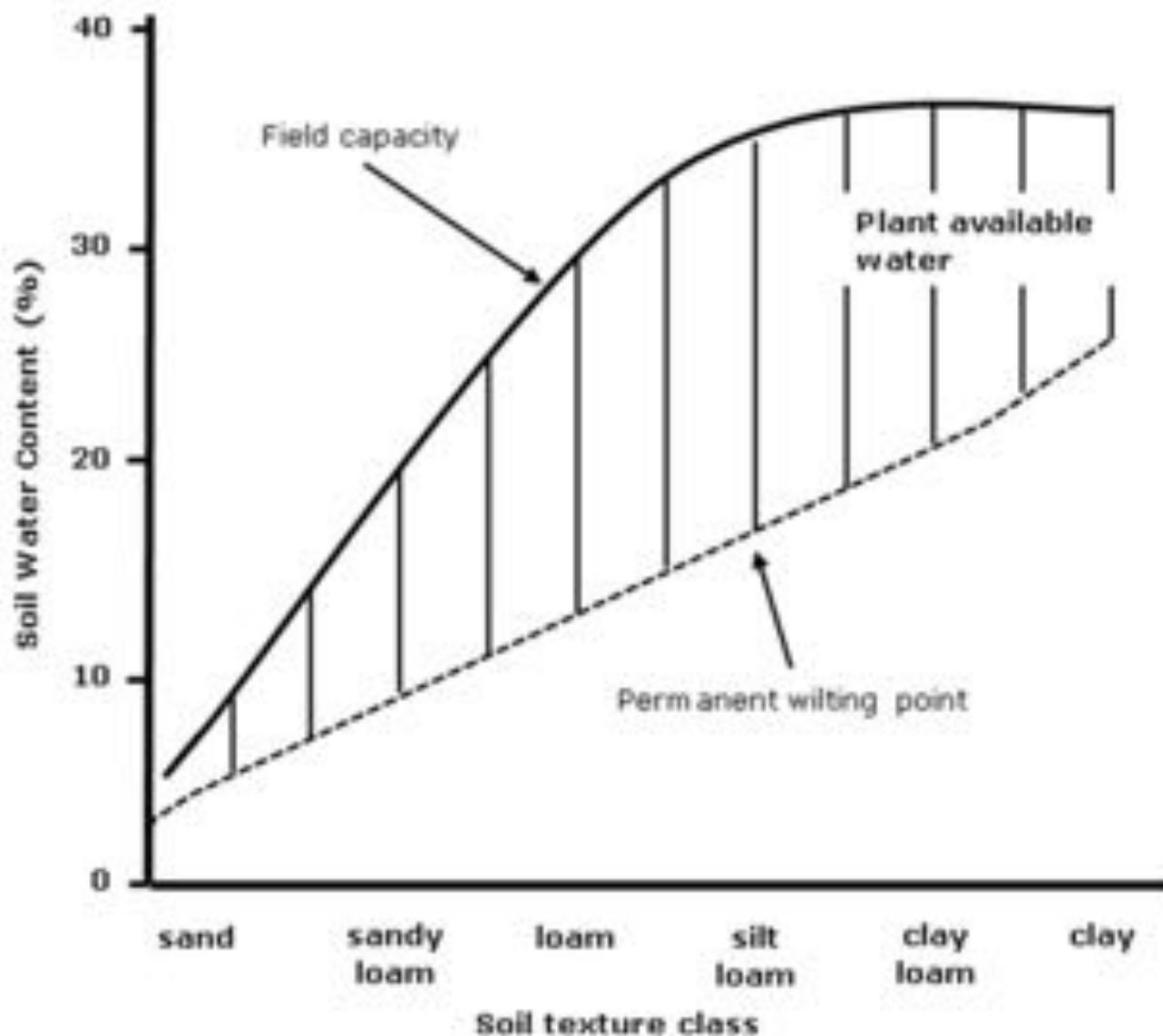
Gravitational  
water



Drains out of the  
root zone

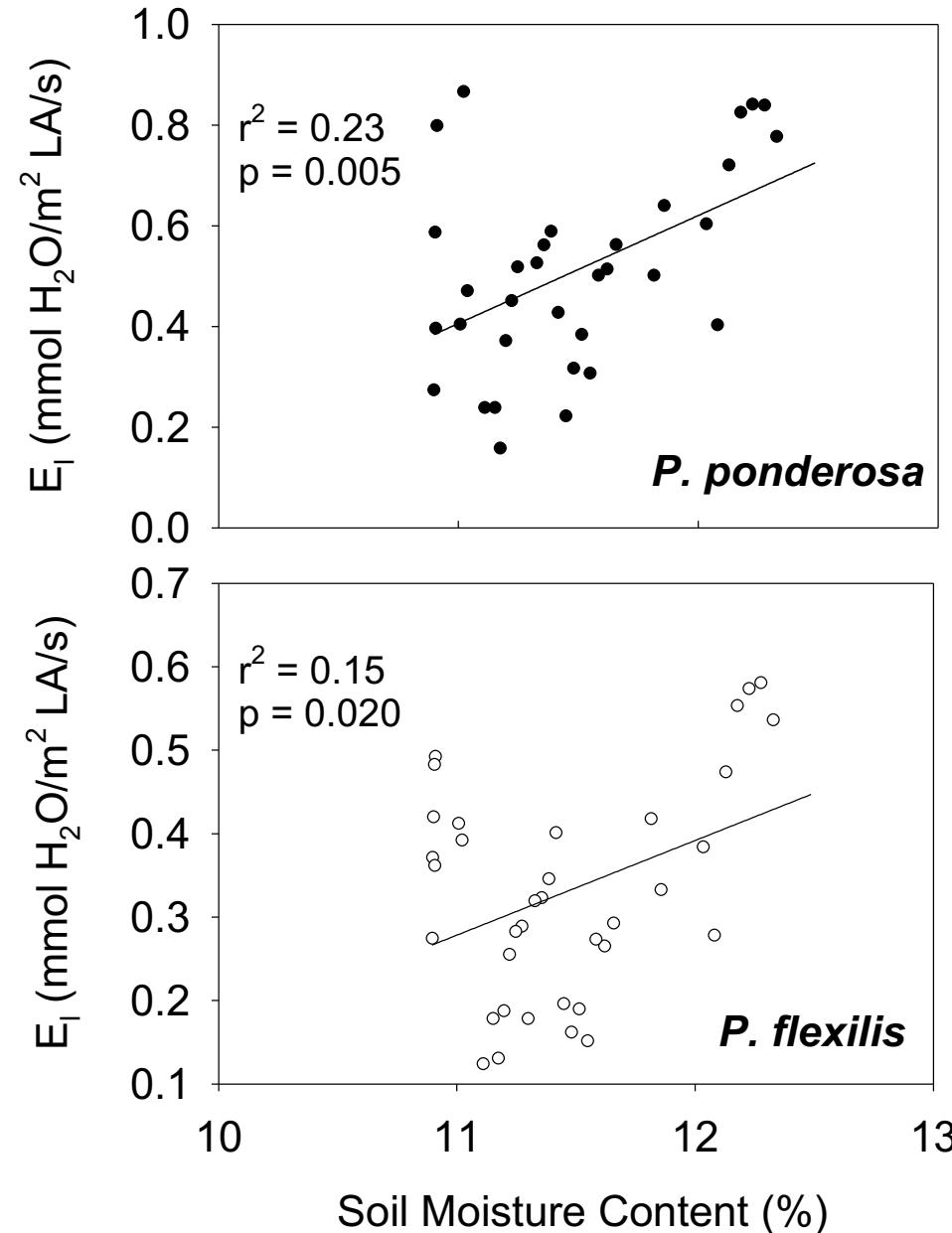
← Field capacity

**Available water for plant growth**



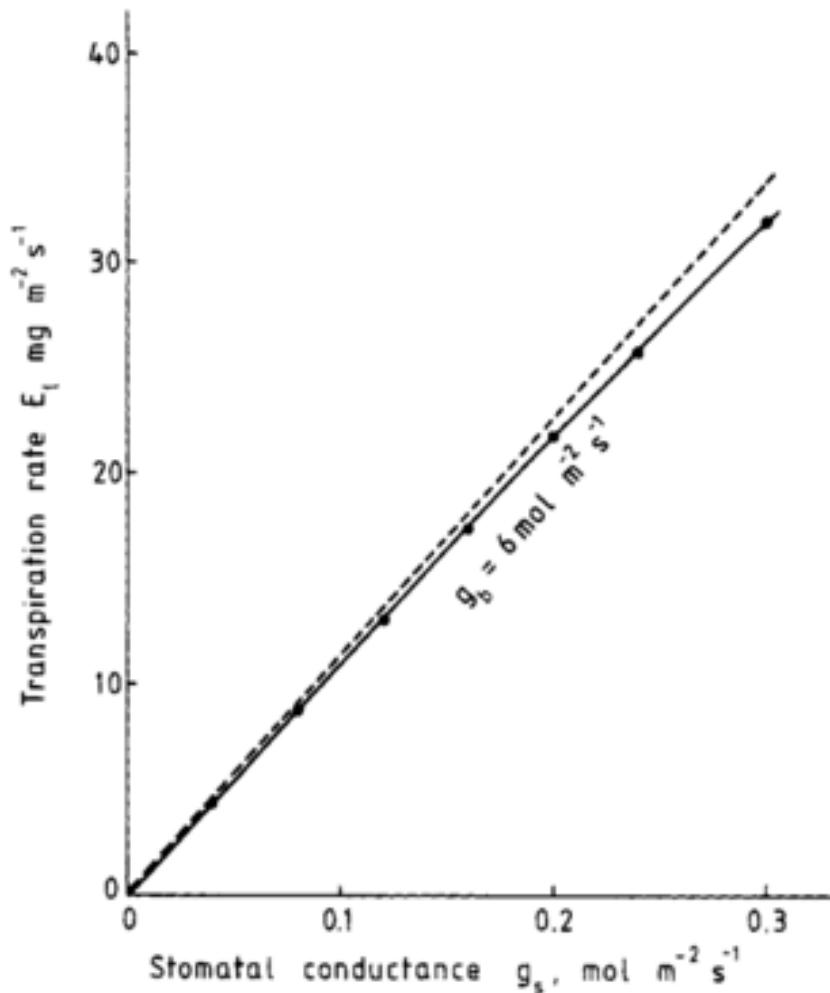
# Coupling to the energy budget: Transpiration

# Transpiration is positively related to soil water availability...



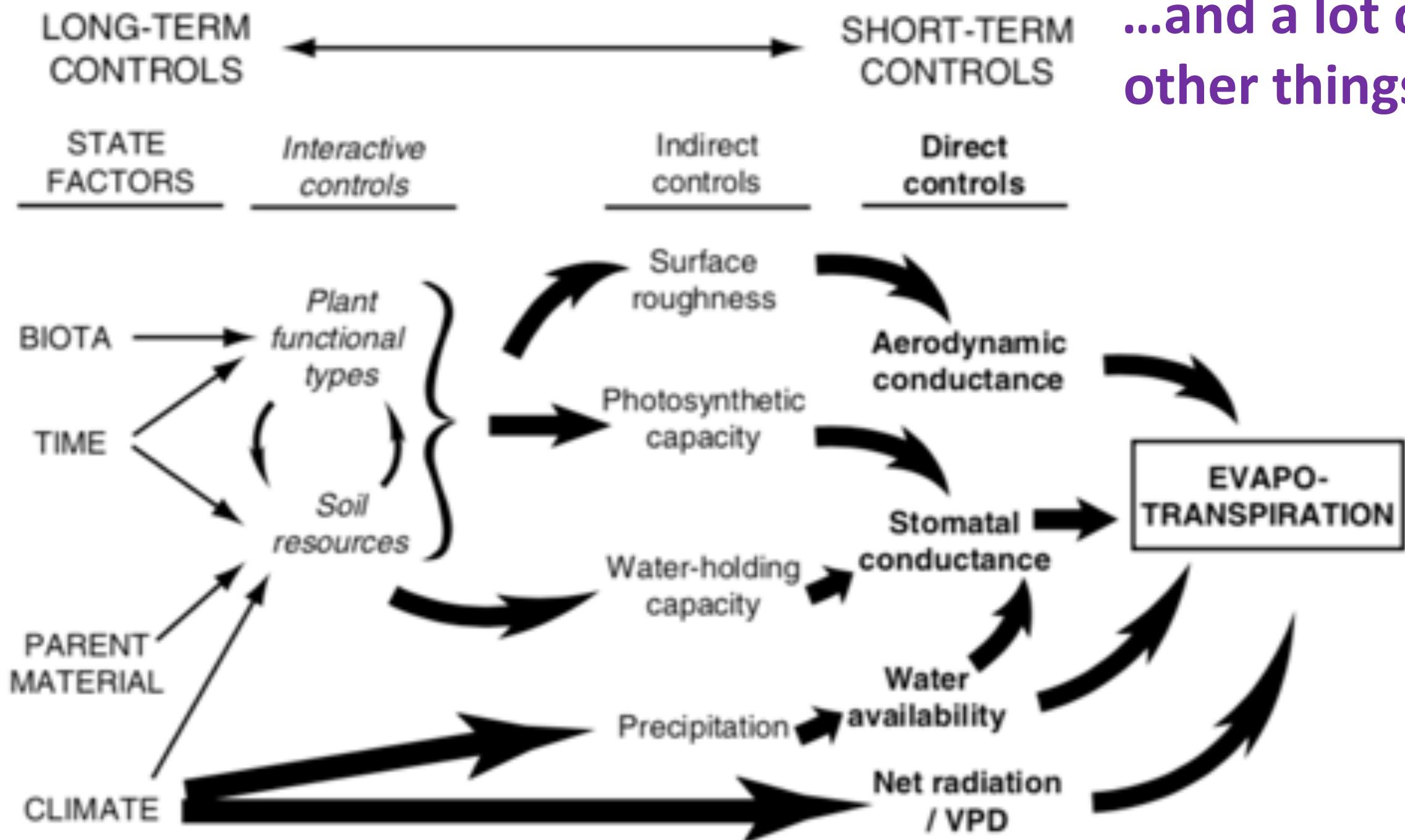
(Fischer et al. 2003 Tree Phys.)

# ...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.

...and a lot of  
other things!



LONG-TERM  
CONTROLS

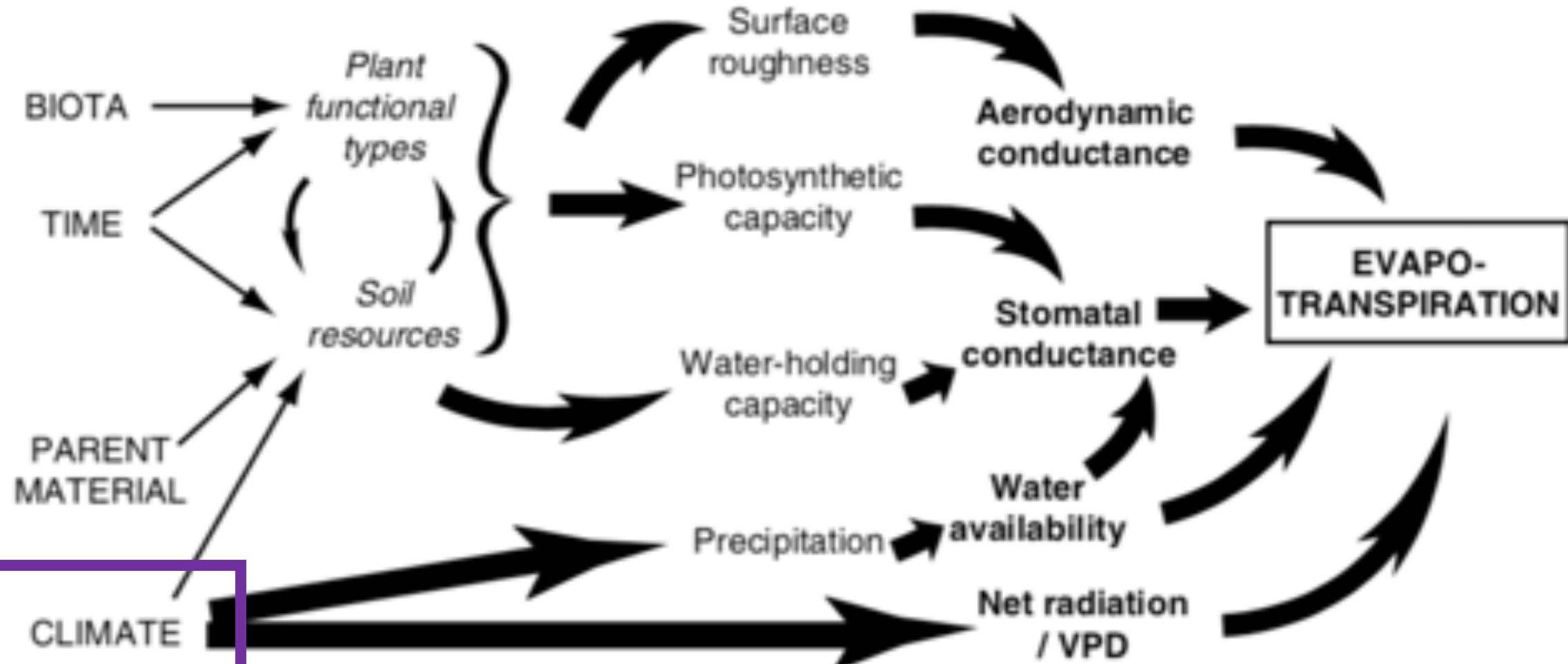
SHORT-TERM  
CONTROLS

STATE  
FACTORS

*Interactive  
controls*

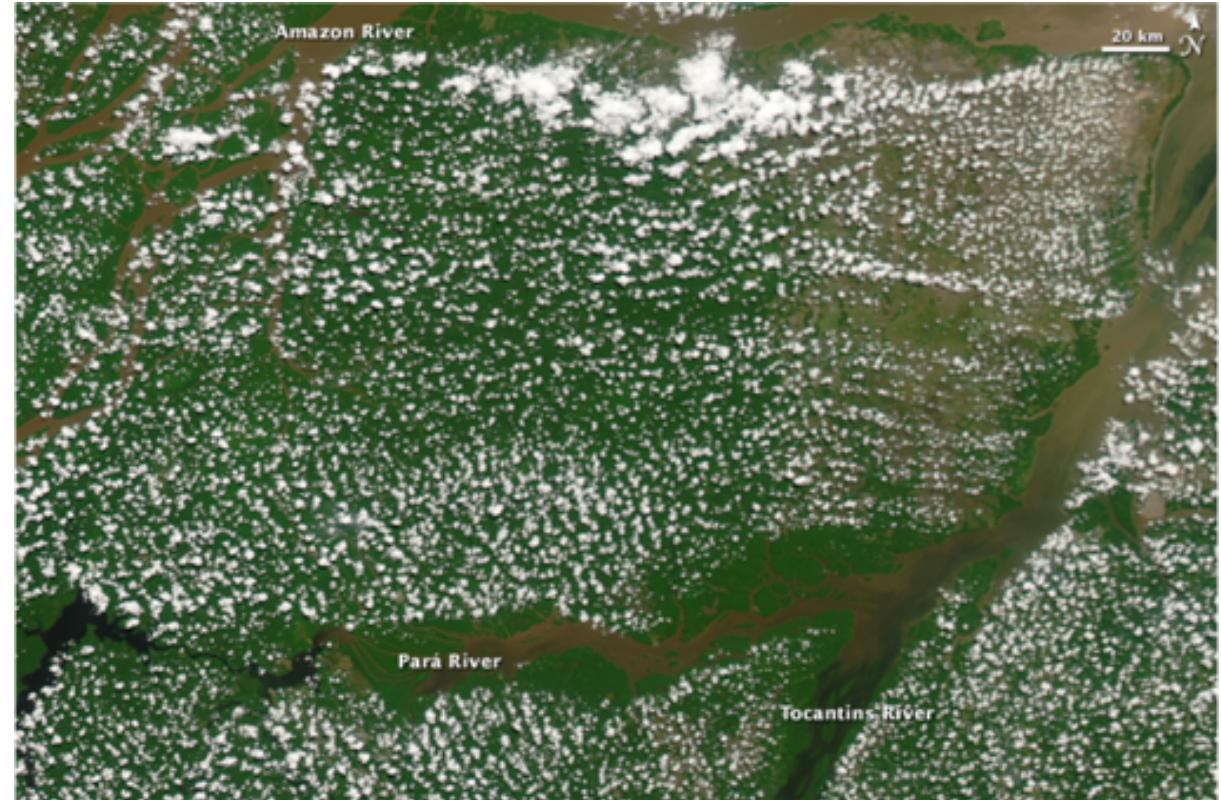
Indirect  
controls

Direct  
controls

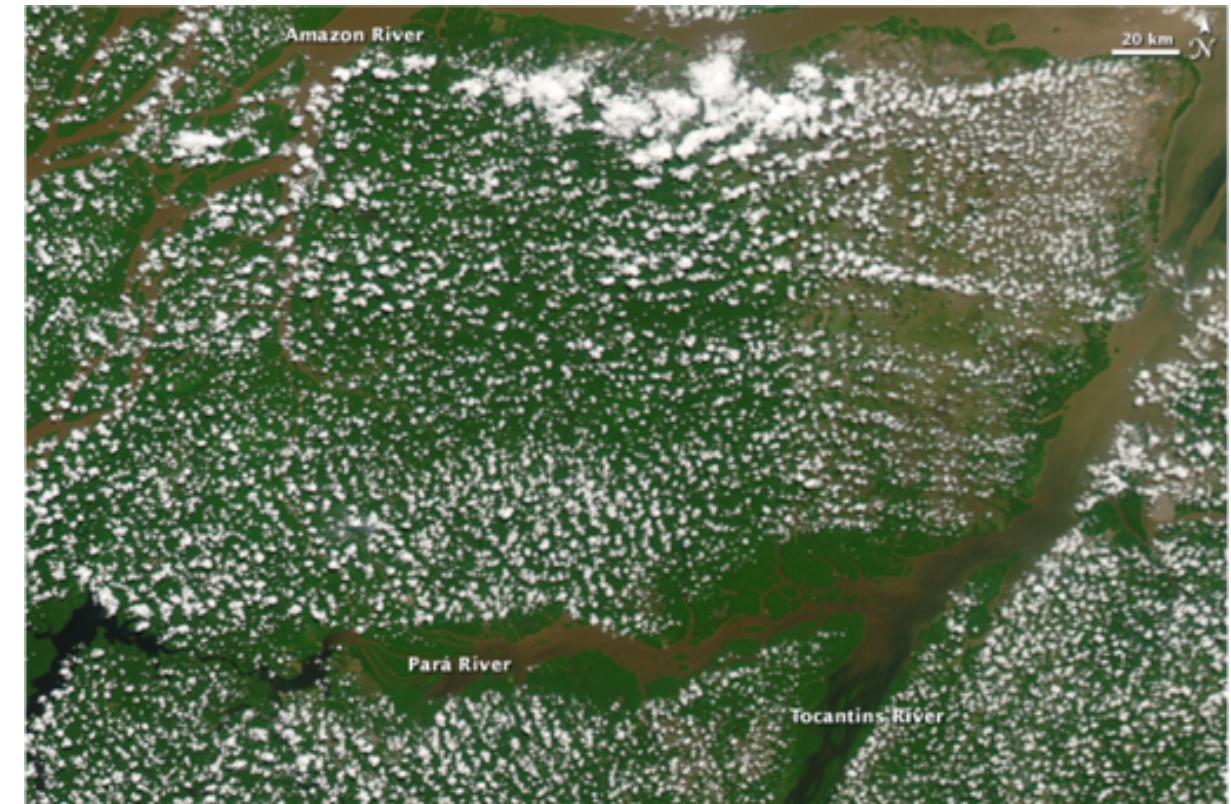


# How does transpiration respond to...

- Higher temperatures?
- Reduced humidity?
- Higher light?
- Higher CO<sub>2</sub>?



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

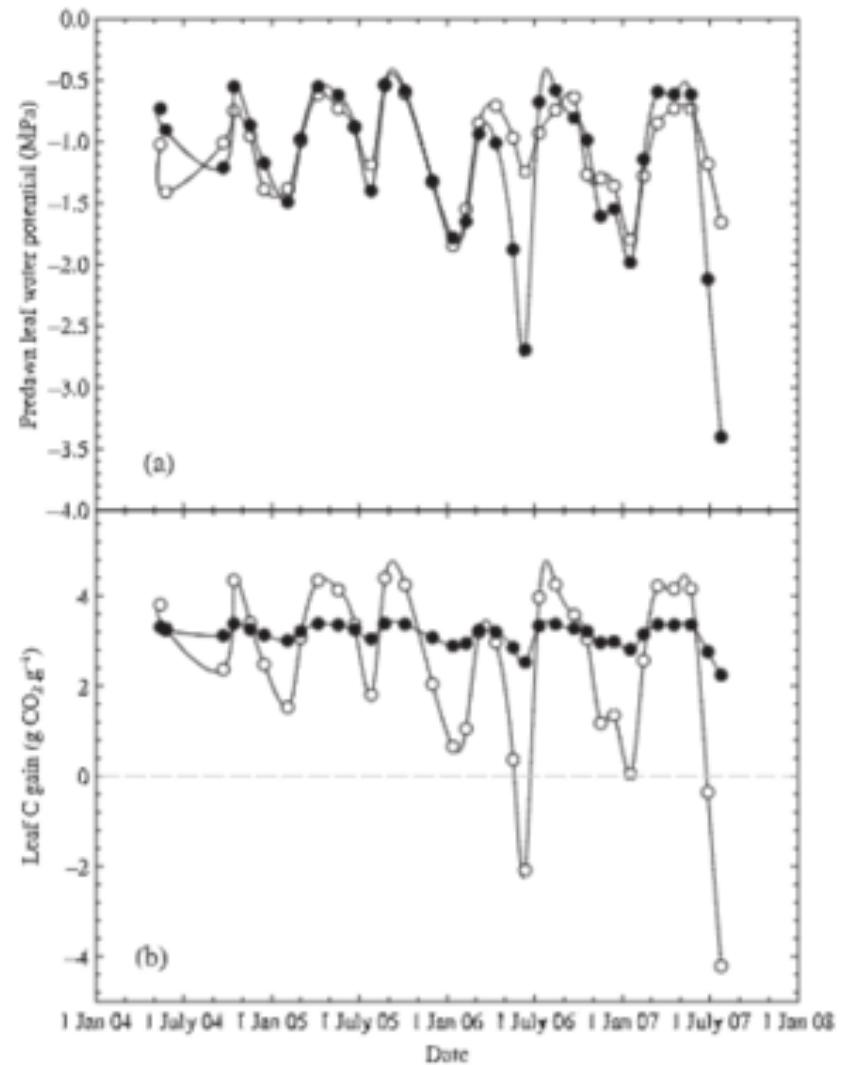
- Drought avoiders
- Maintain high  $\Psi$



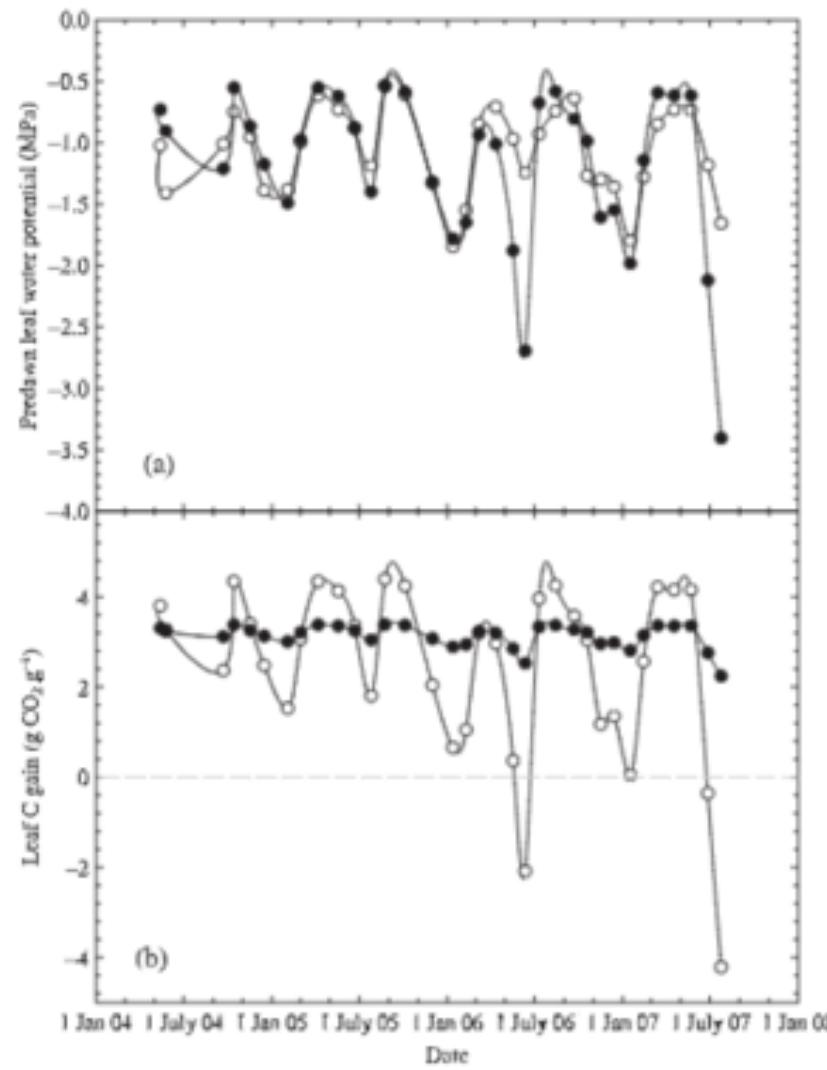
Anisohydric species tend to respond more slowly to drought

- Drought tolerators
- Tolerate low  $\Psi$

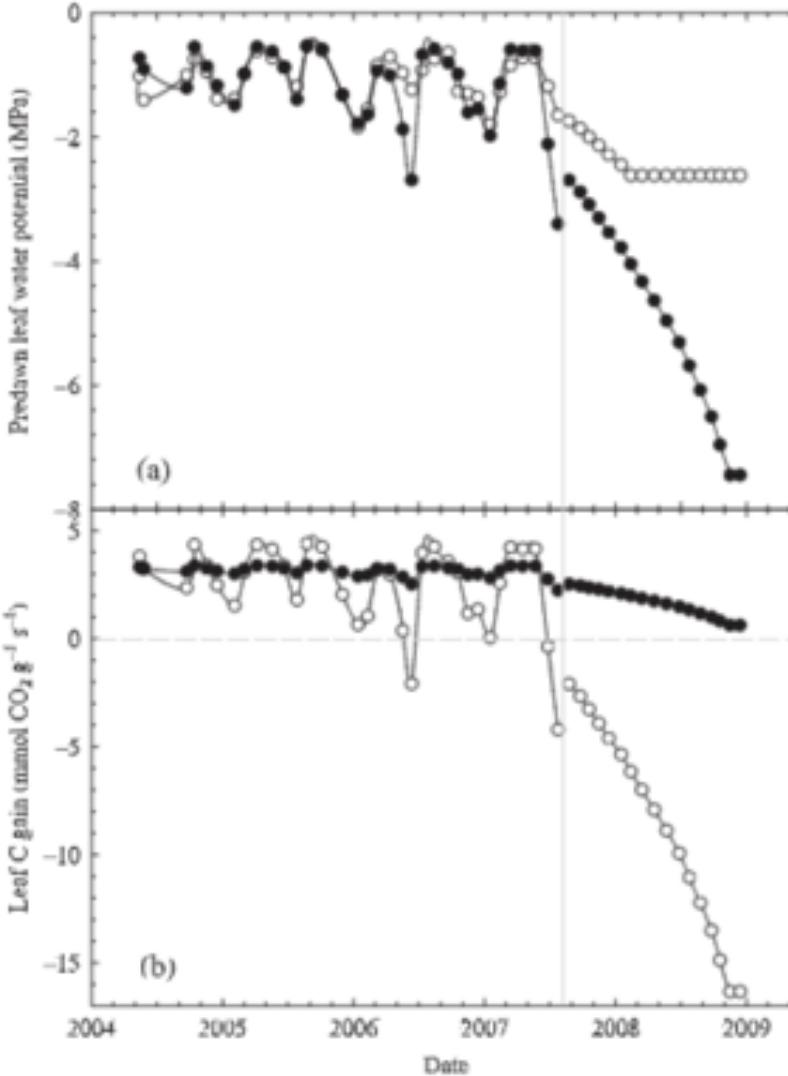




**Fig. 11** (a) Three years of monthly observations of predawn water potential of piñon (open circles) and juniper (closed circles) from Mesita del Buey, Los Alamos, New Mexico. Twigs were sampled at least 20 min before sunrise and kept in plastic bags until measurement, which took place within 1 h of 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).



**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).



**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 bar is 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).

How would isohydry strategy  
influence the water cycle?

# The Water Budget

Precipitation +/- Storage =  
Evapotranspiration + Runoff

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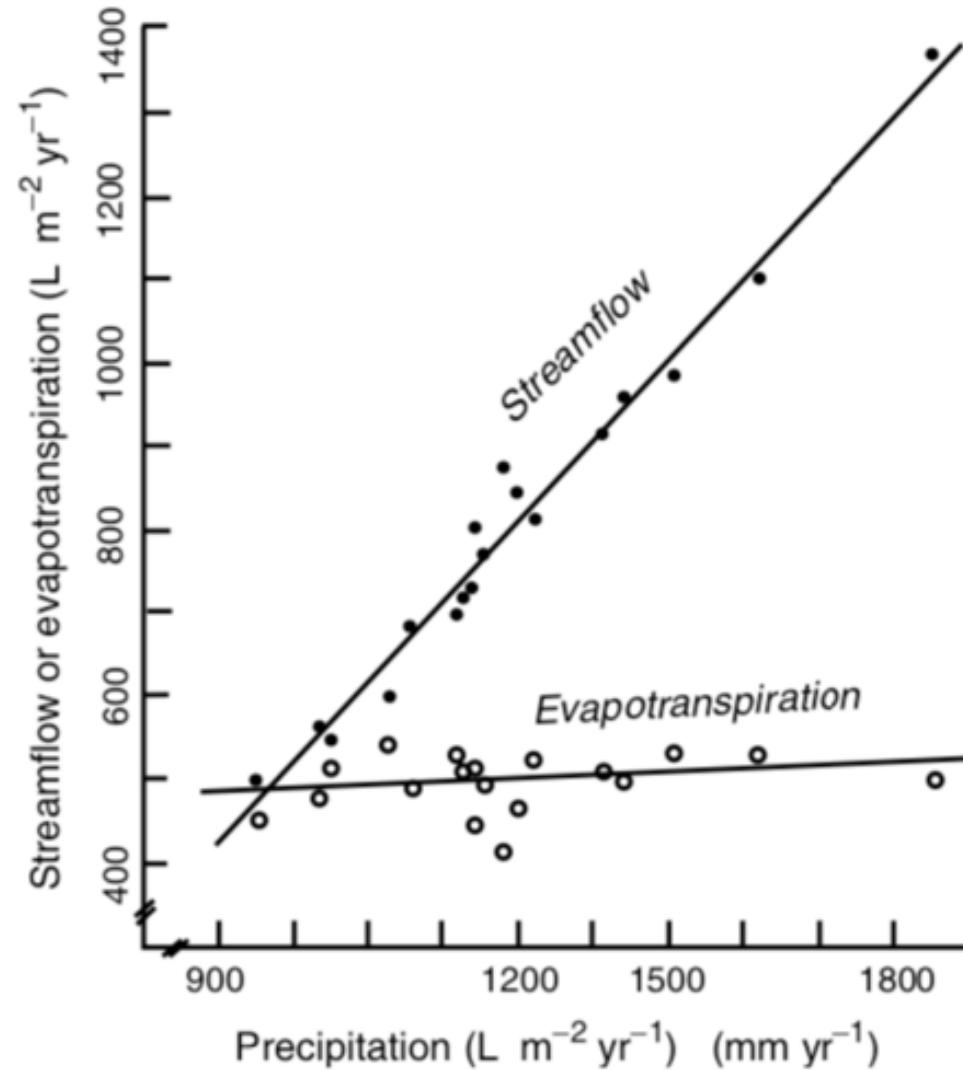
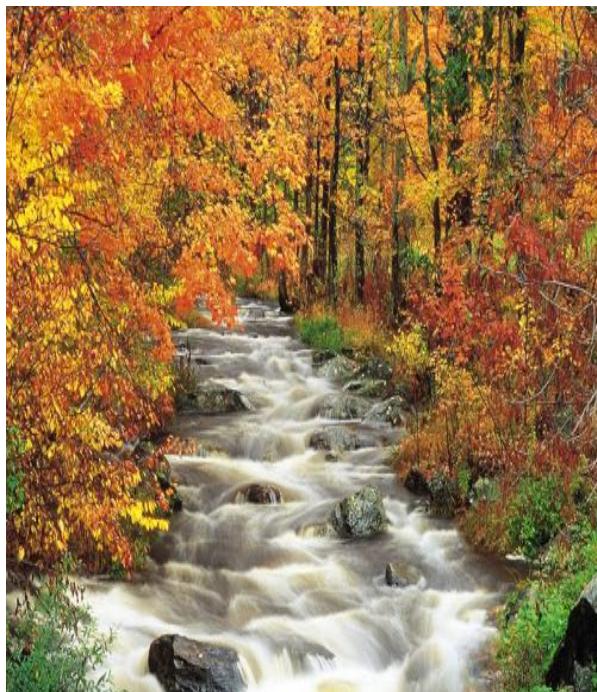
$$P + \Delta S = E + R$$

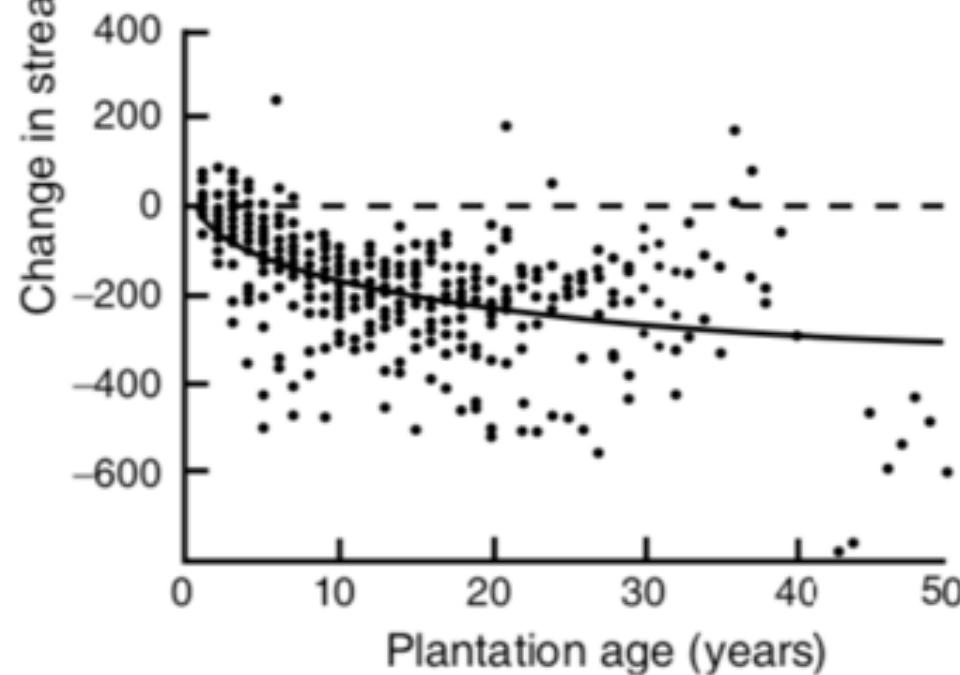
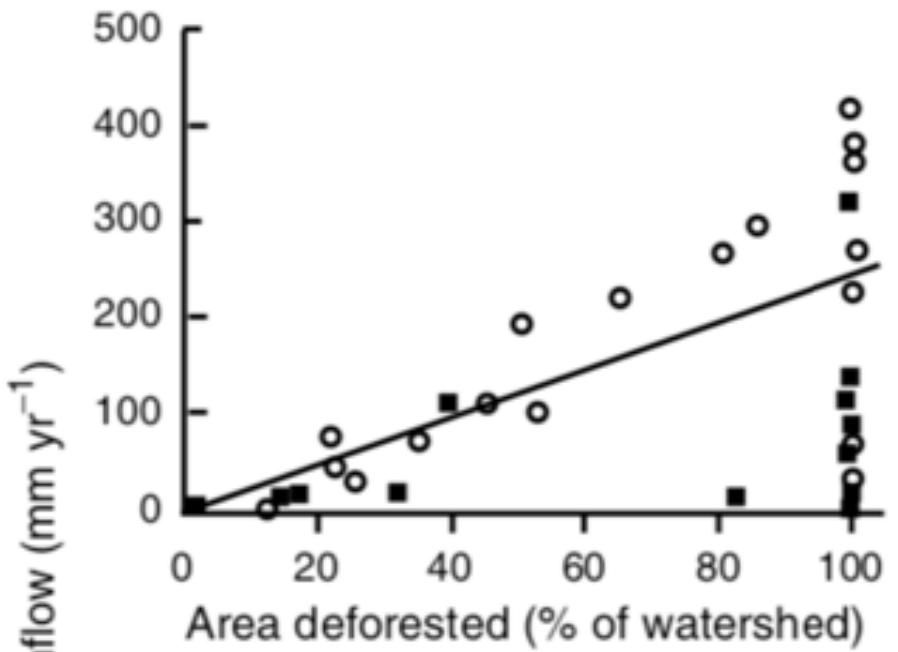
P = Precipitation

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