Introduction to the soil-plant-atmosphere continuum

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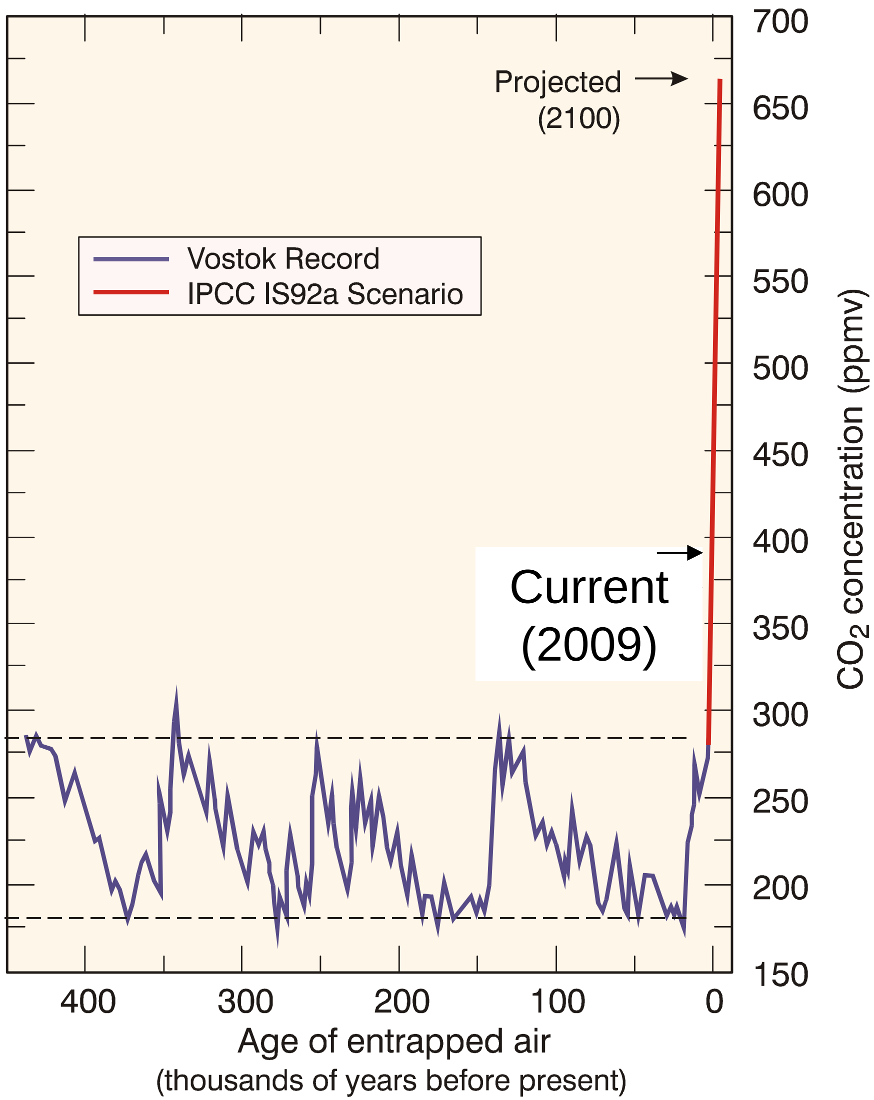
Outline

- **Global climate change and the land surface**
- **Some basic plant physics & biology**
  - Mass and energy balances of leaves, plants and land surfaces
  - Radiation absorption
  - Leaf energy balances
  - Water flow through soil & plant
  - Photosynthesis
  - Stomatal conductance
- **Measurements**
  - Micrometeorology
- **Modelling concepts**
  - Model states
  - Model parameters
  - Non-linearity
  - Scaling up – classification/aggregation
- **Putting it all together**
  - CABLE – Community Atmosphere-Biosphere-Land Exchange model

Why the interest in scaling from leaves to continents?



Atmospheric CO_2 Past and Future

Last 400,000 years: Vostok ice core record

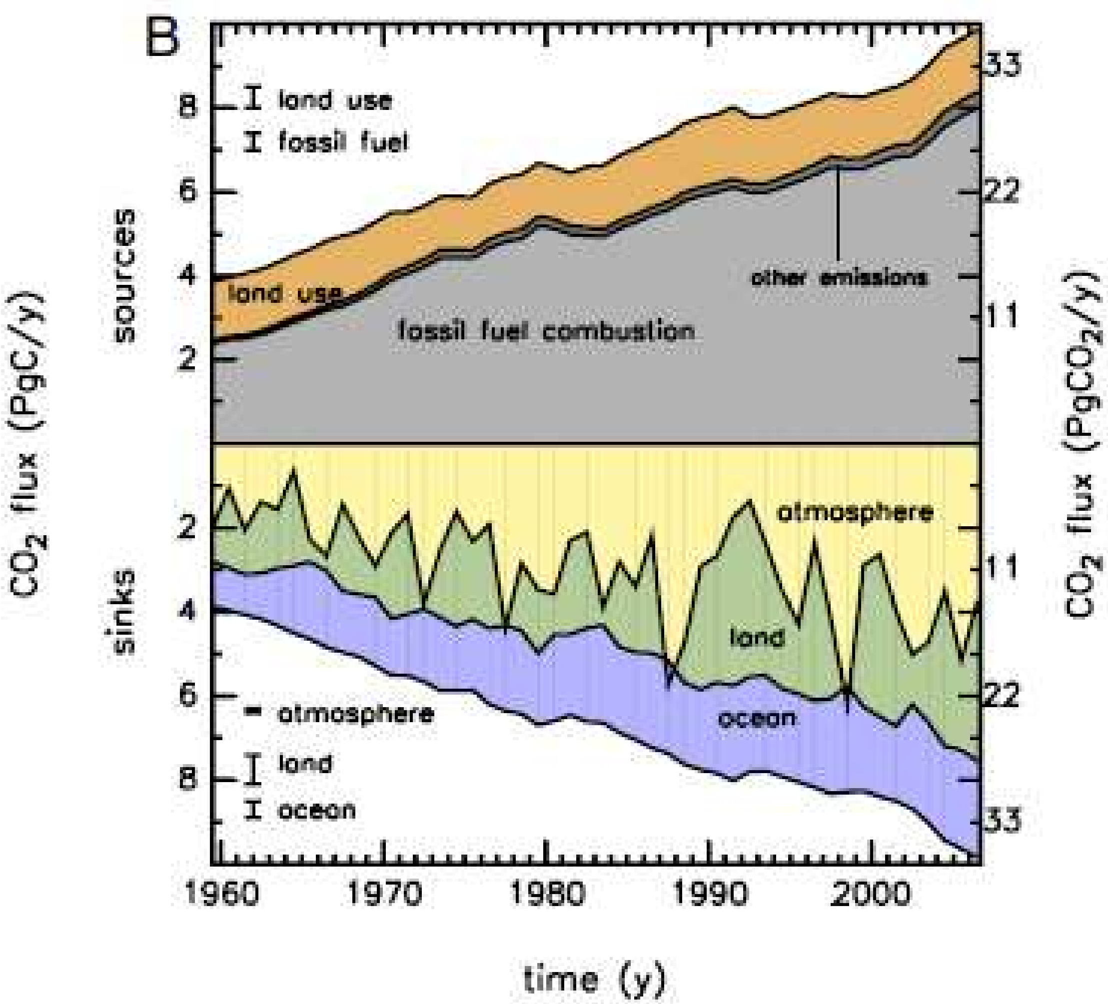
Last 100 years: Contemporary record

Next 100 years: IPCC BAU scenario

Increases over last 100 years results from:

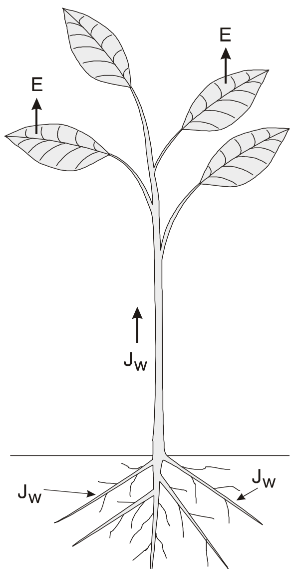
- Fossil fuel emissions
- Land use change

Global carbon budget

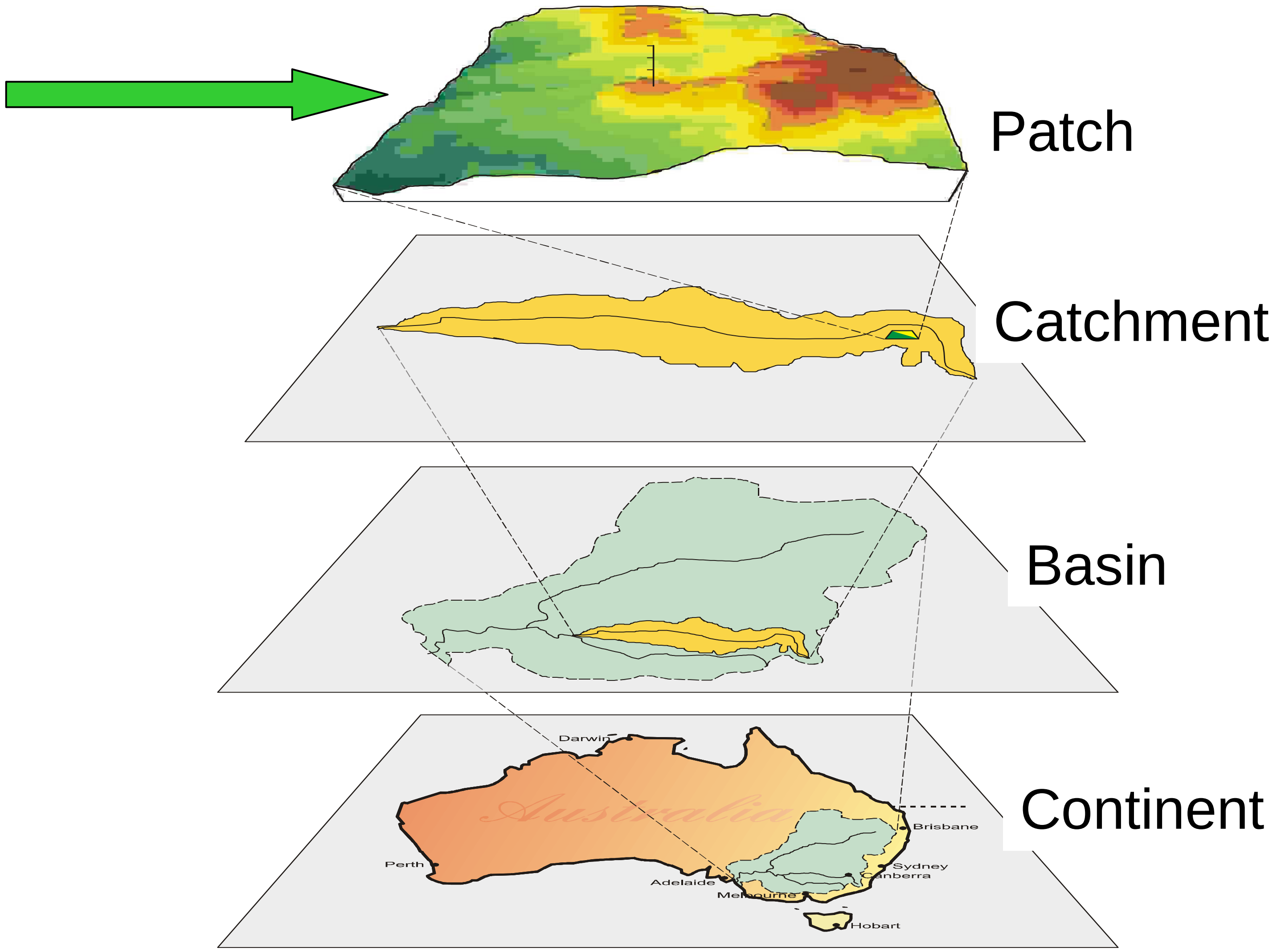


Canadell et al (2007) PNAS 104, 18866-18870 Contributions to accelerating atmospheric CO2 growth.

To predict response of land to climate change we need models & measurements



Plant, canopy



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- Global climate change and the land surface
- **Mass and energy balances of leaves, plants and land surfaces**
  - Radiation transmission & absorption
  - Leaf energy balances
  - Water flow through soil & plant
  - Photosynthesis
  - Stomatal conductance
- Measurements
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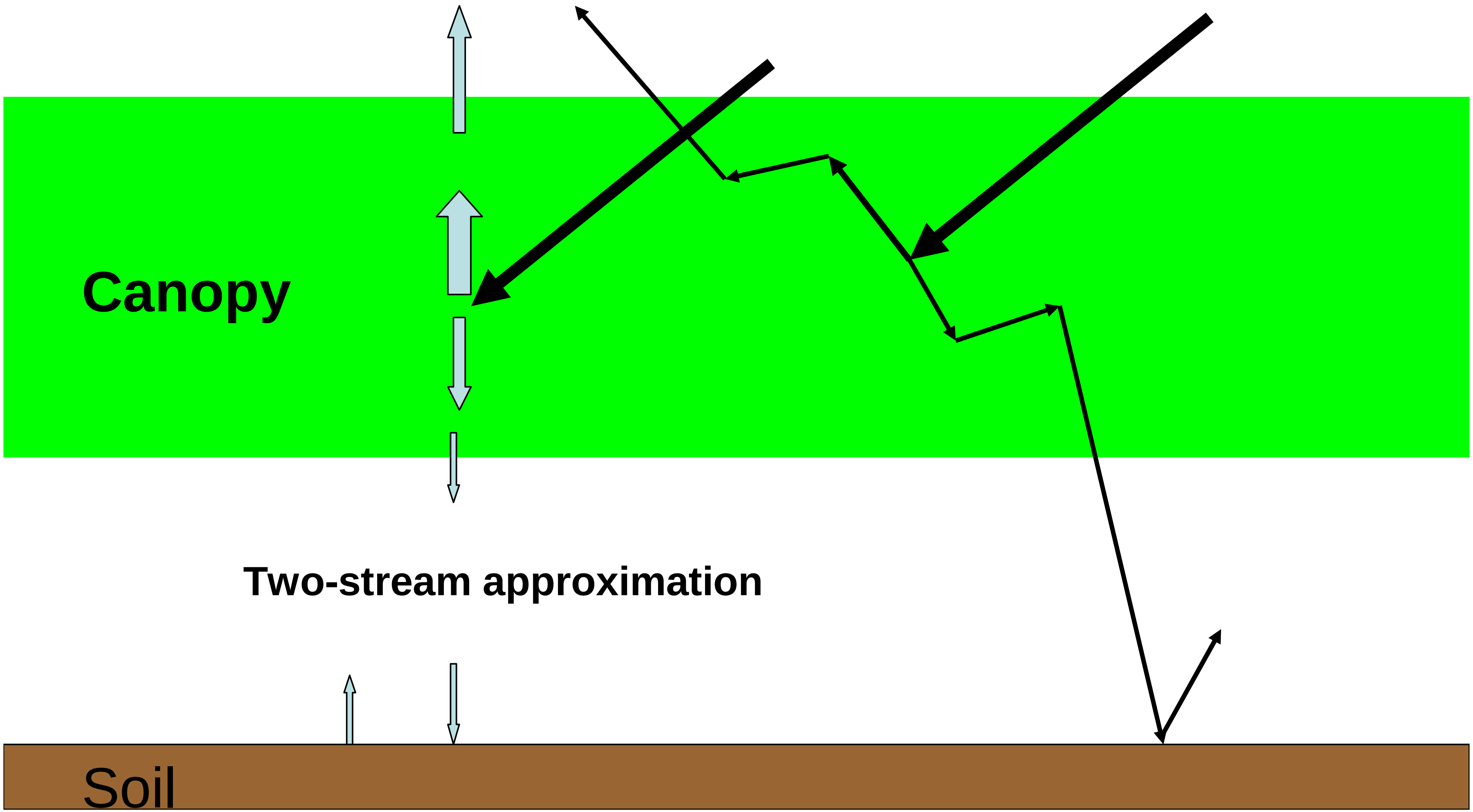
Overview of a typical land-surface flux model

Key processes:

- Radiative transfer
- Leaf energy balance
- Stomatal conductance
- Water flow through soil & plant
- Photosynthesis
- Not discussed
  - Plant and soil respiration
  - heat, water transfer in soil and snow

(Leaf energy balance, Stomatal conductance, Water flow through soil & plant, Photosynthesis:) 2-leaf canopy model

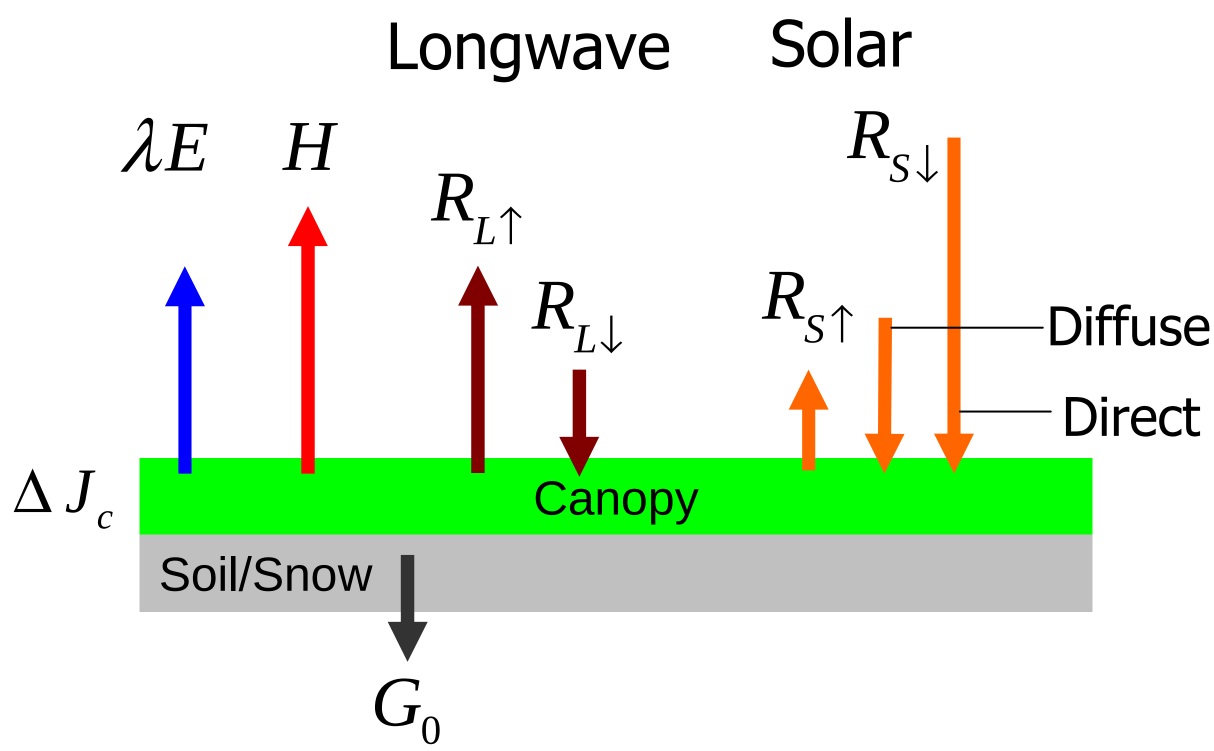
Two-stream radiation approximation



Three radiation wavebands

- Solar radiation :
  - Visible (0.4 to 0.7 μm), 46-50%
  - Near infra red (0.7 to 1.5 μm) 44-46%
- Long-wave (thermal) radiation >10 (μm)
  - Emitted by anything with a temperature >0°K
- Sunlit & shaded leaves considered separately
  - Reflection, transmission & absorption

Canopy energy balance



$$\overbrace{R_{S\downarrow} - R_{S\uparrow} + R_{L\downarrow} - R_{L\uparrow}}^{R_n} - H - \lambda E - G_0 - \Delta J_c = 0$$

solar longwave heat evap^n soil storage

Canopy fluxes – big leaves + soil

$$R_n - G_0 - \Delta J_c = \lambda E + H$$ Energy balance

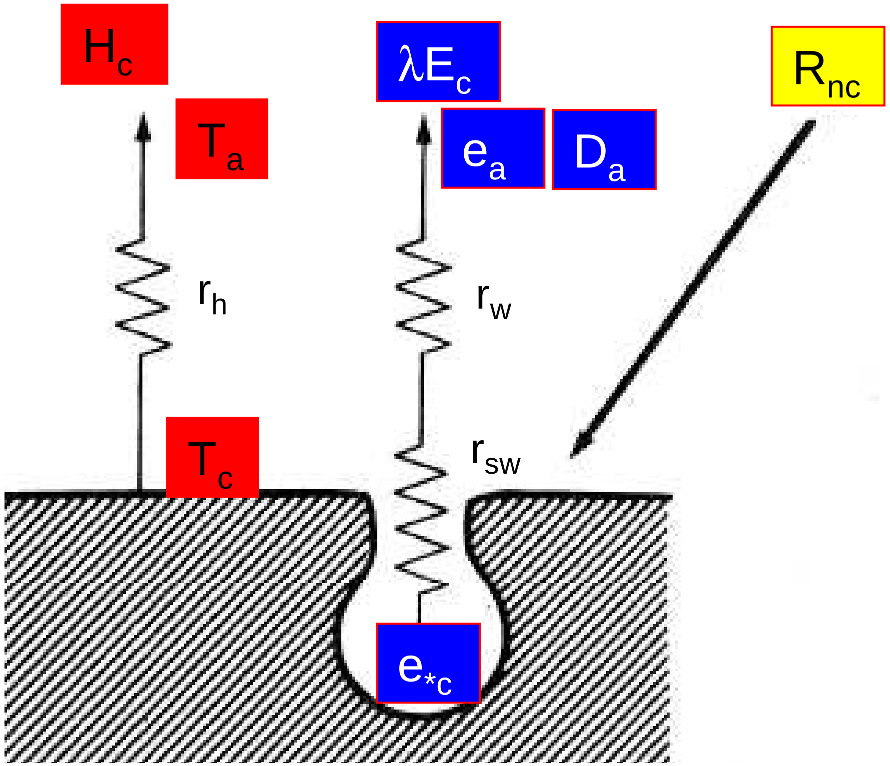
$$\lambda E = \sum_{i=1,2} \lambda E_{c,i} + \lambda E_s$$ Evaporation

$$H = \sum_{i=1,2} H_{c,i} + H_s$$ Sensible heat

$$F_c = \sum_{i=1,2} A_{n,i} - R_p - R_s$$ CO_2 flux

$i = 1$ *sunlit 'big' leaf* $i = 2$ *shaded 'big' leaf*

Energy balance of 'big' leaf



$$R_{nc} - \Delta J_c = \lambda E_c + H_c$$

$$H_c = c_p \rho_a (T_c - T_a) / r_h$$

$$\lambda E_c = \frac{\rho_a c_p}{\gamma} \frac{e_c^* - e_a}{r_w + r_{sw}}$$

Unknowns

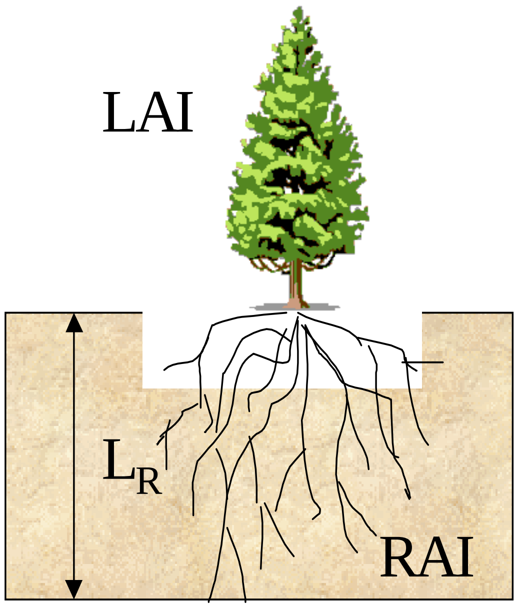
$$H_c, E_c, T_c \; \& \; r_{sw}$$

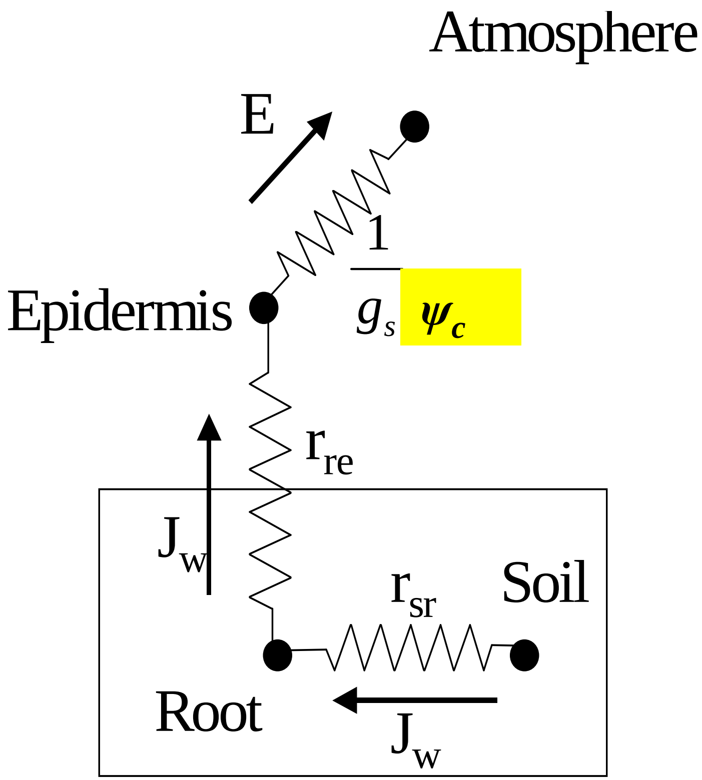
$$r_h = r_{bh} / 2 + r_{ah}$$

$$r_w = r_{bw} + r_{aw}$$

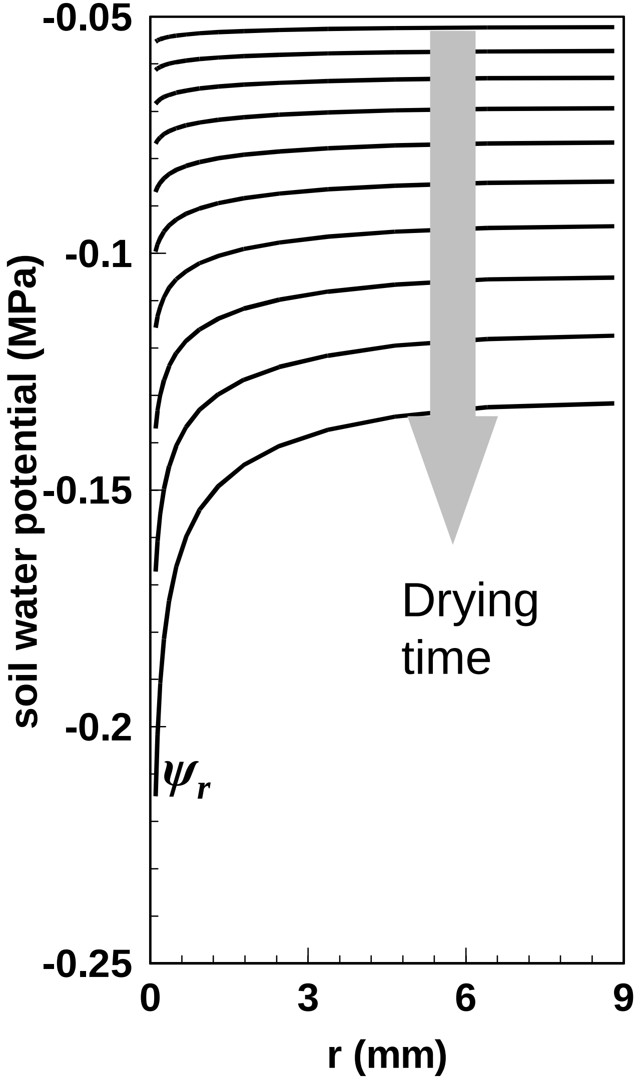
4 unknowns with only three equations?

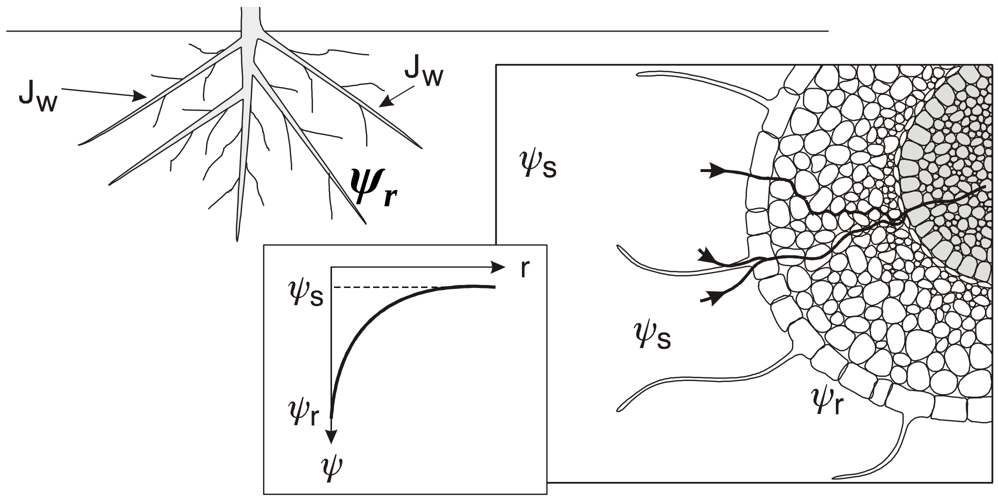
Water flow through plant



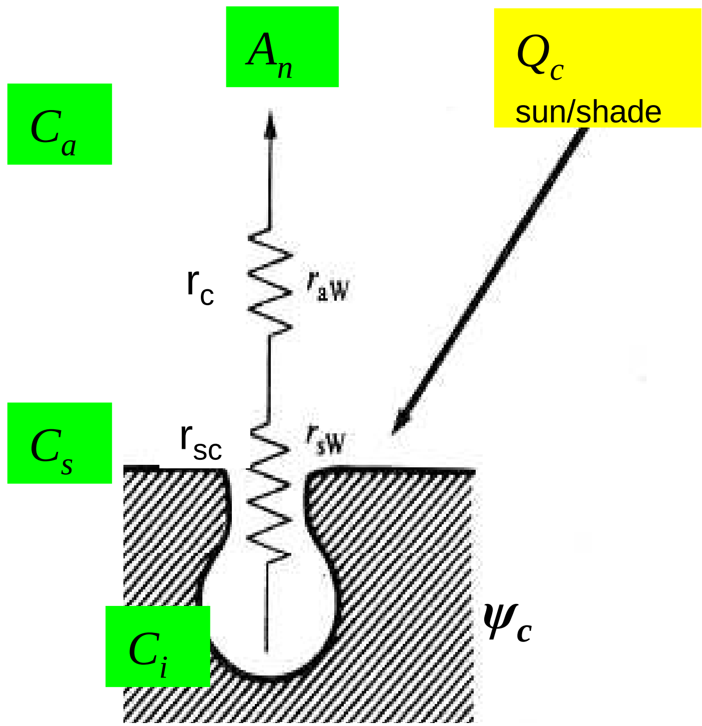


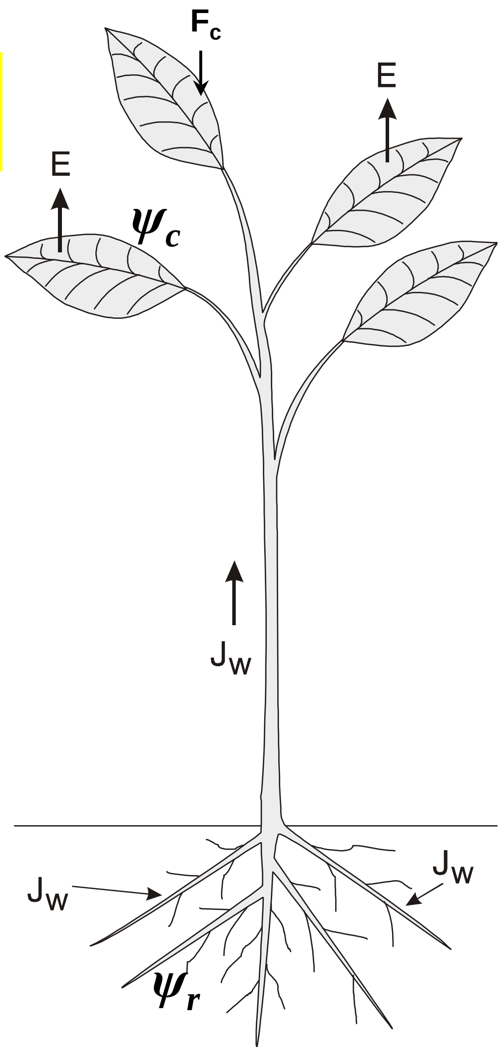
Soil water potential vs radial distance from root

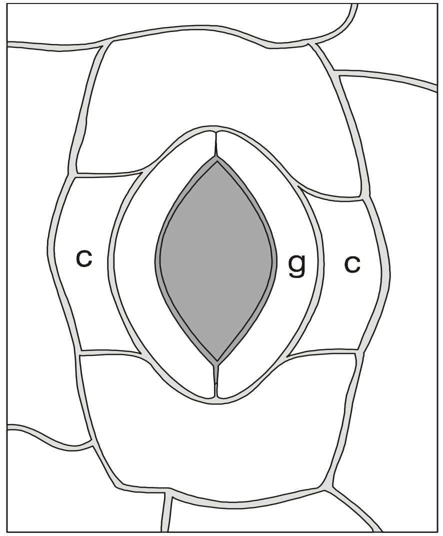


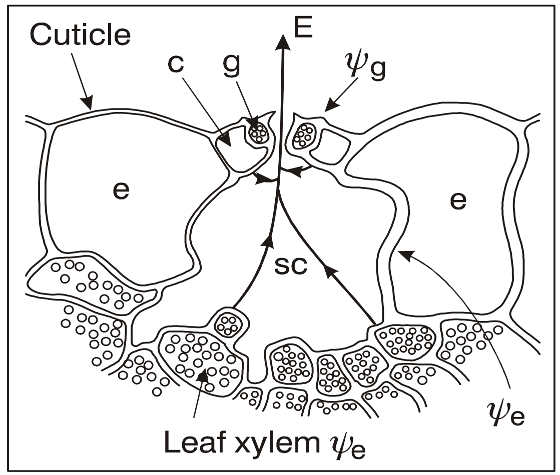


Stomata – linking photosynthesis & transpiration

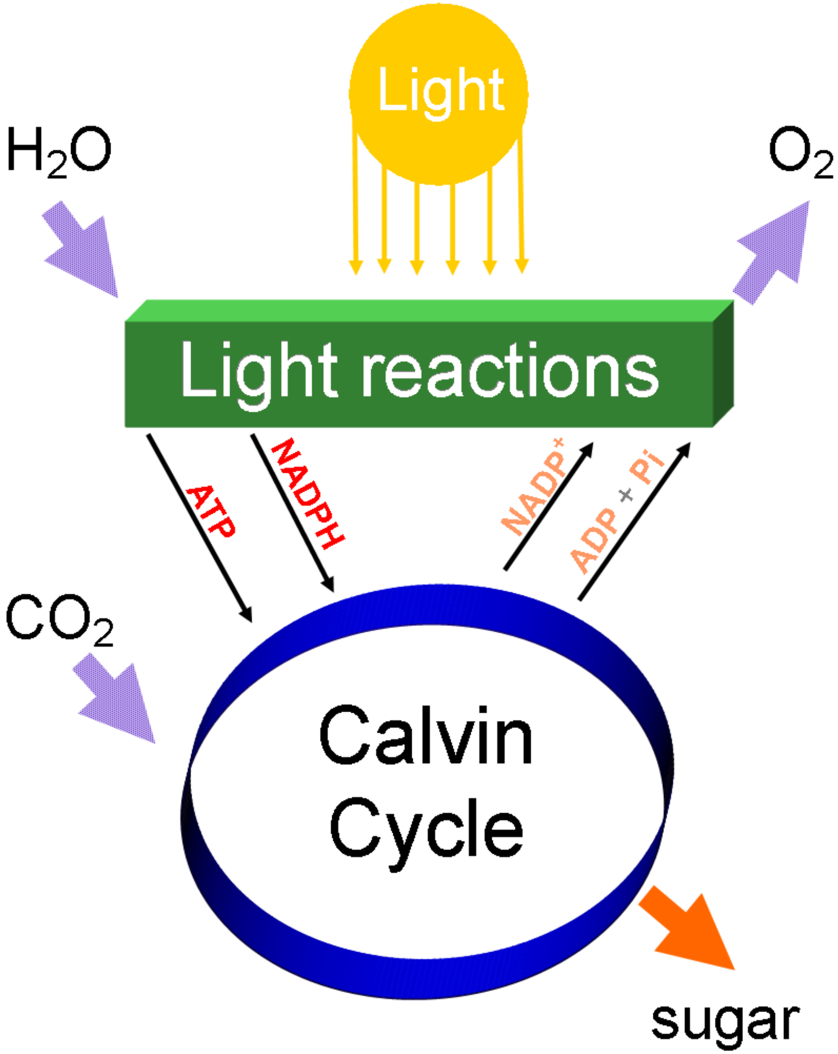








Leaf photosynthesis: simple overview



Coupled leaf energy balance, photosynthesis & stomatal conductance

$$R_{nc} = \lambda E_c + H_c$$

$$H_c = c_p \rho_a (T_c - T_a) / r_h$$

$$\lambda E_c = \frac{c_p \rho_a}{\gamma} \frac{e_c^* - e_a}{r_w + r_{sw}}$$

$$A_n = \min\left(V_c, V_j\right) - R_d$$

$$A_n = g_{sc}(c_s - c_i)$$

$$g_{sc} = g_{c0} + \frac{a\ A_n}{c_i - \Gamma} \cdot f_{\psi c}$$

Ball-Berry-Leuning model

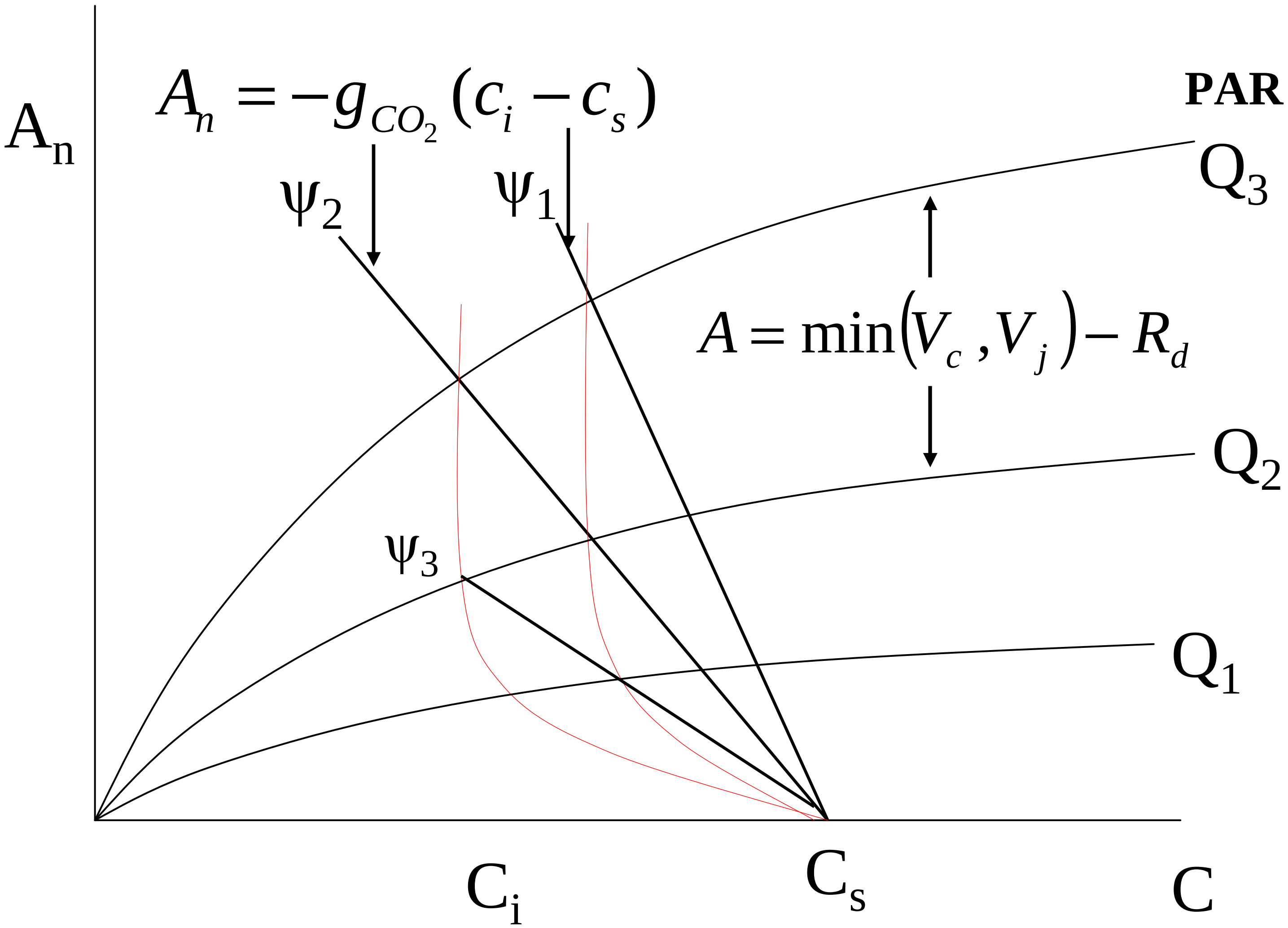
Links photosynthesis, stomatal conductance and transpiration

Unknowns

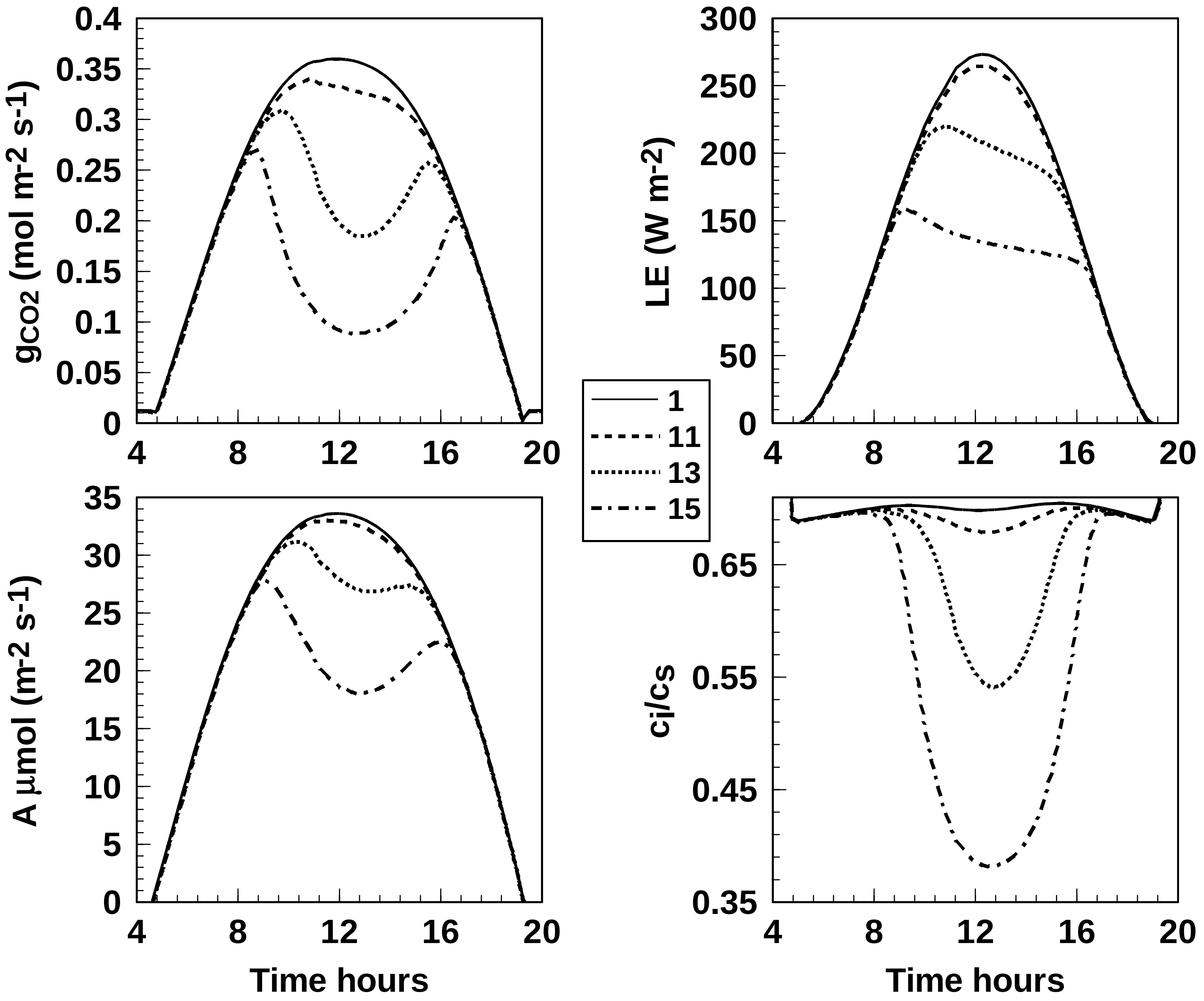
$$H_c, E_c, T_c, \psi_c, C_i, A_n, \&\ g_{sc}$$

7 unknowns with 7independent equations & many parameters for auxiliary equations

Demand - supply for CO_2



Predictions for plant canopies during a soil drying cycle



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Measurements

Use to test model performance and to estimate model parameter values

e.g. Tumbarumba Ozflux site

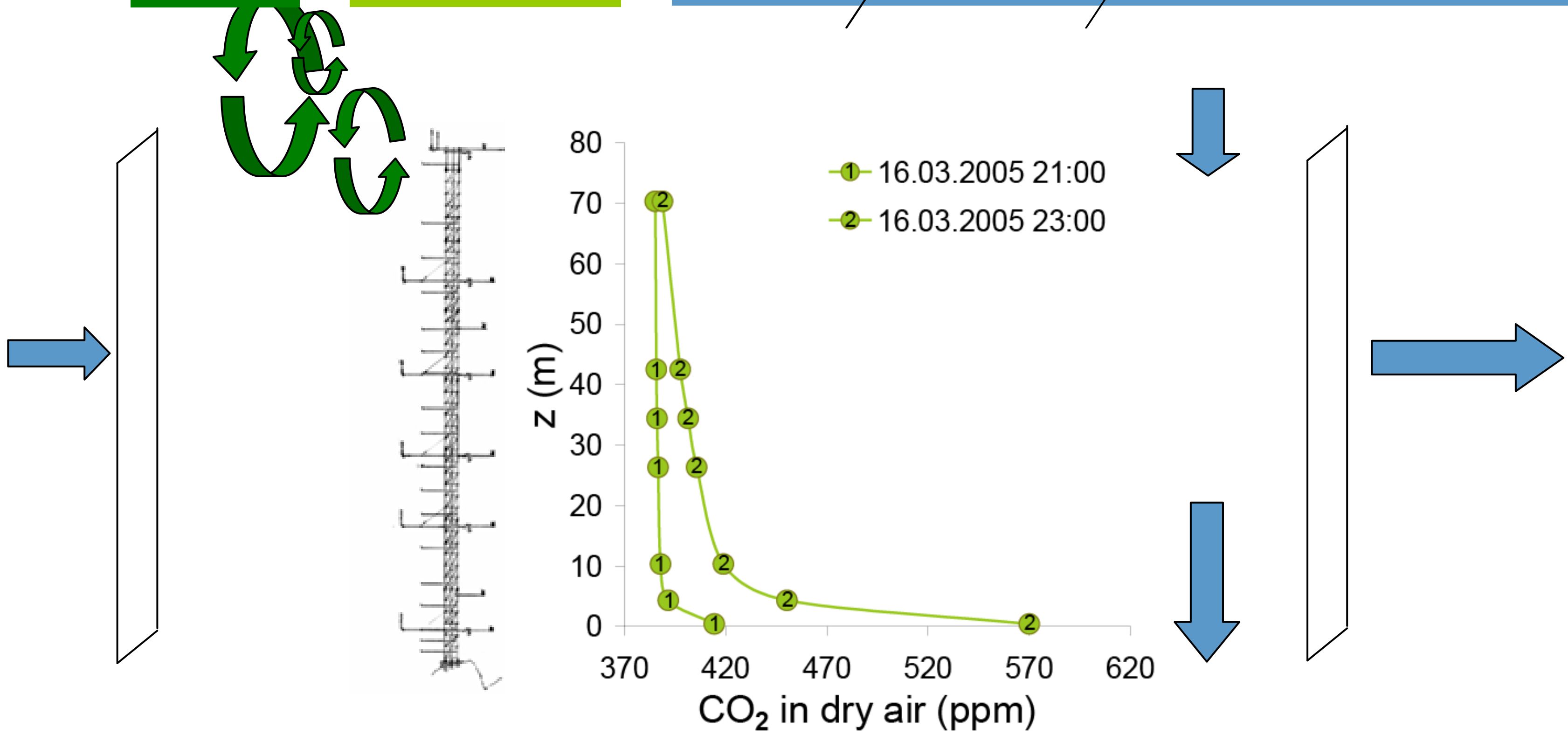
70 m tower in 40 m temperate Eucalyptus forest
Continuous measurements at 70 m:

- eddy fluxes (H, λE, CO_2)
- R_{net}
- upward and downward solar radiation fluxes
- meteorological measurements
- continuous temperature and water vapour profiles

Tumbarumba - micrometeorology

Micrometeorology – mass balance

$$F_c = \overline{c_d}\,\overline{w'\chi_c'} + \int_0^{h_r} \overline{c_d}\,\frac{\partial \overline{\chi_c}}{\partial t}\,dz + \frac{1}{L^2}\int_0^L\int_0^L\int_0^{h_r}\left[\overline{uc_d}\,\frac{\partial \overline{\chi_c}}{\partial x} + \overline{vc_d}\,\frac{\partial \overline{\chi_c}}{\partial y} + \overline{wc_d}\,\frac{\partial \overline{\chi_c}}{\partial z}\right]dx\,dy\,dz$$



Tumbarumba - micrometeorology

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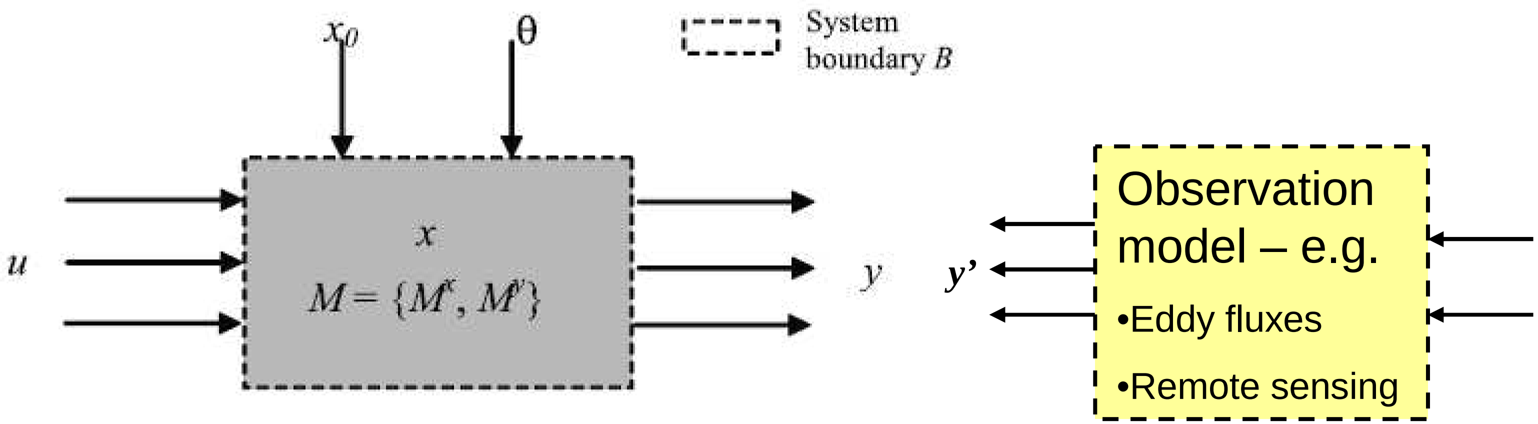
Schematic diagram of model components from a systems perspective



$$\text{minimize} \sum_i \left(y_i - y_i' \right)^2 \ldots$$

1. **system boundary, *B***
2. **inputs, *u***
3. **initial states, x_0**
4. **parameters, *θ***
5. **model structure, *M***
6. **model states, *x***
7. **outputs, *y***
8. **Observations, *y'***

Errors in each component affects model performance

Liu, Y. Q. and Gupta, H. V. (2007). Uncertainty in Hydrologic Modeling: Toward an Integrated Data Assimilation Framework. *Water Resources Research* 43, W07401, doi:10.1029/2006/WR005756.

Scaling up – non-lineararity

How do we transfer knowledge at one scale to another?

Linear models are scale-independent

$$y = ax + b$$

Variables

Parameters

Double x, double y

Not true for non-linear models

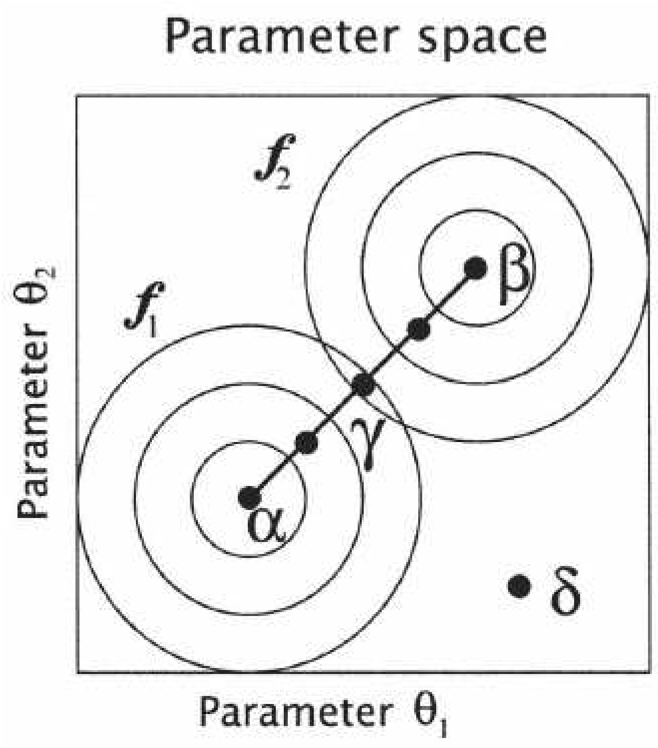
$$R = R_0 \exp(\alpha T)$$

Soil respiration

Temperature

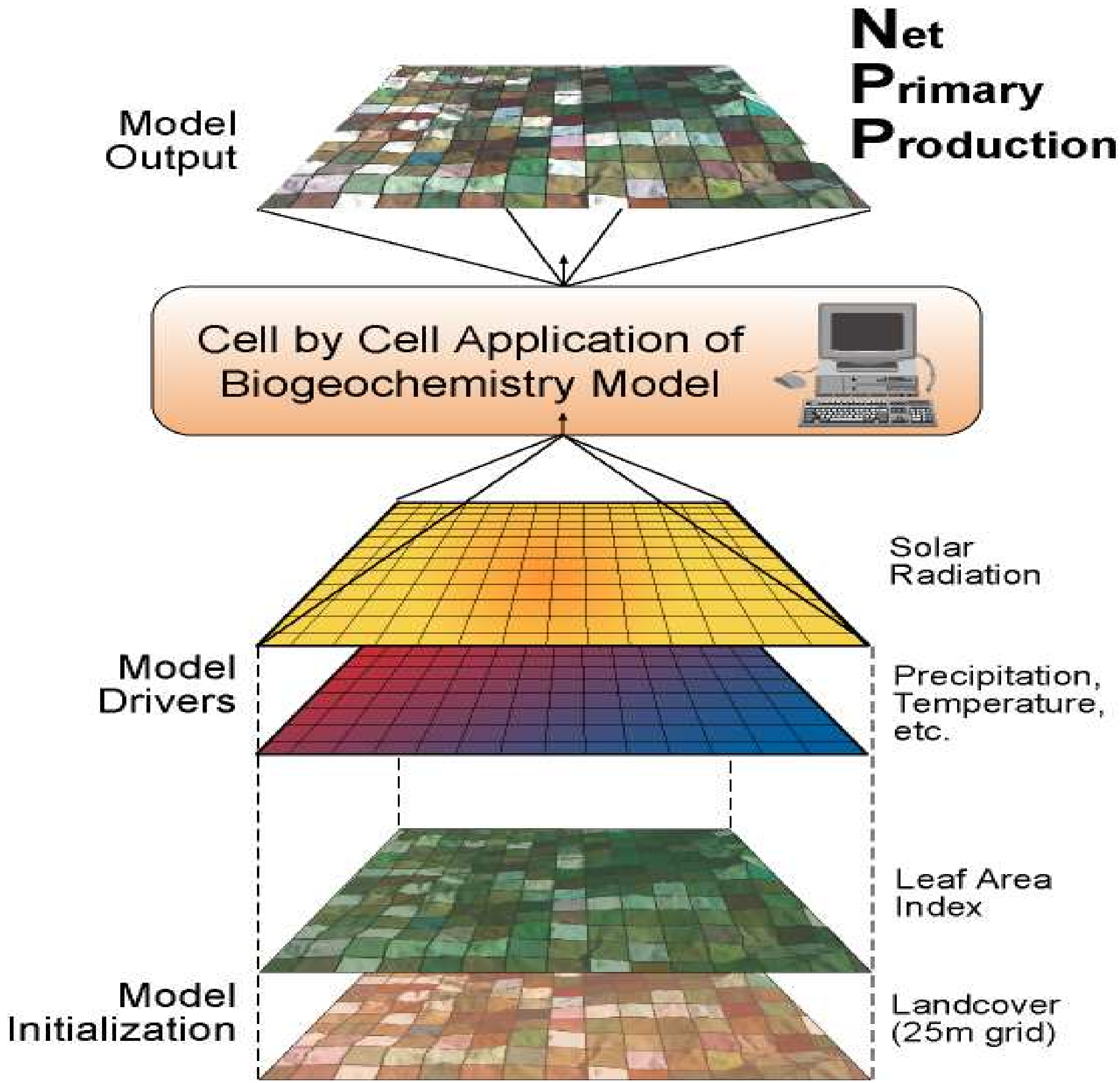
Double *T*, do not double *R*

Parameter estimation
Multiple criteria possible, e.g. λE, NEE



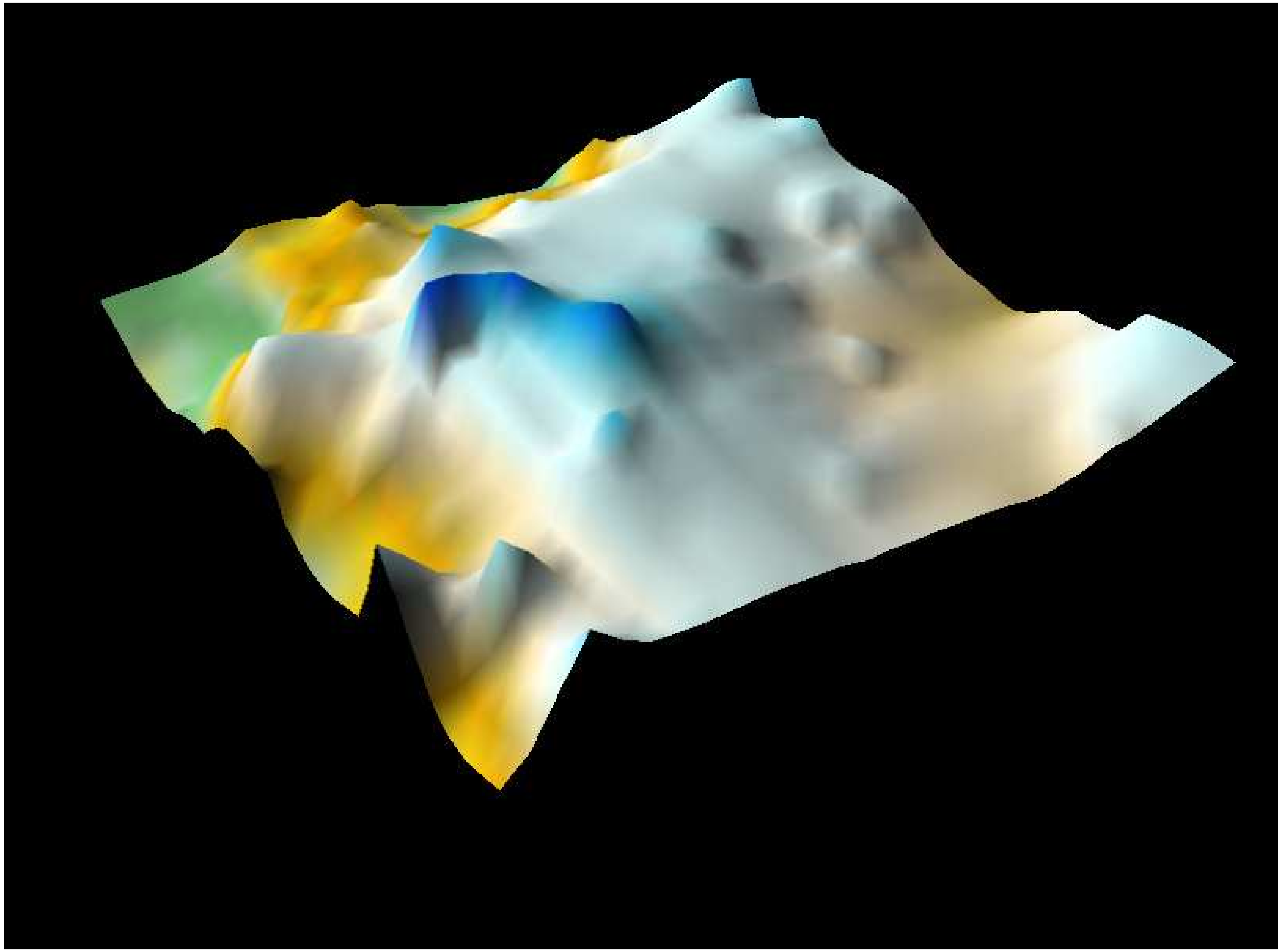
The dark line between the two criteria's minima, α and β, represents the Pareto set

Scaling using land surface models and data layers

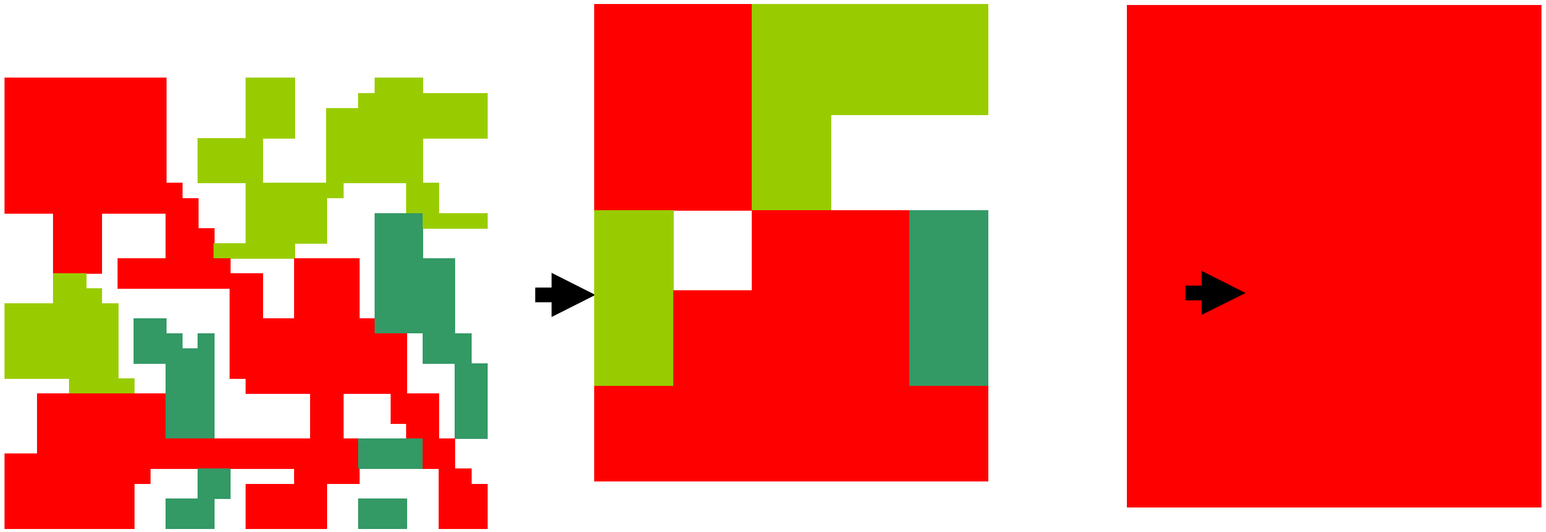


Courtesy
S. Running
U. of Montana

Scaling up - spatial heterogeneity, topography, climate, landcover



Scaling up - classification and aggregation of landcover classes



30 x 30

5 x 5

1 x 1

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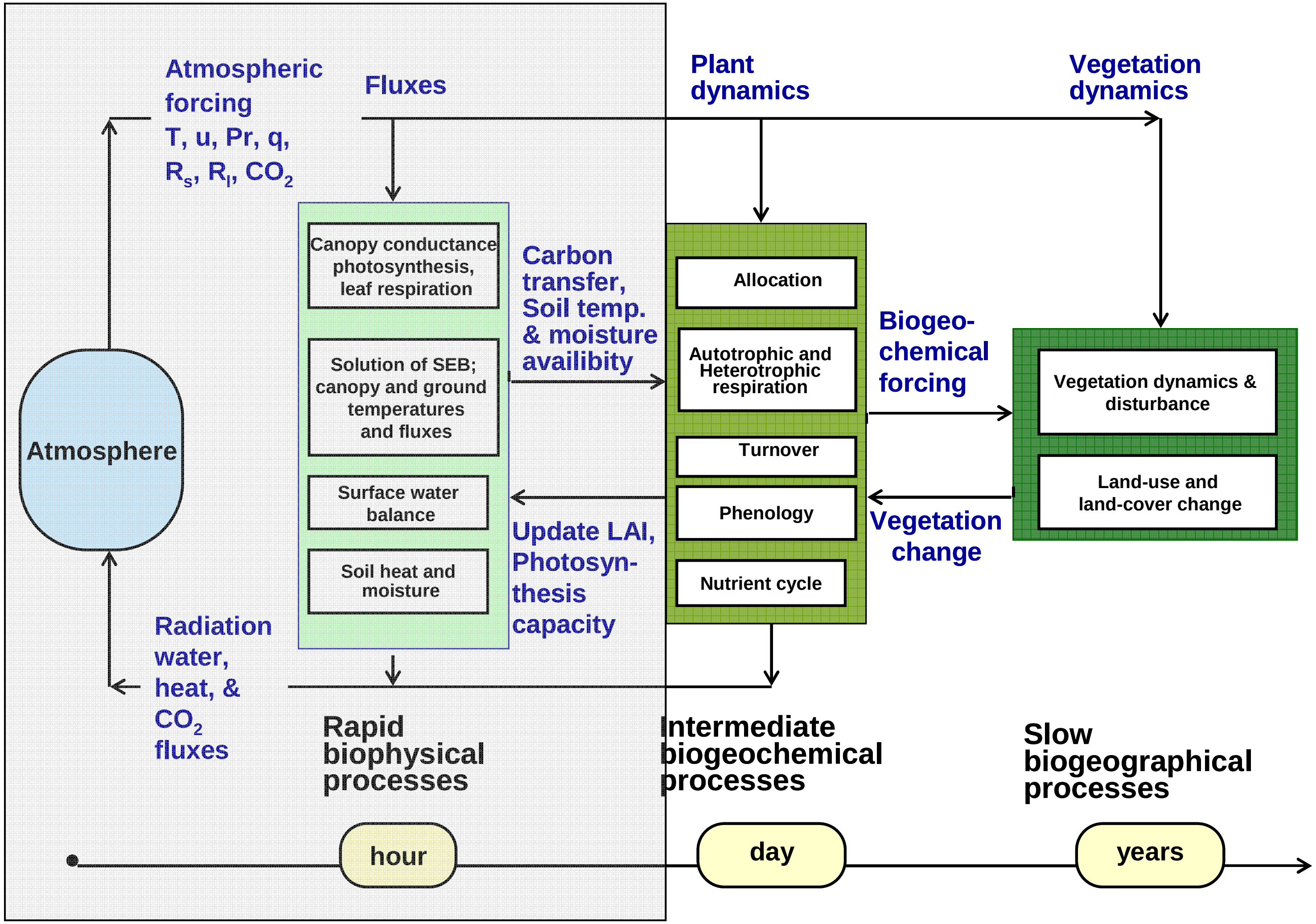
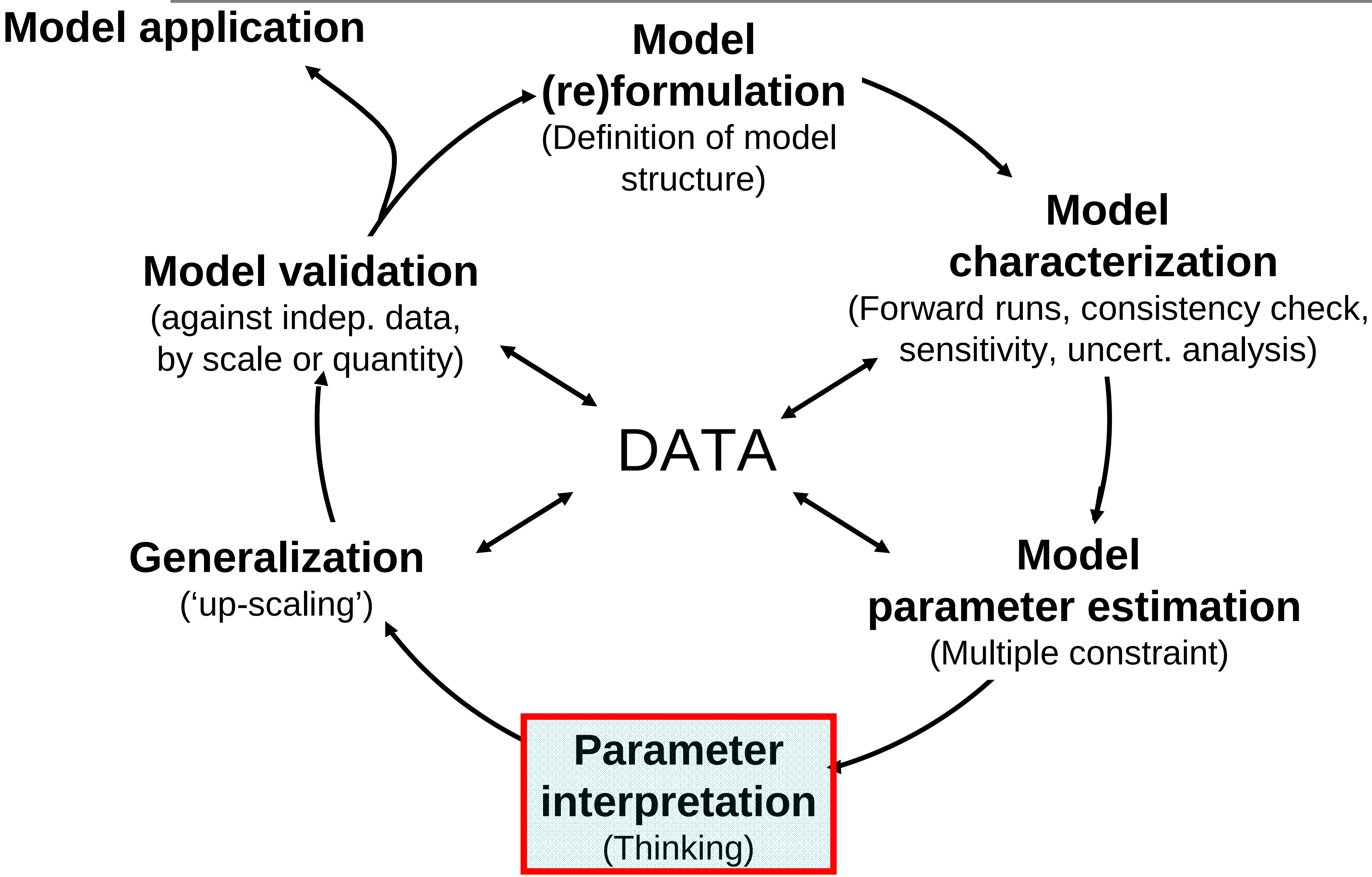
CABLE simulates processes at multiple time scales



Wang

Ideal model-data integration cycle (bottom-up)



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Summary

1. Knowledge of vegetation response to changing climate is needed at all scales from individual plants, ecosystems to regions
2. Land surface schemes in climate models include many processes and parameters
3. Assume that parameter information at one scale can be used at higher scales
4. Problems with non-linear models “the scaling problem”, need to measure at scale we want predictions