EcoHydrology: WATER & ECOSYSTEM ECOLOGY, ESPM 111

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Liquid

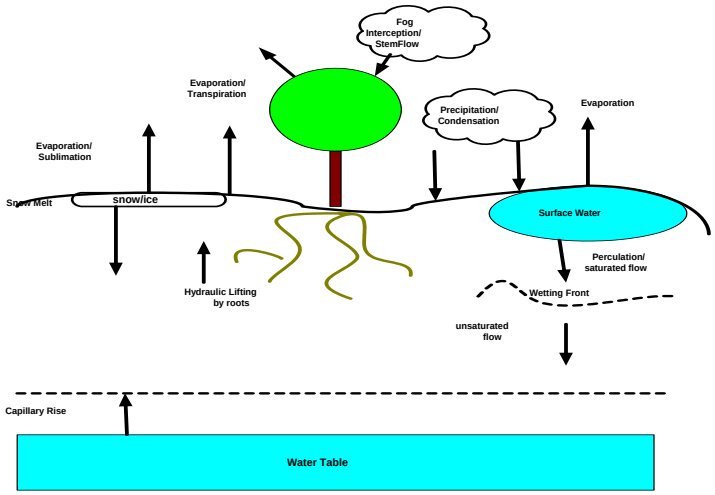
Solid

Gaseous

Topics Covered

- Principles
  - Water Balance
  - Water Potential
- Water in the Soil
- Water in the Air
- Evaporation
- BioPhysical Controls on Evaporation

Hydrological Cycle and Ecosystems



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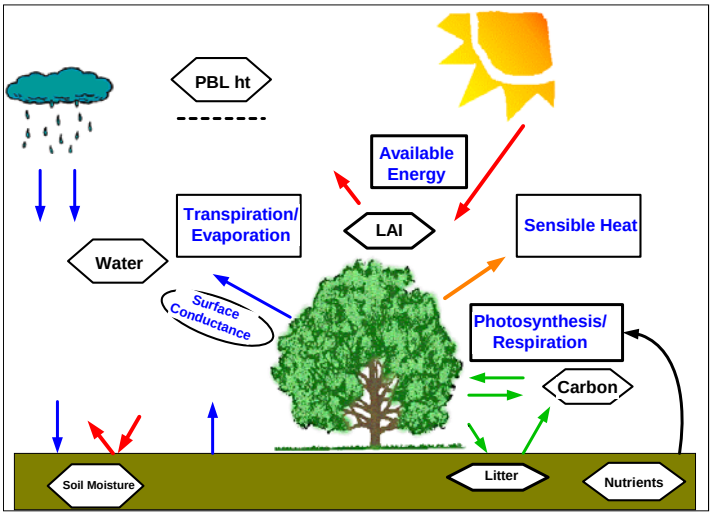
Water and the Environment: Biogeophysical-Ecohydrological View



Chemical Potential of Water

Chemical potential quantifies
the driving force for movement of water between two locations

The chemical potential of water is related to the change
in the Gibbs free energy of the system, subjected by pressure, gravity,
temperature and minor constituents
, e,g., salts, .

By convention, Water potential is normalized by V_w, the partial molal volume of water (18.05 10^{-6} m^3 mol^{-1}), giving it units of **Pressure**.

kg m^2 s^{-2}/ m^3 = kg m^{-1} s^{-2} =P= F/A= kg m s^{-2}/m^2

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Water Potential

- The **total water potential** of a system consists of the sum of water potentials forces per unit area associated
  - **Pressure (+/-)**
  - **Osmosis (-)**
  - **Soil and Plant Matrix** (-)
  - **Gravitation** (+/-)

$$\psi = \psi_p + \psi_\pi + \psi_m + \psi_g$$

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- **Turgor (pressure) potential**
  - is related to the hydrostatic pressure, as when someone is blow on or sucking on straw that is inserted in a reservoir of water. Its sign can be positive or negative.
- **osmotic potential**
  - The presence of solutes reduces the activity of water.
- **matric potential**
  - interactions between water and solid surfaces act to reduce the activity of water.
- **gravity Potential**
  - gravitational force is a function of the density of water, the acceleration due to gravity and the height of the water reservoir above or below a reference height:

$$\psi_g = \rho_w g h$$

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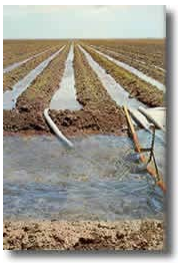
Saturated Flow, Pure Water

$$\psi = \psi_p + \psi_g$$

$$0 = \psi_p + \psi_g;$$

$$\psi_p = -\psi_g$$



Takes Negative Pressure (suction) to lift water against gravity
The Gravitational Burden of Water Overhead Imposes a Positive Pressures

Dominated by Pressure and Gravity

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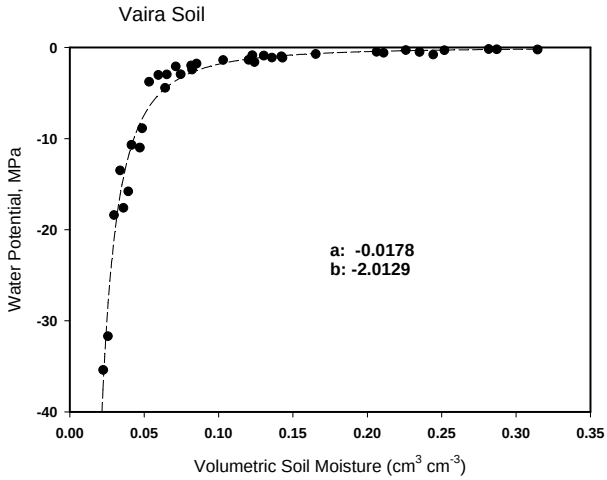
Soil Water Retention function for Unsaturated Soils
Water Potential =f(volumetric water content, soil Texture)



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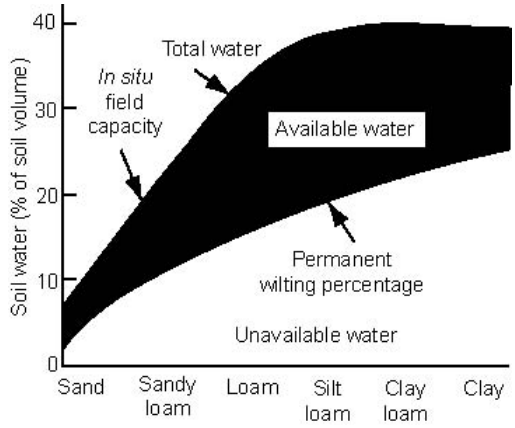
Plant-available water:
Difference between field capacity and permanent wilting point



Field Capacity: -0.03MPa

Permanent Wilting Point: -1.5 MPa

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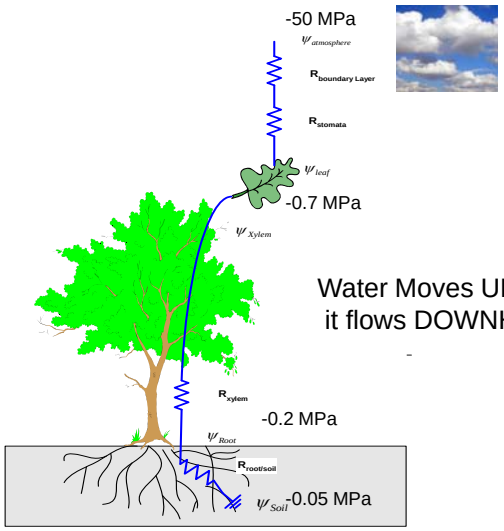
Soil-Plant-Atmosphere-Water Continuum



Water Moves UPWARD because it flows DOWNHILL Energetically

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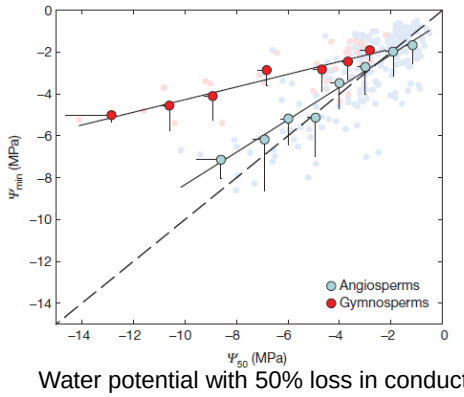
Trees, Drought and Vulnerability to Embolism



Water potential with 50% loss in conductivity

70% of 226 tree species, from 81 sites, operate within 1 MPa of Hydraulic Safety Margin for Injury..
Explains Why Drought Decline is Occurring World-Wide

Choat et al 2012 Nature

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Atmospheric Humidity

- Relative Humidity,
  - Ratio between ambient, e_a, and saturated vapor pressures, $e_s(T)$

$$h_r = \frac{e_a}{e_s(T)}$$

- Absolute Humidity

$$\rho_v = \frac{e_a m_v}{R T_k}$$

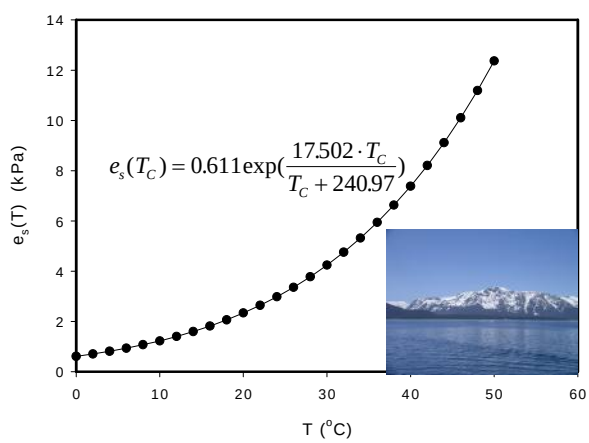
- Dew Point Temperature, T_d

$$T_d = \frac{240.97 \cdot \ln(e_a / 0.611)}{17.502 - \ln(e_a / 0.611)}$$

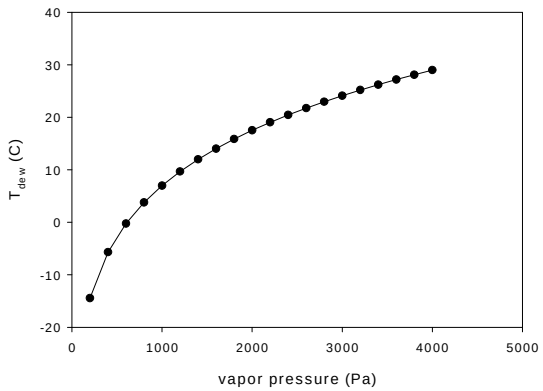
- Wet Bulb Psychrometry

$$C_p(T_a - T_w) = \frac{\lambda(e_s(T_w) - e_a)}{P}$$

SATURATION VAPOR PRESSURE



Dewpoint Temperature and Vapor Pressure



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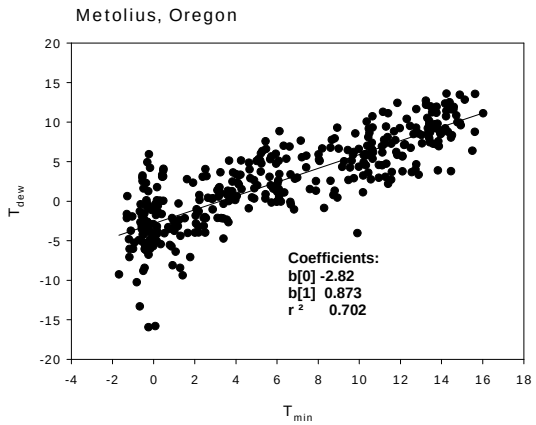
Dewpoint Scales with Minimum Temperature



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Evaporation

- Evaporation is the “physical process by which a liquid or solid is converted to a gaseous state” (Glossary of Meteorology).
- Plant canopies introduce water vapor into the atmosphere via **transpiration** and the **evaporation** of water from the soil and free water on the leaves and stems.

Evaporation: EcoPhysiological View point

Current=potential/resistances

$$I = \frac{V}{R}$$

Evaporation is a function of the ratio between potential difference In humidity, V, and the resistances against that potential, R

$$E = \frac{\rho\, m_v}{m_a} \frac{(e_s(T_s) - e_a)}{\sum R}$$

R = resistances, stomata & boundary layer =1/G, conductances

m_v and m_a are molecular masses for vapor and dry air

EVAPORATION is Energy Driven: Meteorologist Viewpoint

$$\lambda E = R_n - H - G - S - P_s$$

- Net Radiation (Rn) is partitioned into
  - Sensible Heat Exchange (H)
  - Latent Heat Exchange (λE)
  - Soil Heat Exchange (G)
  - Heat Storage in the Air and Vegetation (S)
  - Photosynthesis (Ps)
  - Bowen Ratio, β, λE/H

$$\lambda E = \frac{R_n - G}{1 + \beta}$$

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Potential Evaporation

- "the evaporation from an extended surface of a short grass that is supplied with water and the canopy covers the ground completely."

UC Davis Lysimeter

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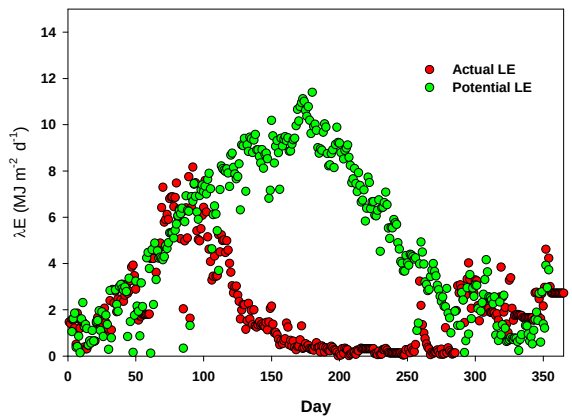
Potential vs Actual Evaporation

Annual Grassland, 2004



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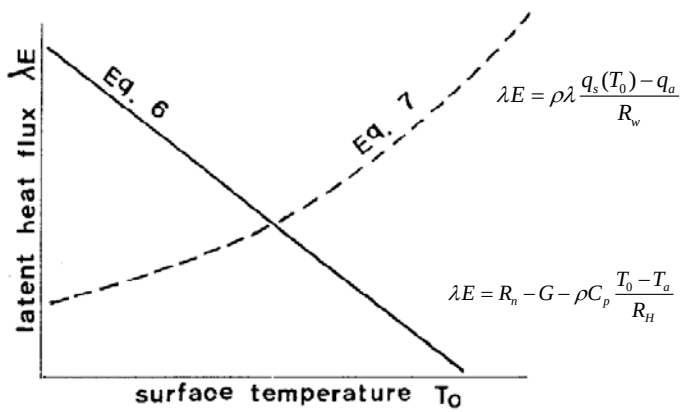
Conflicting Controls on Evaporation,
Supply of Water vs Demand by Available Energy



$$\lambda E = \rho\lambda \frac{q_s(T_0) - q_a}{R_w}$$

$$\lambda E = R_n - G - \rho C_p \frac{T_0 - T_a}{R_H}$$

Monteith, 1981 QJRMS

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Penman Monteith Eq

- λE is a Balance between the supply and demand for moisture
- Reconciles the Meteorological and Physiological Viewpoints

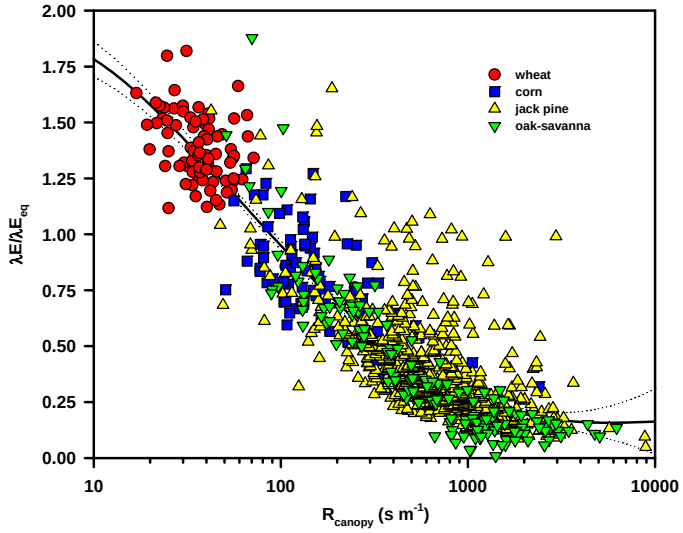
$$\lambda E = \frac{s(R_n - S) + \rho \cdot C_p \cdot G_H \cdot D}{s + \gamma + \gamma \frac{G_H}{G_s}}$$

s: slope of $e_s(T)$ and T curve
γ: pychrometric constant
G_s & G_h: surface and aerodynamic conductances

Big-Leaf Surface Conductance, G_s

f(LAI, soil moisture, photosynthetic capacity(N))

Effects of Functional Types and Surface Resistance



Baldocchi and Xu, 2008 Adv Water Res

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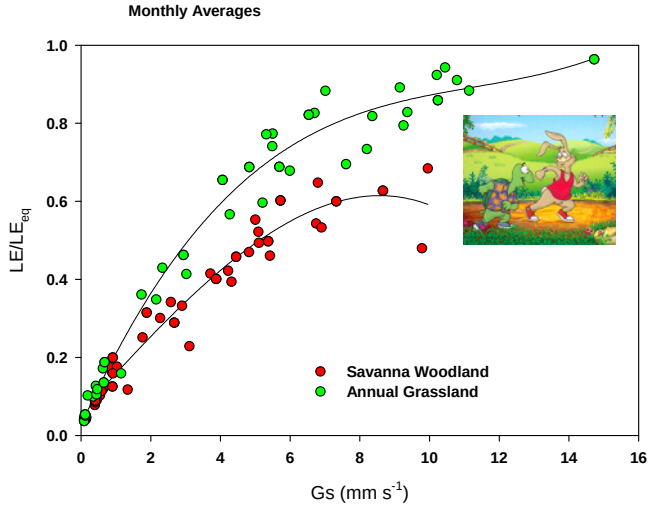
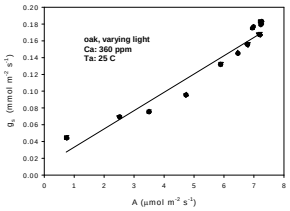
Landscape Differences on Evaporation Rates, normalized by Available Energy On Short Time Scales, Grass ET > Forest ET



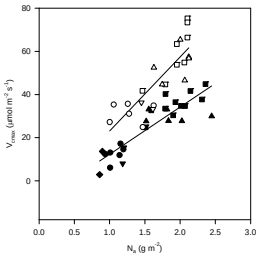
Ryu, Baldocchi, Ma and Hehn, JGR-Atmos, 2009

Stomatal Conductance Scales with N, via Photosynthesis

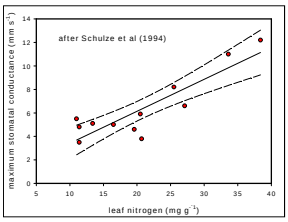
Stomatal Conductance Scales with Photosynthesis



Photosynthetic Capacity Scales with Nitrogen



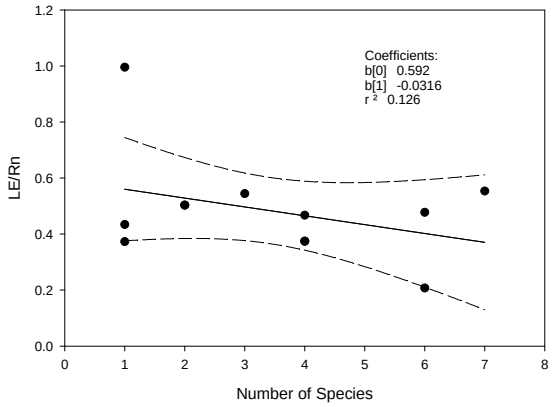
Stomatal Conductance scales with Nitrogen



Wilson et al. 2001, Tree Physiology
Schulze et al 1994. Annual Rev Ecology

Does Biodiversity affect Evaporation?

Biodiversity and Evaporation on Annual Time Scales



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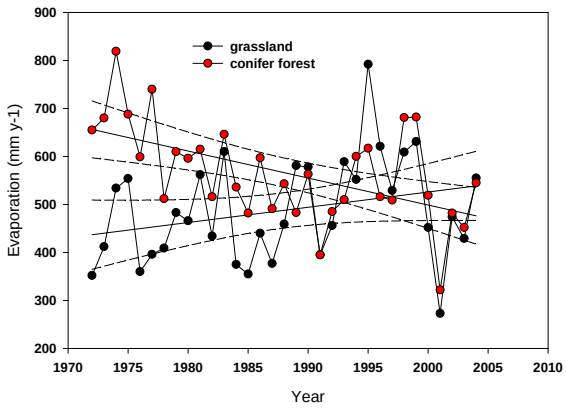
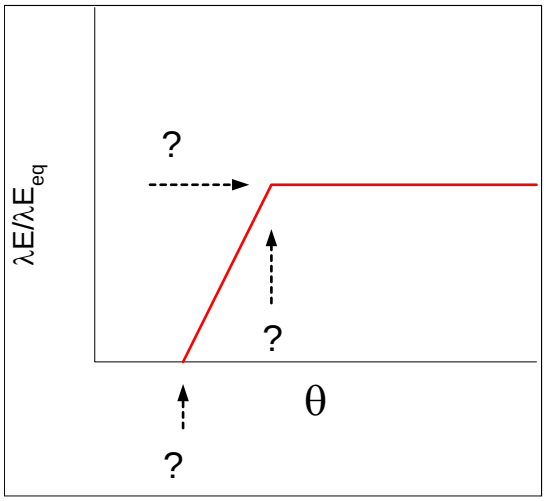
Stand Age also affects differences between ET of forest vs grassland

Plynlimon, Wales



Marc and Robinson, 2007 HESS

EcoHydrology, Evaporation & Soil Moisture



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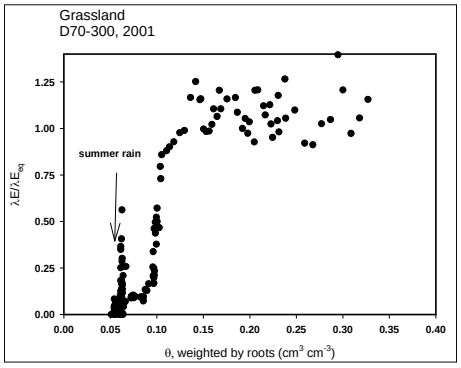
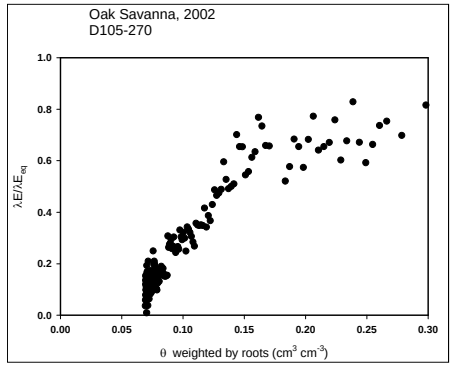
Evaporation and Drought





Grass Uses Water Quick as Possible, Then Die

Oaks meter out Water Conservatively

Baldocchi et al. 2004

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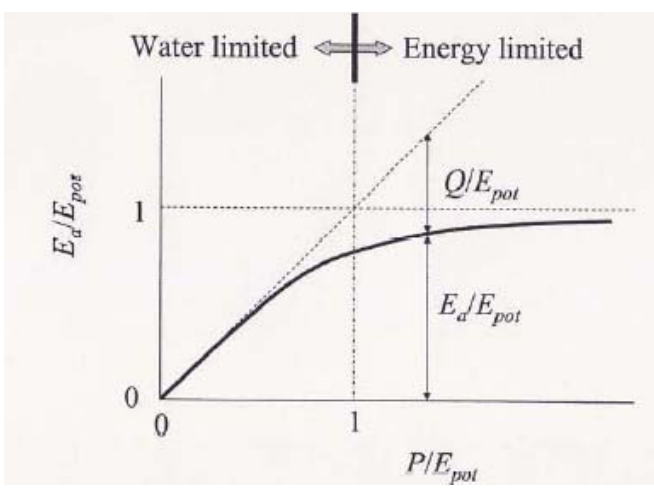
Budyko Evaporation-Precipitation Relationship



From Farquhar and Roderick, 2007

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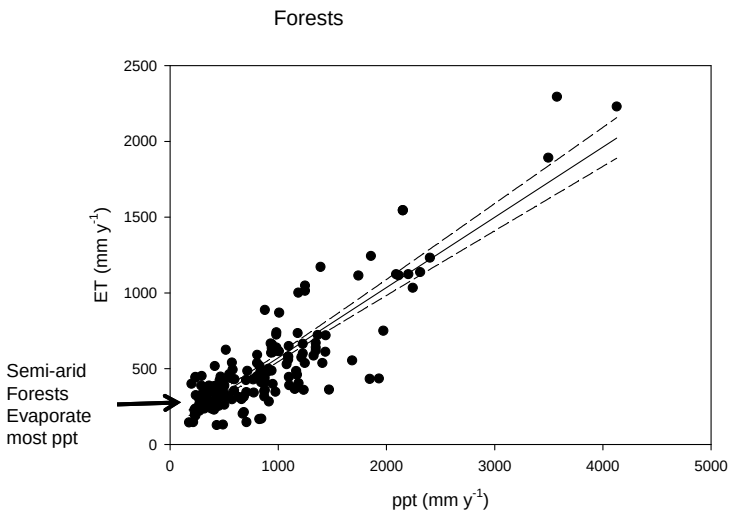
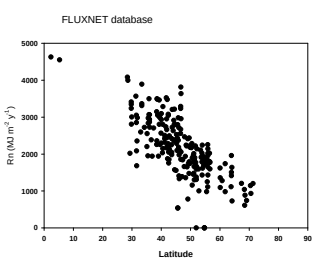
Annual Evaporation of Forests is, on average, about one-half Precipitation



Baldocchi and Ryu, 2010, book chapter

Why is the Arctic so Wet, if it can be Classified as a Desert by its Meager Rainfall (< 300 mm/y)?



Equilibrium Evaporation

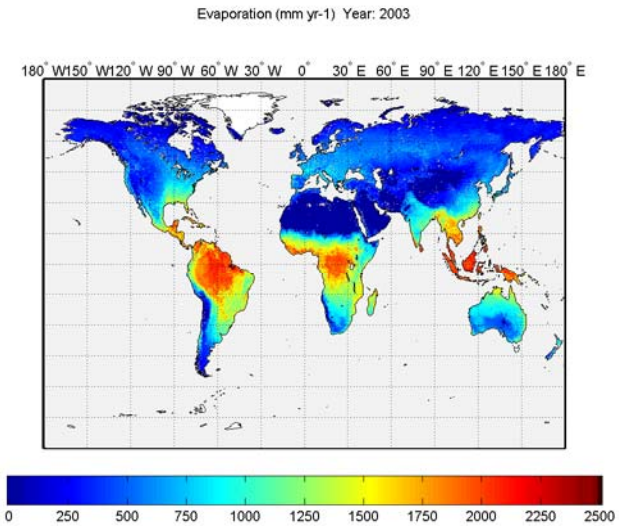
$$E_{eq} = \frac{1}{\lambda}\frac{s}{s+\gamma}R_n$$

$$\frac{s}{s+\gamma} \sim 0.432 + T_a \cdot 0.0116$$

$$E_{eq} = \frac{1}{2.41 MJ/kg} 0.39 \cdot 1000 MJm^{-2}y^{-1} = 161 mm$$

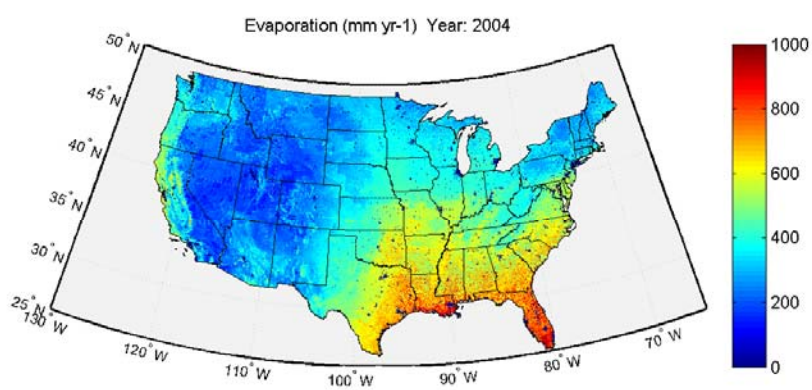
ppt >> E_{eq}

<ET> = 500 mm/y == 63,000 km^3/y



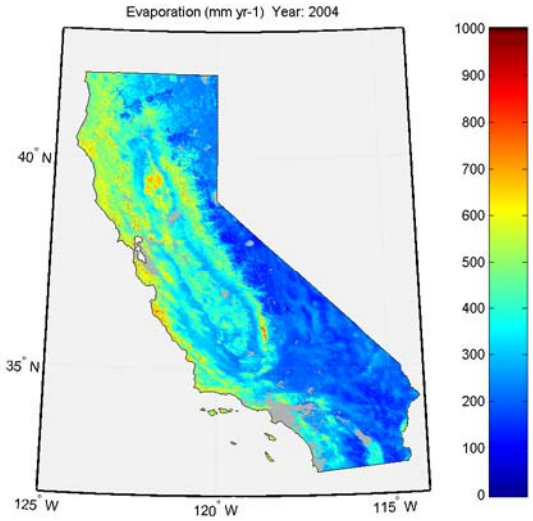
Ryu, Baldocchi et al. Global Biogeochemical Cycles, 2012

MODIS-Driven Product Using Biophysics via Cloud Computing



Ryu, Baldocchi et al. Global Biogeochemical Cycles, 2012

Down-Scale to Regions for Policy and Management Decisions



Ryu, Baldocchi et al. Global Biogeochemical Cycles, 2012

Points to Ponder

- How does land use (conifer/deciduous forests vs grasslands) affect energy and water balances?
- How does biodiversity affect evaporation and water yield?
- What will happen to Evaporation with Global Warming and Higher CO2 concentrations?

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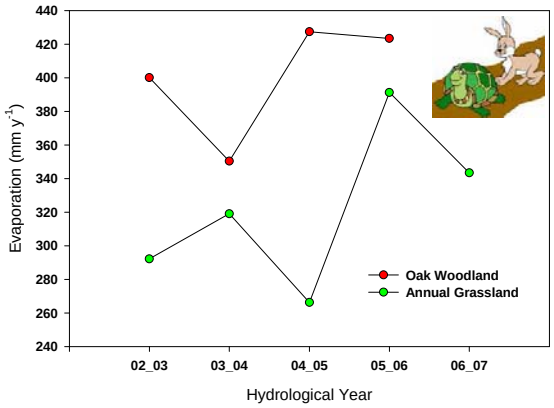
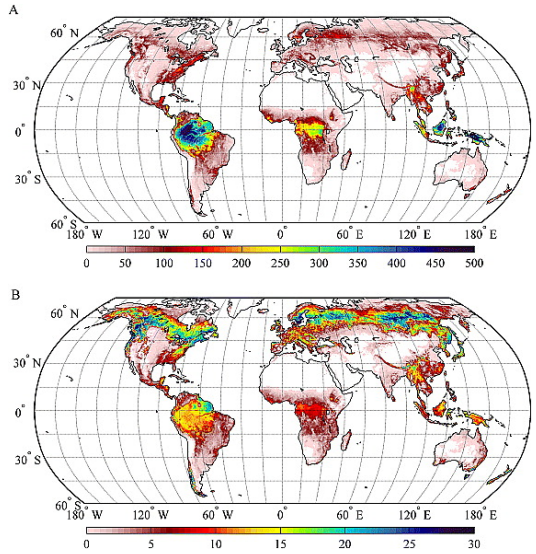
Role of Land Use on ET:
On Annual Time Scale, Forest ET > Grass ET

California Savanna



Ryu, Baldocchi et al, JGR-Atmos, 2010

Forest Rainfall Interception



Mm/yr

% of Rainfall

Miralles et al 2010 JGR Atmos

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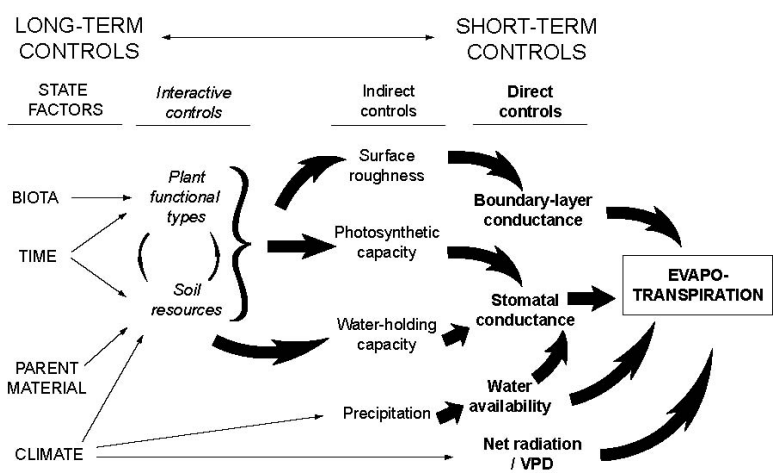
Summary



Chapin et al.

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