Introduction to JULES

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JULES Training Workshop
University of Exeter
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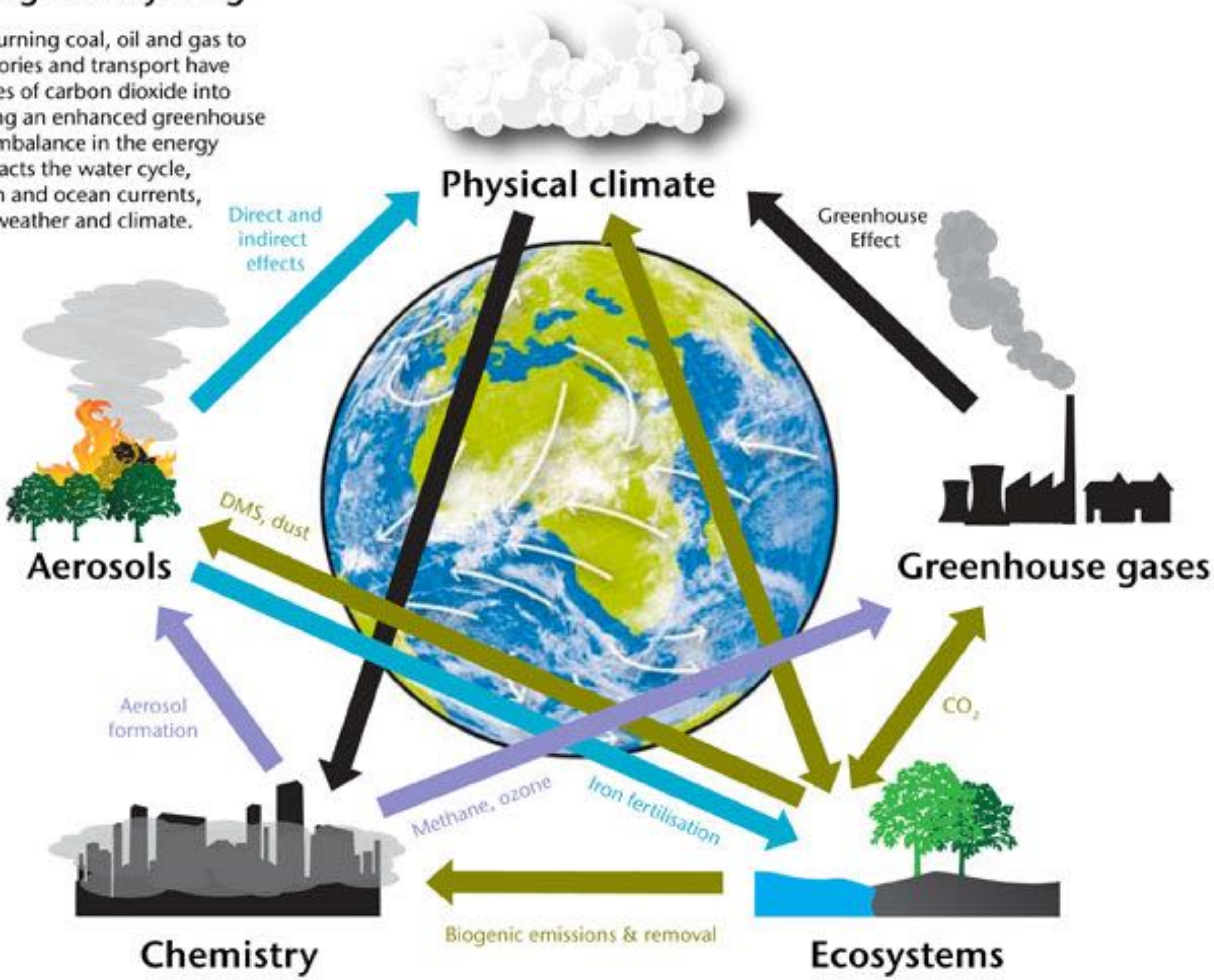
The Earth System

One thing changes everything

Human activities like burning coal, oil and gas to power our homes, factories and transport have released huge quantities of carbon dioxide into the atmosphere, causing an enhanced greenhouse effect. This causes an imbalance in the energy cycle that, in turn, impacts the water cycle, atmospheric circulation and ocean currents, leading to changes in weather and climate.



What is a land surface model?

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- Something that solves the energy and water budgets:
- Based on conservation of energy and mass

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$$Rn = \lambda E + SH + G$$

$$\frac{dS}{dt} = P - E - Rs - Rg$$

Net radiation=

Latent heat flux

+ Sensible heat flux

+ Ground heat flux

1st Generation LSM; Pitman 2003, *J. International Climatology*

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$$Rn = \lambda E + SH + G$$

$$\frac{dS}{dt} = P - E - Rs - Rg$$

Change in soil water=

Precipitation

+ Evaporation

+ Sub-surface runoff

+ Overland runoff

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- Based on conservation of energy and mass

$$Rn = \lambda E + SH + G$$

$$\frac{dS}{dt} = P - E - Rs - Rg$$

- Later generations added carbon budgets

Recipe for a JULES run

- Model code
- Namelists with parameter settings
  - Driving meteorological data
  - Soil physical properties
  - Model grid
  - Optional prescribed datasets (time-varying CO_2, land use, O_3)

So what about JULES?

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MOSES: surface exchange

P. M. Cox · R. A. Betts · C. B. Bunton
R. L. H. Essery · P. R. Rowntree · J. Smith

Climate Dynamics (1999)

The impact of new land surface physics on the GCM simulation of climate and climate sensitivity

A canopy conductance and photosynthesis model for use in a GCM land surface scheme

P.M. Cox[a,*], C. Huntingford[b], R.J. Harding[b]

Journal of Hydrology 212–213 (1998) 79–94

+

TRIFFID: dynamic vegetation

Description of the "TRIFFID" Dynamic Global Vegetation Model

Peter Cox

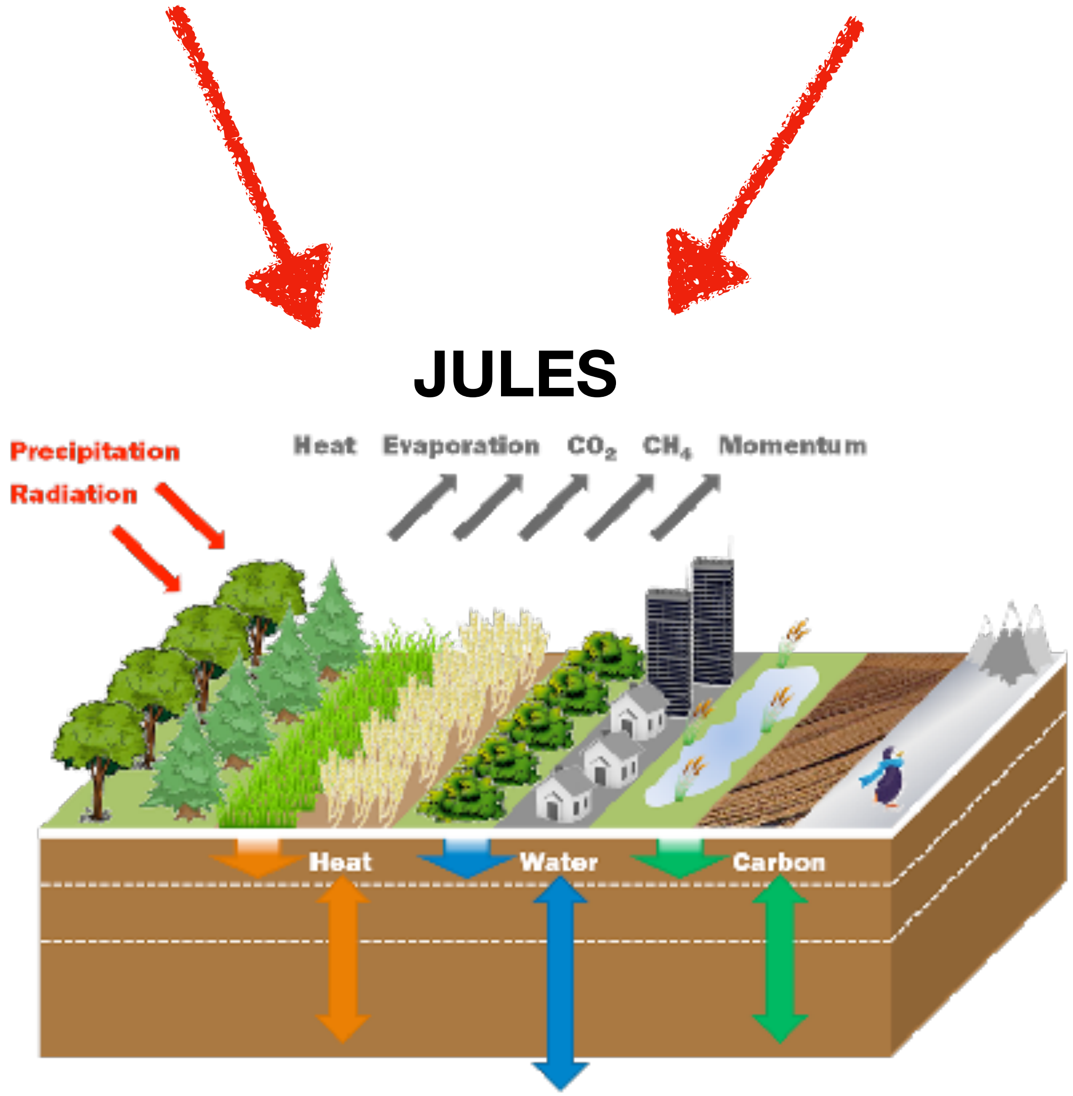
Hadley Centre, Met Office, London Road, Bracknell, Berks R12 2SY, UK
pmcox@meto.gov.uk

January 17, 2001

So what about JULES?

MOSES: surface exchange

TRIFFID: dynamic vegetation



The Joint UK Land Environment Simulator (JULES), model description – Part 1: Energy and water fluxes

M. J. Best[1], M. Pryor[2], D. B. Clark[3], G. G. Rooney[1], R .L. H. Essery[4], C. B. Ménard[4], J. M. Edwards[1], M. A. Hendry[1], A. Porson[1], N. Gedney[2], L. M. Mercado[3], S. Sitch[5], E. Blyth[3], O. Boucher[1,*], P. M. Cox[6], C. S. B. Grimmond[7], and R. J. Harding[3]

The Joint UK Land Environment Simulator (JULES), model description – Part 2: Carbon fluxes and vegetation dynamics

D. B. Clark[1], L. M. Mercado[1], S. Sitch[2], C. D. Jones[3], N. Gedney[4], M. J. Best[3], M. Pryor[4], G. G. Rooney[3], R. L. H. Essery[5], E. Blyth[1], O. Boucher[3,*], R. J. Harding[1], C. Huntingford[1], and P. M. Cox[6]

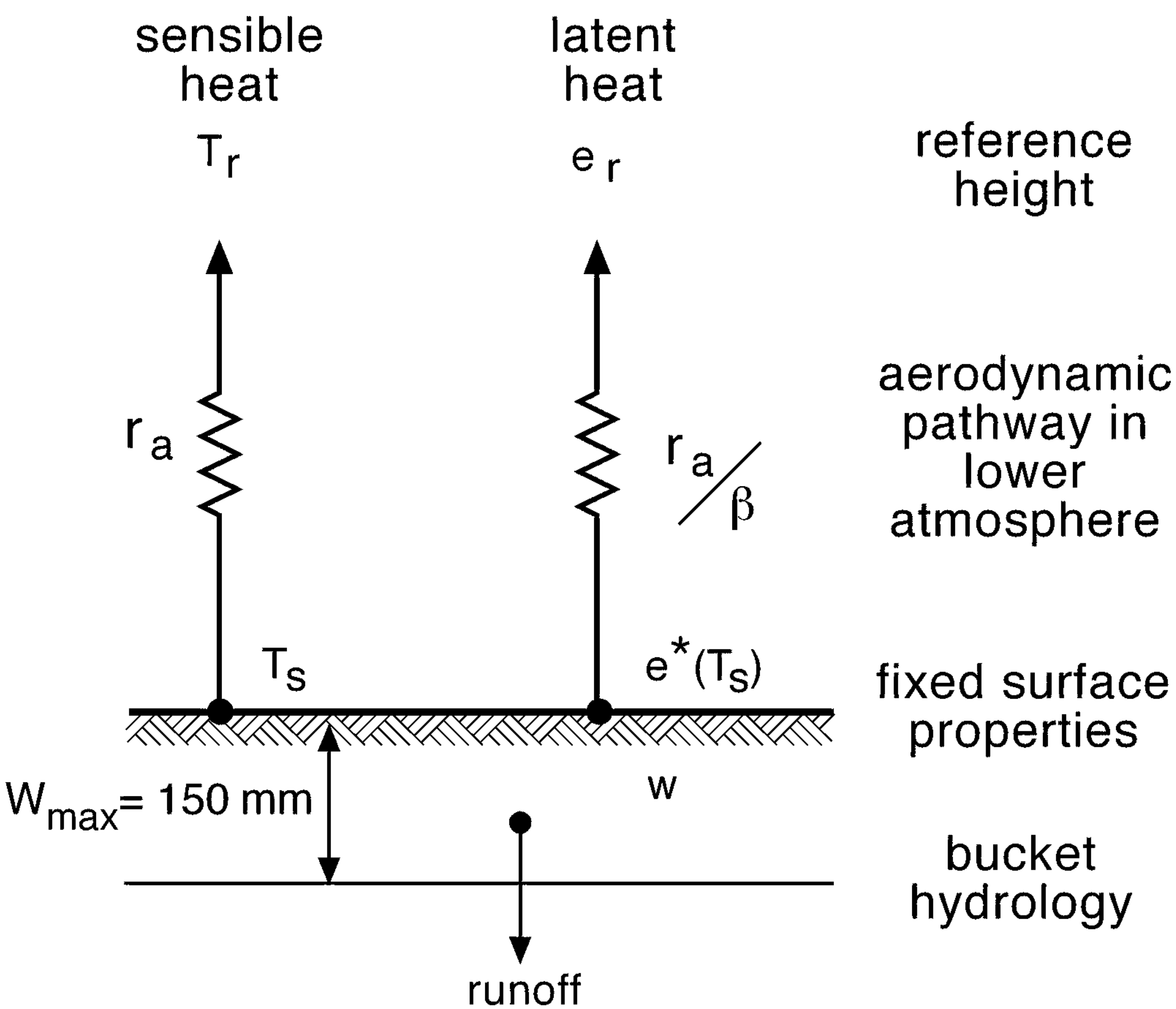
Vegetation distribution and terrestrial carbon cycle in a carbon cycle configuration of JULES4.6 with new plant functional types

Anna B. Harper[1], Andrew J. Wiltshire[2], Peter M. Cox[1], Pierre Friedlingstein[1], Chris D. Jones[2], Lina M. Mercado[3,4], Stephen Sitch[3], Karina Williams[2], and Carolina Duran-Rojas[1]

Evolution of LSMs

First generation

- "Bucket" model of hydrology
- No representation of vegetation



Sellers et al. 1997; Pitman 2003, *J. International Climatology*

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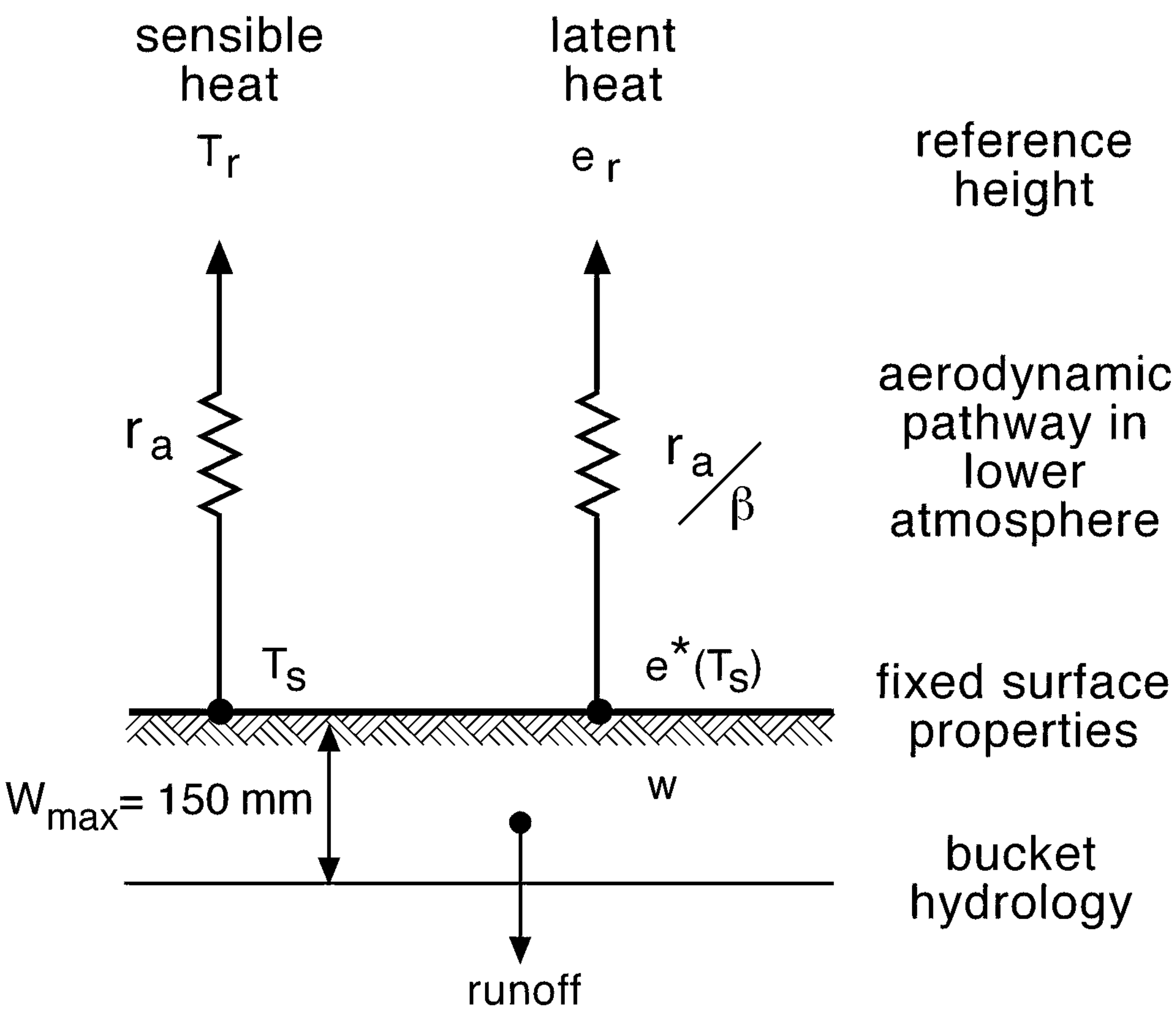

$$H = \frac{\rho c_p}{r_a}(T_* - T_A)$$

$$E = \frac{\rho}{r_a + r_s}(Q_{sat}(T_*) - Q_1)$$

From Best et al. 2011

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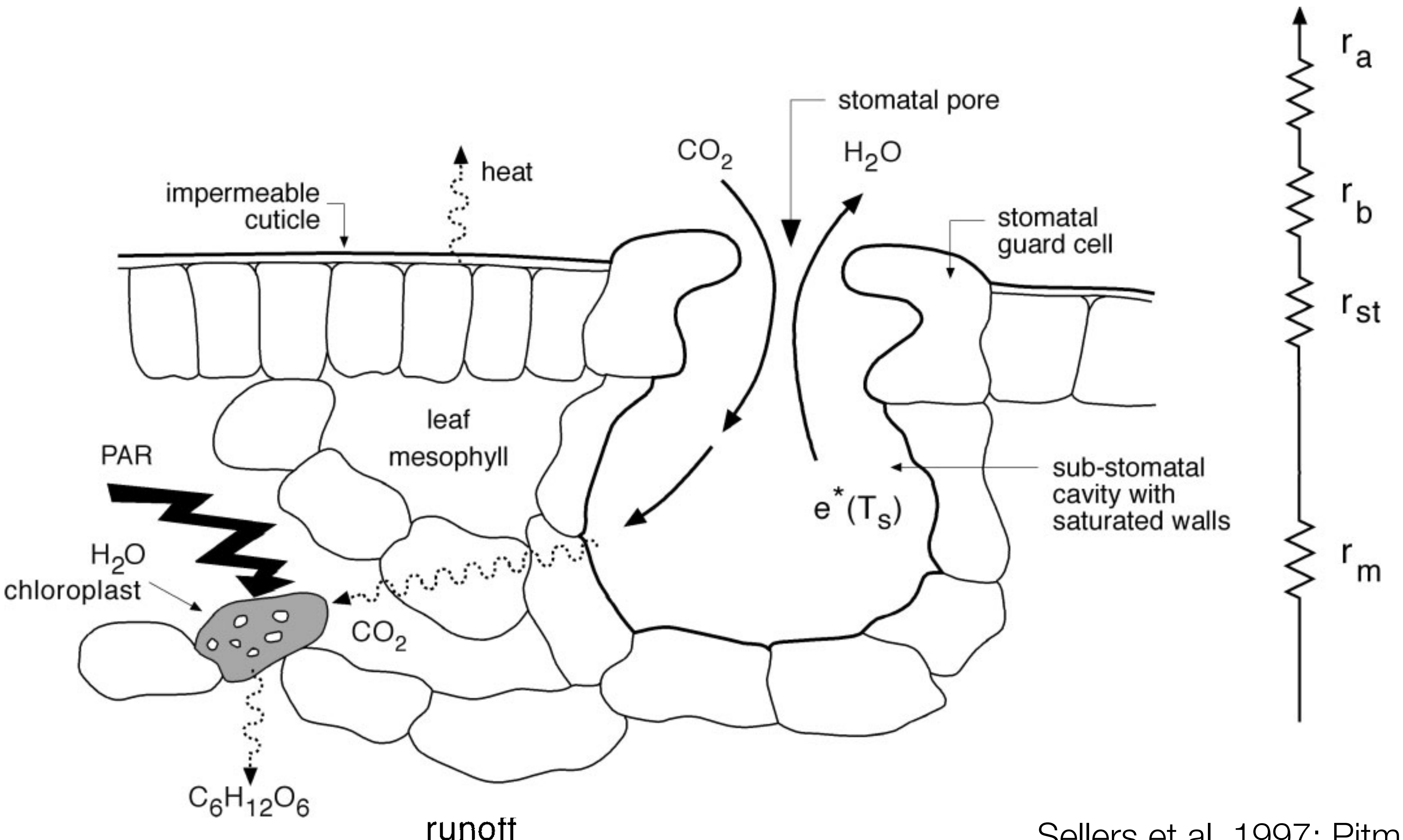

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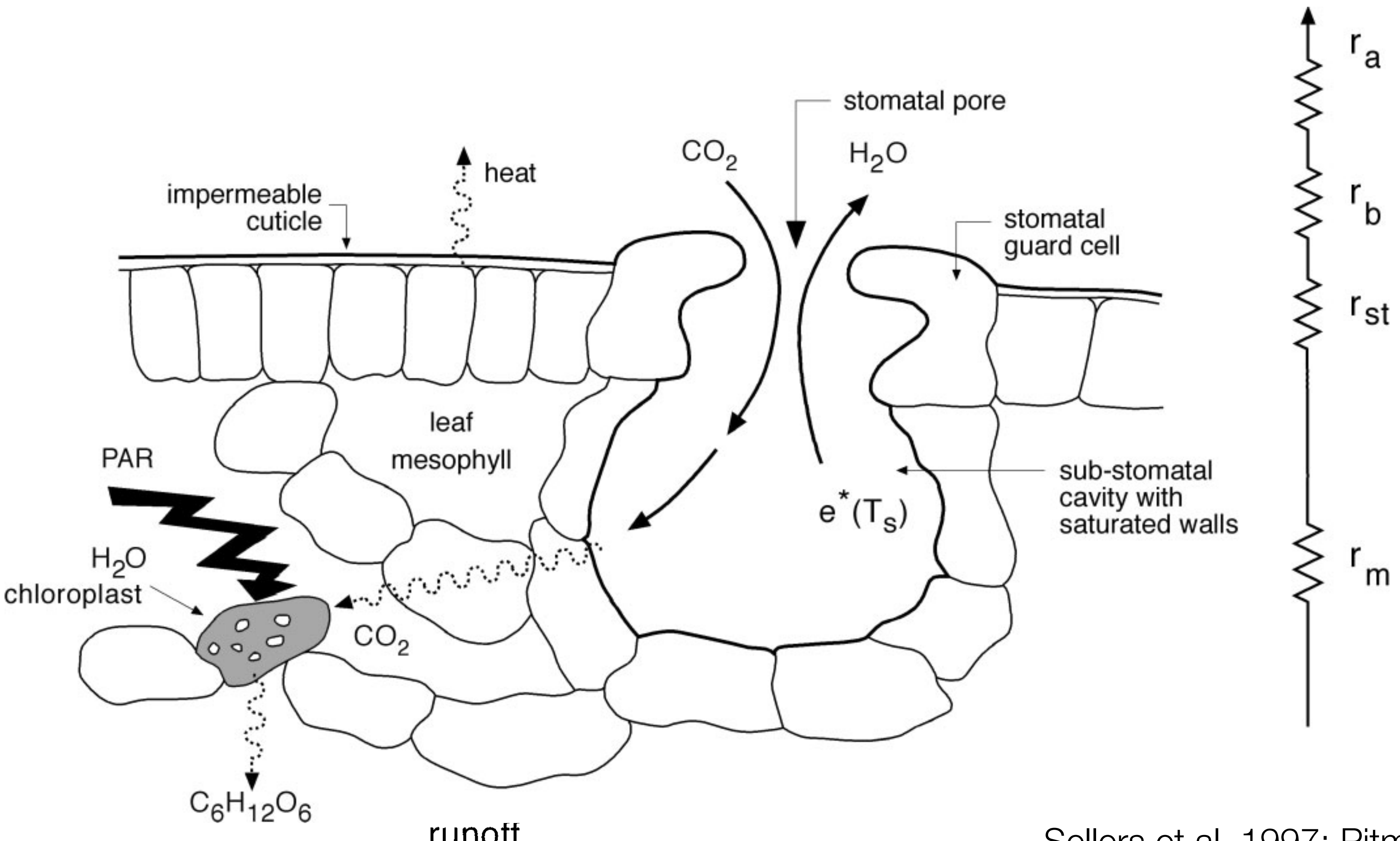

Calculations of photosynthesis and stomatal conductance

$$A = g_s (C_c - C_i)/1.6$$

$$A_P = \min(W_C, W_L, W_E)$$

From Clark et al. 2011

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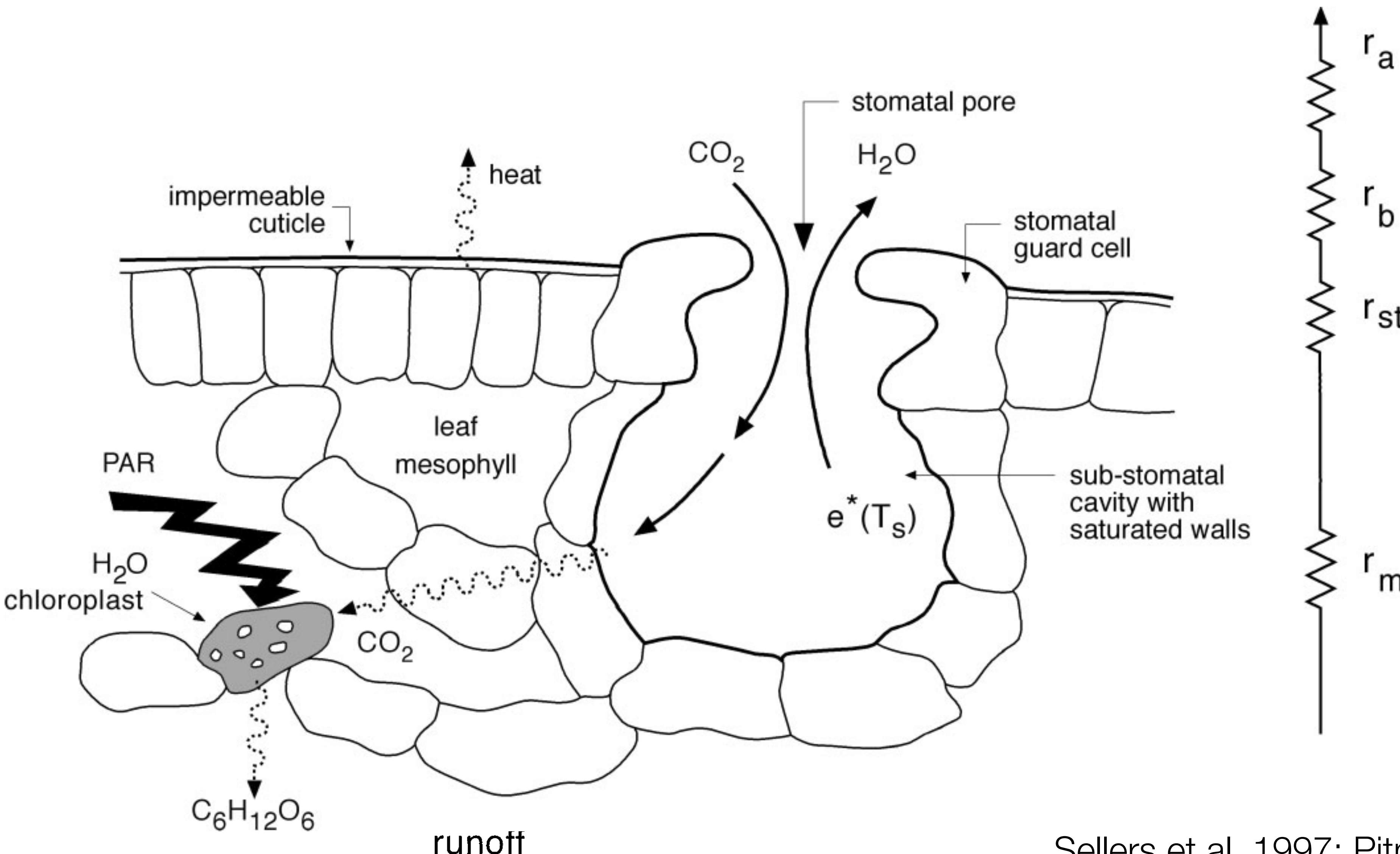

In the subroutine sf_stom

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- Scale from leaf to canopy **(depends on canopy radiation scheme)**
- Net primary production of plants input carbon into land, respiration removes it —> representation of terrestrial carbon cycle

Clark et al. 2011; Sellers et al. 1997; Pitman 2003, *J. International Climatology*

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Option	Leaf to canopy scaling	Radiation	N profile	Inhibition of leaf respiration in light
1	Big leaf	Beer's law	Beer's law	no
2	Multi-layer	Two stream	Constant through canopy	no
3	Multi-layer radiation with two classes (sunlit and shaded) for photosynthesis	Two stream	Constant through canopy	no
4	Multi-layer	Two stream	Decreases through canopy	yes
5	Multi-layer including sunlit and shaded leaves in each layer	Two stream with sunfleck penetration	Decreases through canopy	yes

Clark et al. 2011; Sellers et al. 1997; Pitman 2003, *J. International Climatology*

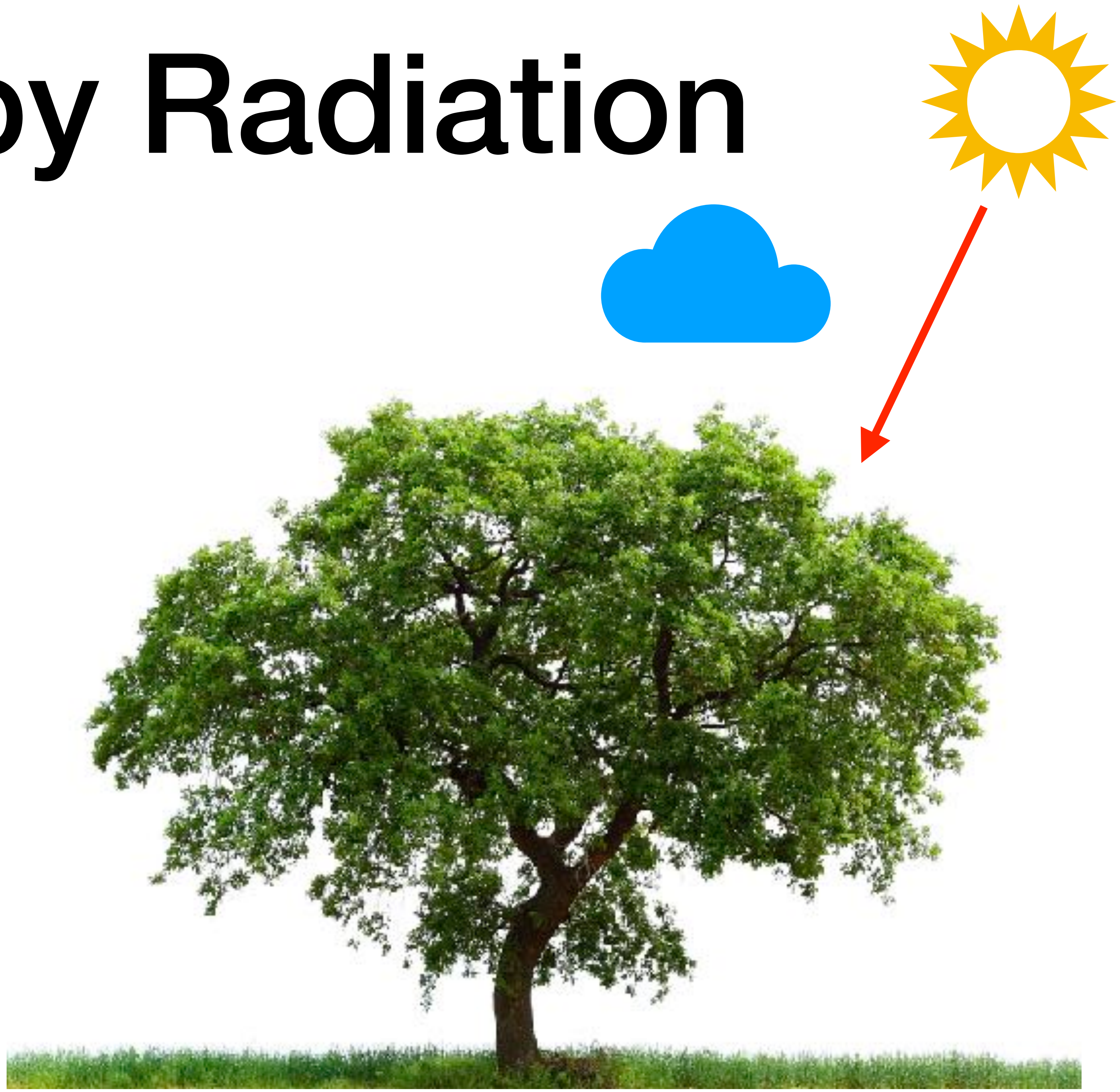
Canopy Radiation

<u>CanRadMod = 1</u>

Average, “big leaf”

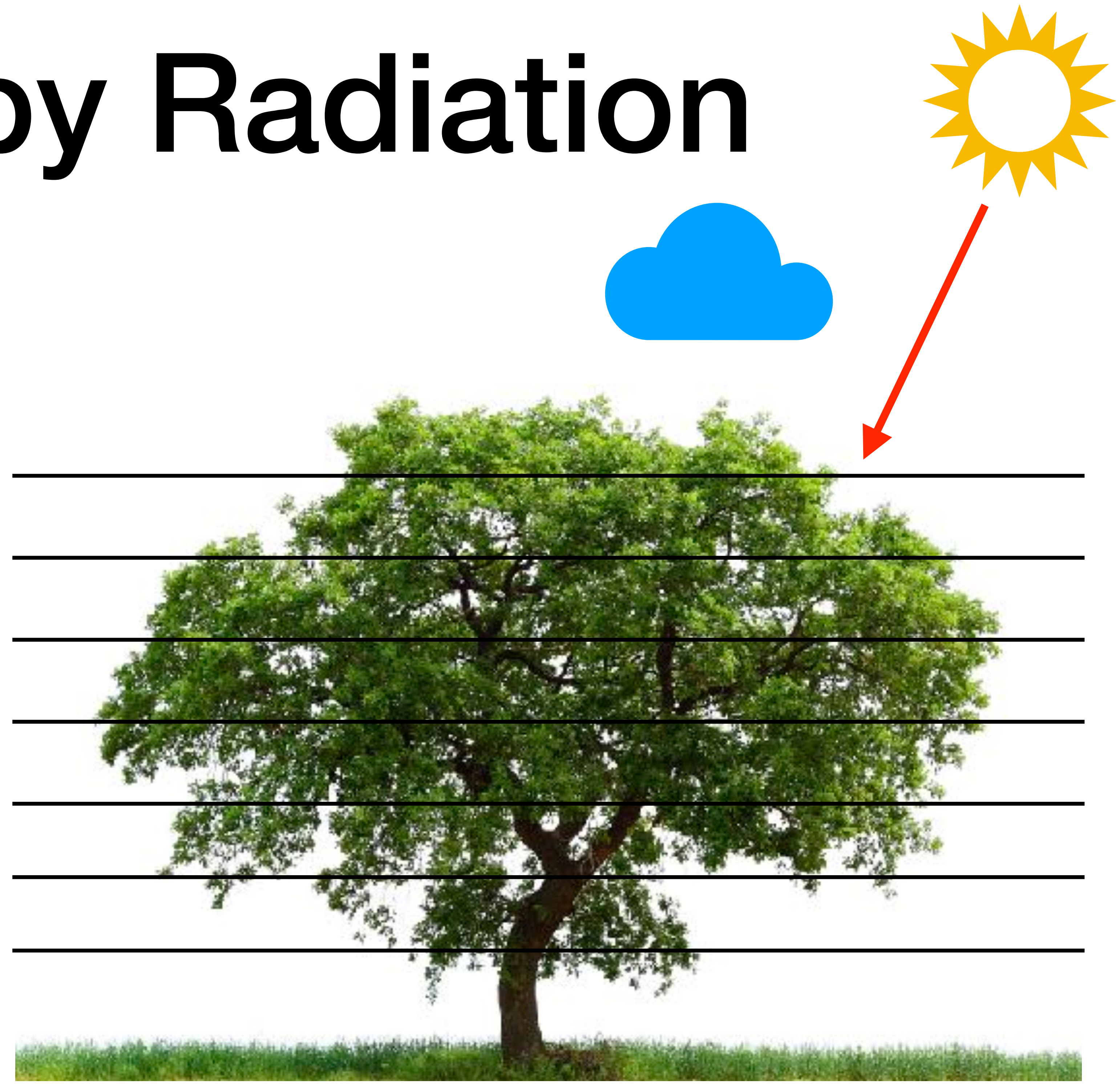
<u>CanRadMod = 6</u>

1. **Canopy divided into 10 layers**
2. **Direct and diffuse beam**
3. **Sunflecks**
4. **Leaf respiration inhibited in light**
5. **N decreases through canopy**



CanRadMod6: See Harper et al. 2018; Mercado et al. 2007

Canopy Radiation



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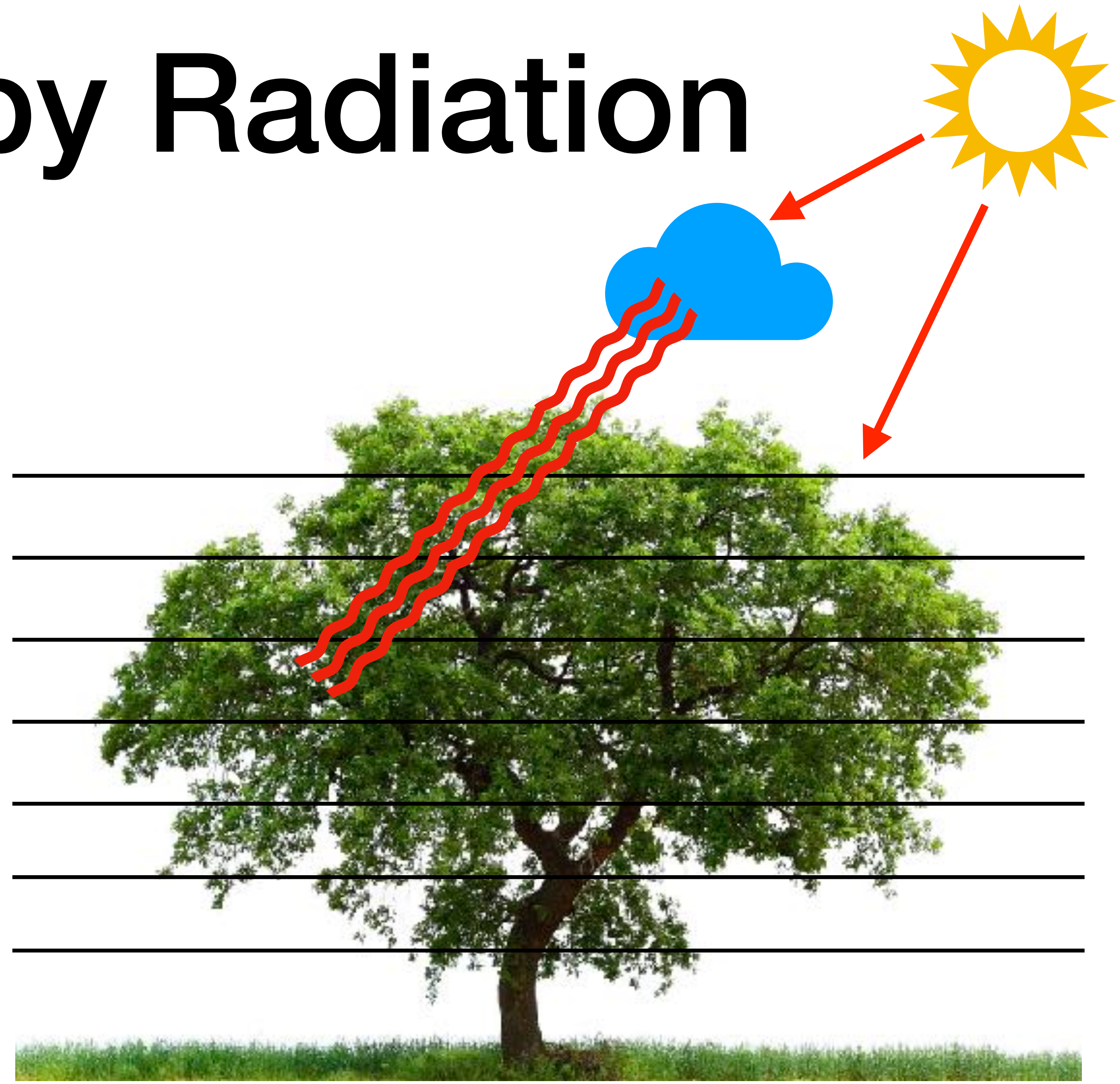

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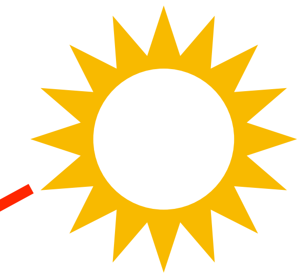

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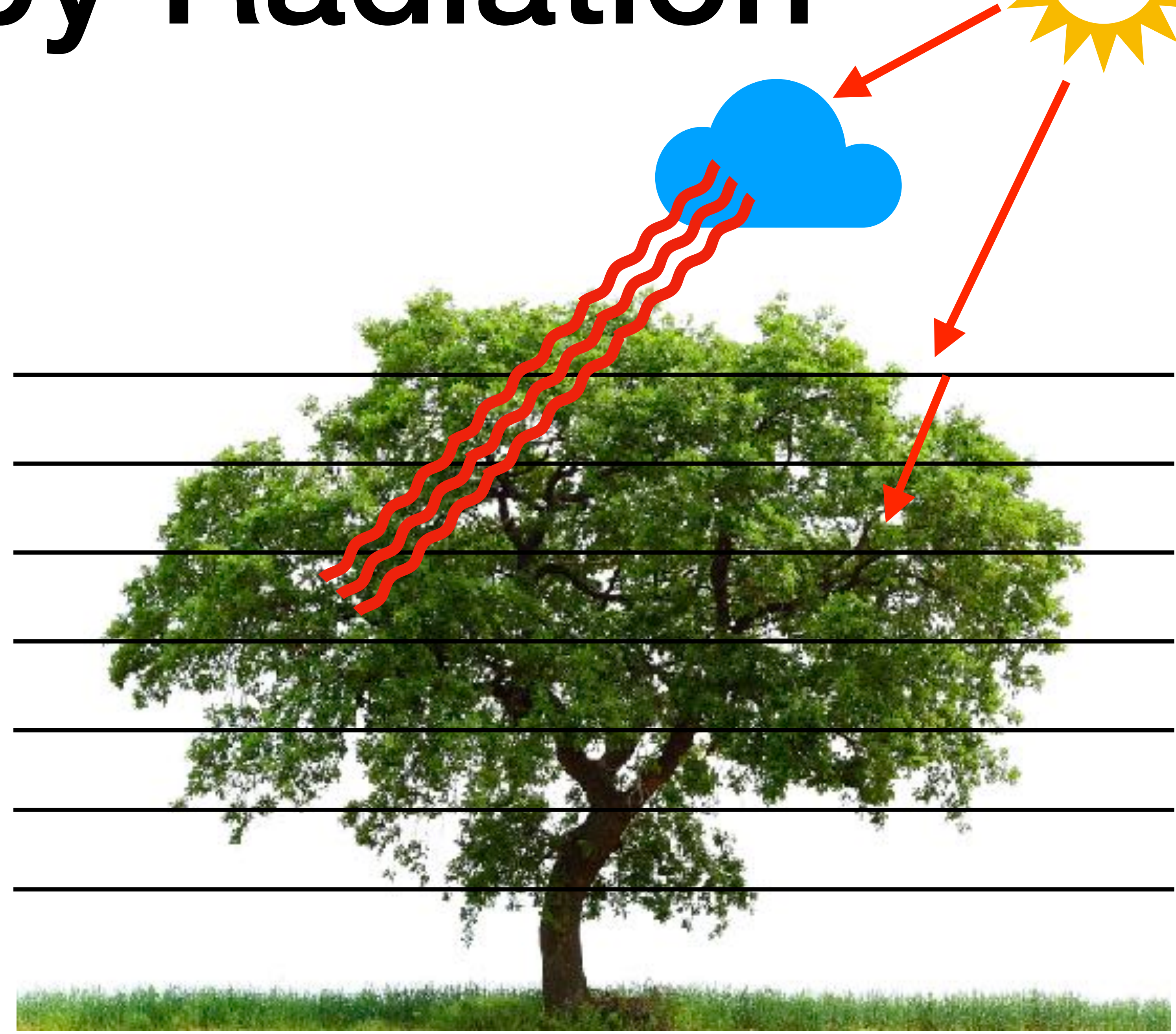

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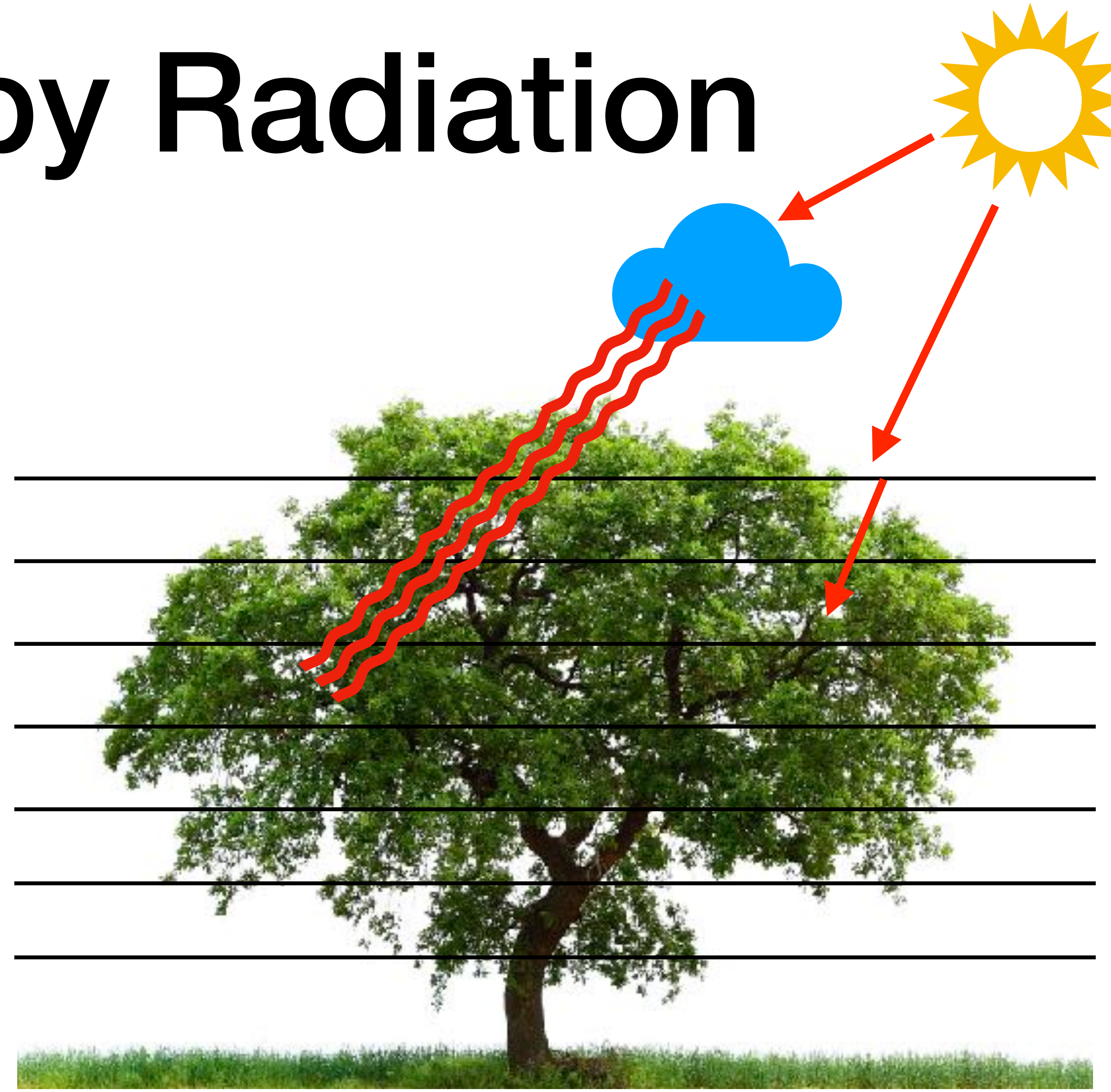

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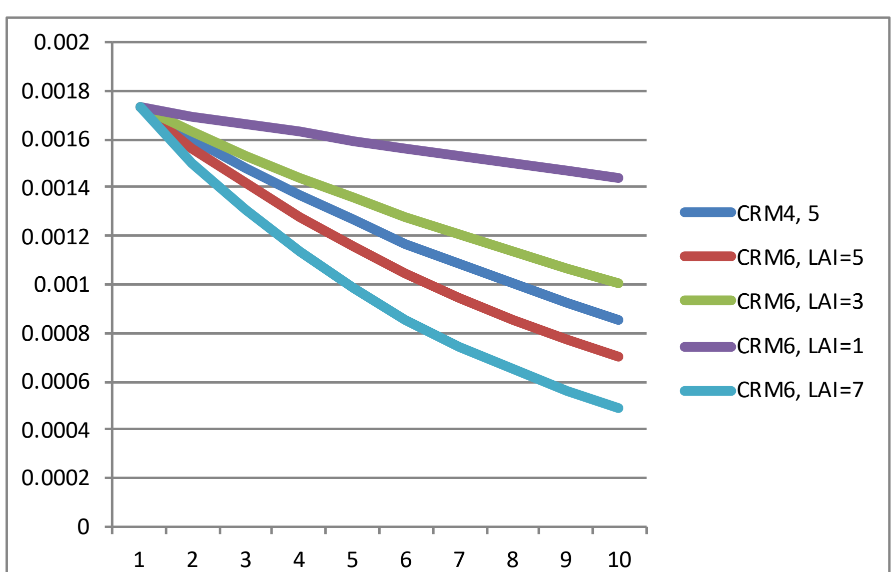

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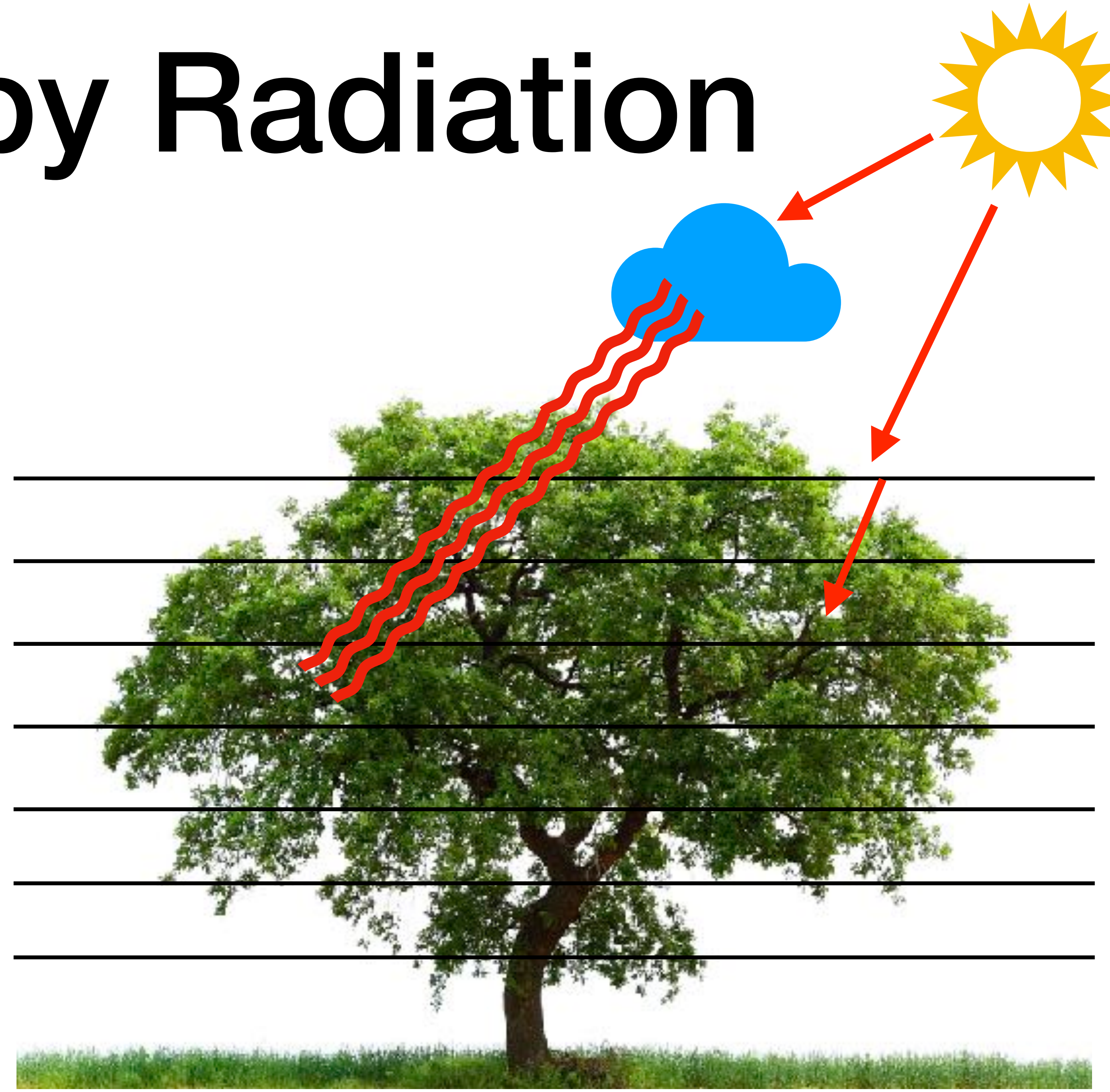

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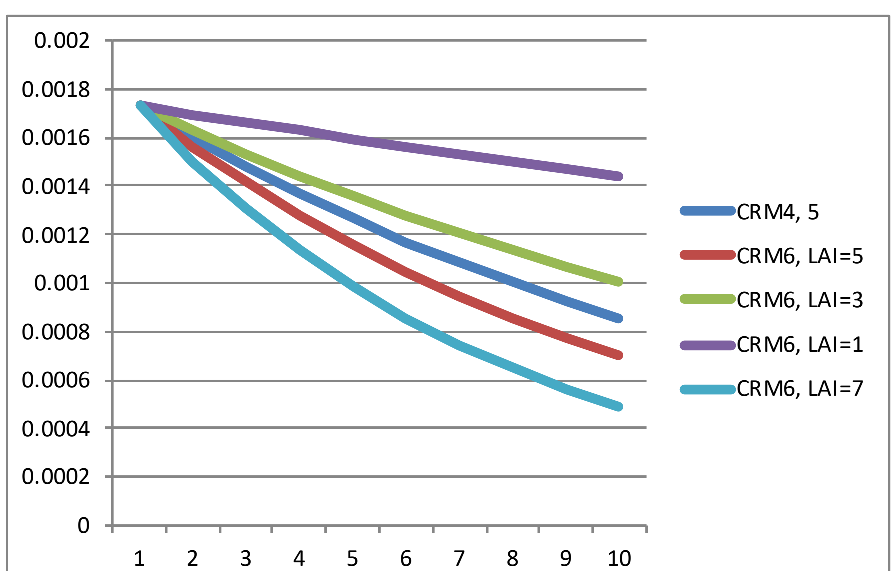

These factors determine net photosynthesis of the plant

CanRadMod6: See Harper et al. 2018; Mercado et al. 2007

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So far, all of this is in the surface part of JULES code

Within surface part of code:

- sf_expl_jls —> physiol (every model tilmestep, e.g. half-hourly or hourly)
- physiol calls:
  - albpft
  - root_frac
  - smc_ext (without and with irrigation)
  - raero
  - sf_stom
  - soil_evap
  - leaf_lit
  - cancap
  - urbanemis
  - microbe
- After physiol, sf_expl aggregates and accumulates fluxes for the next phenology and TRIFFID call (e.g. daily)

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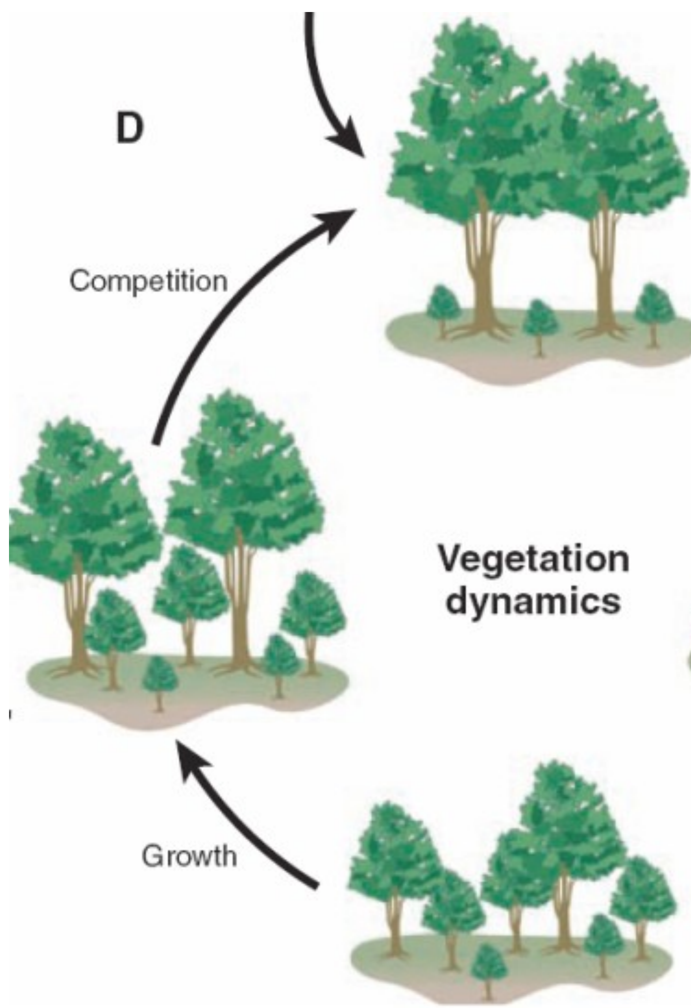
1980 1990

Fourth generation
- Biogeography
- vegetation dynamics

2000s

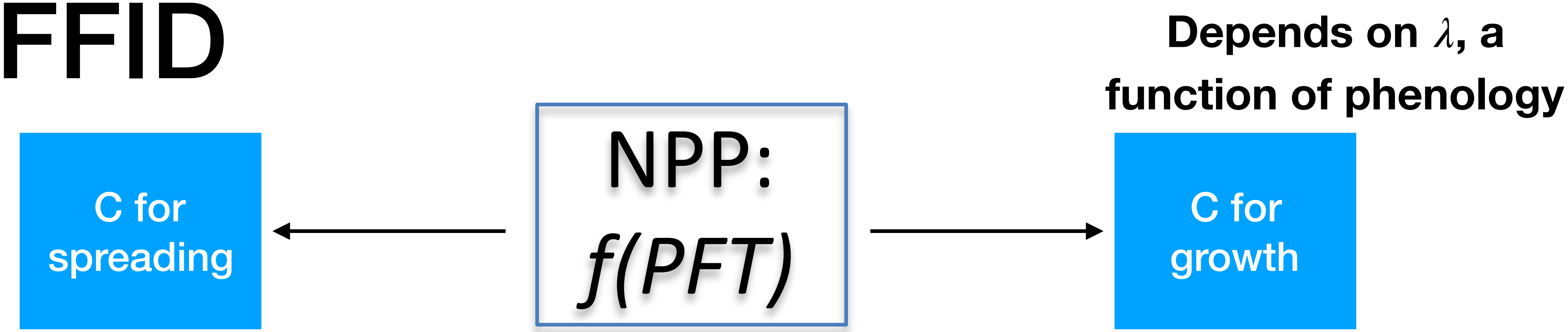


TRIFFID

NPP:
f(PFT)

From Clark et al. 2011, Harper et al. 2018

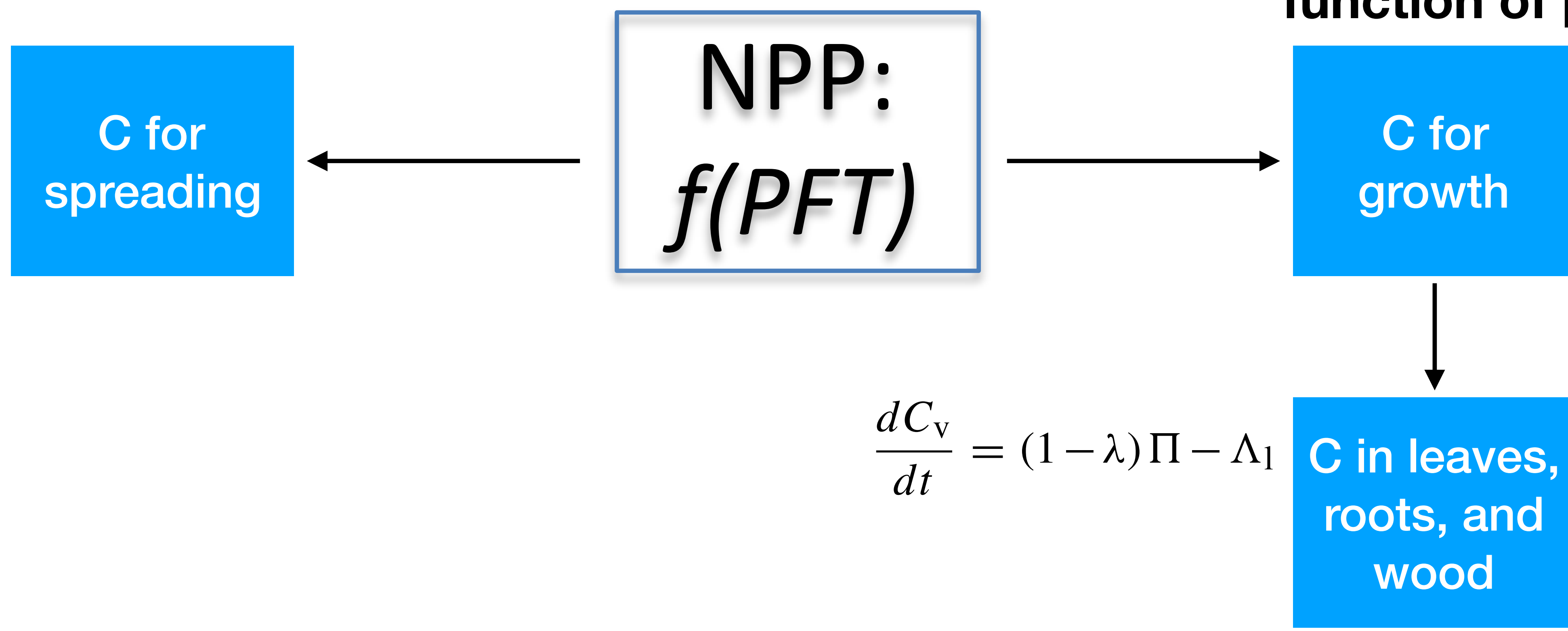
TRIFFID



From Clark et al. 2011, Harper et al. 2018

TRIFFID

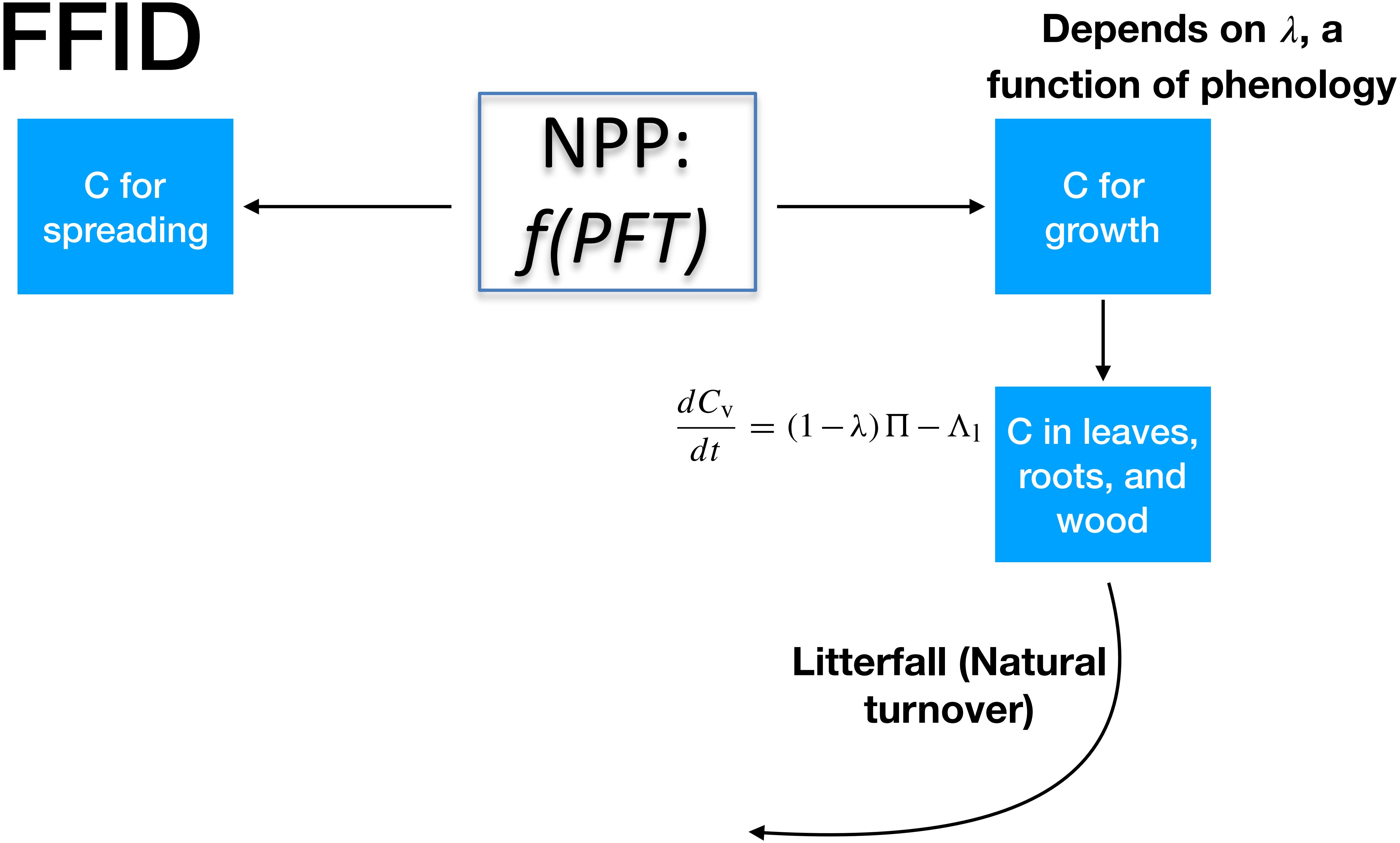
Depends on λ, a function of phenology



$$\frac{dC_v}{dt} = (1-\lambda)\,\Pi - \Lambda_l$$

From Clark et al. 2011, Harper et al. 2018

TRIFFID



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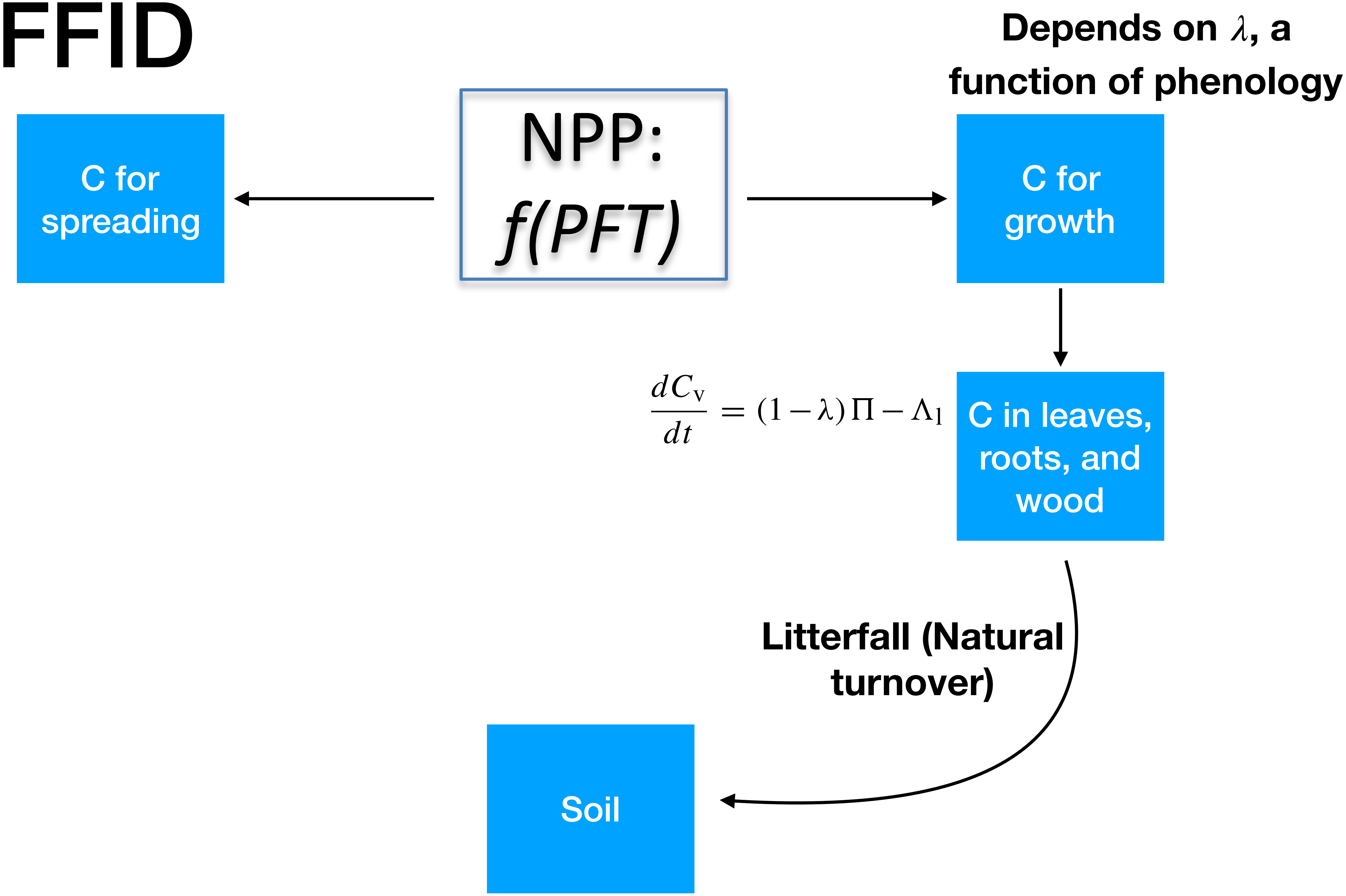

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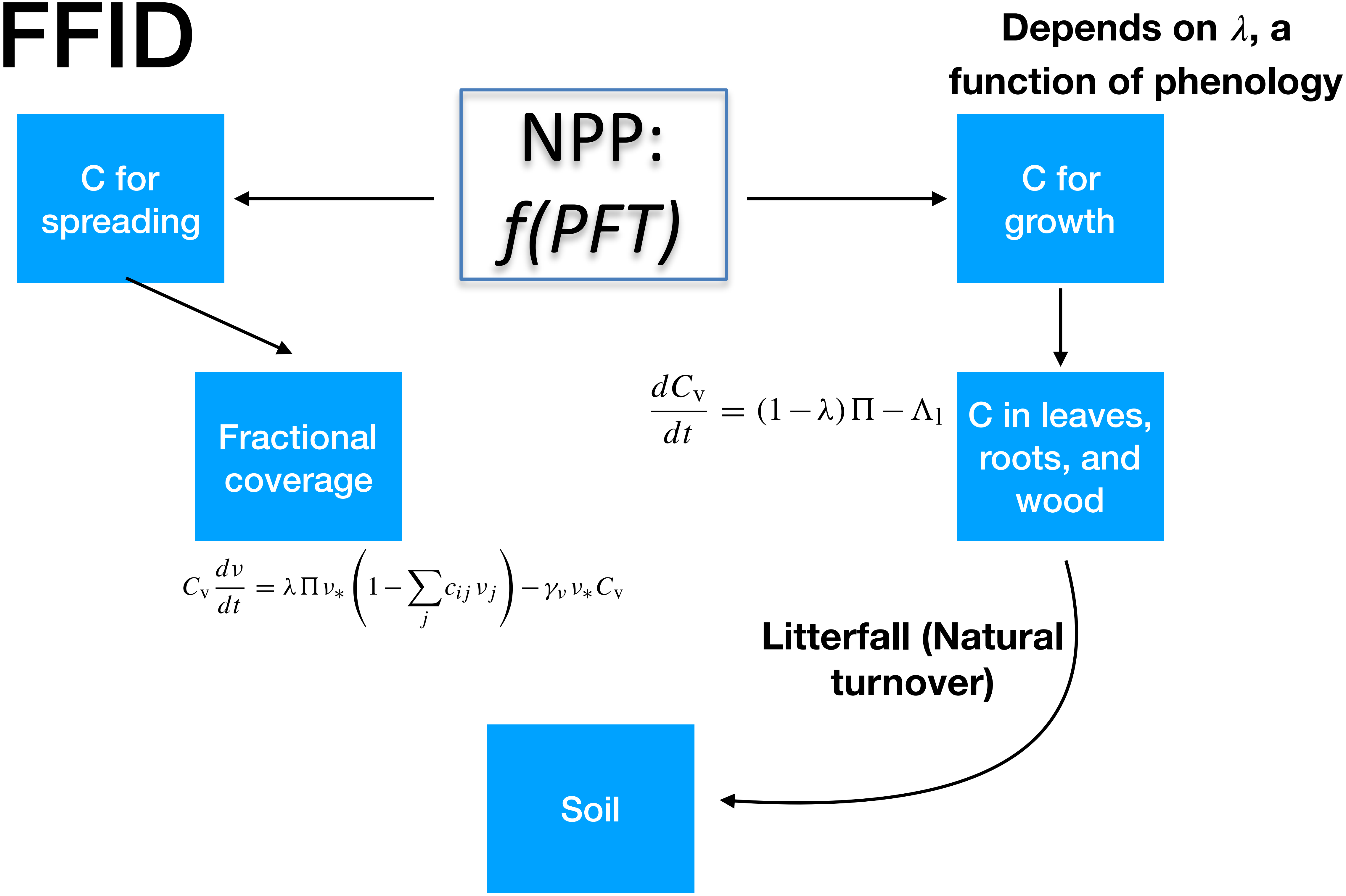

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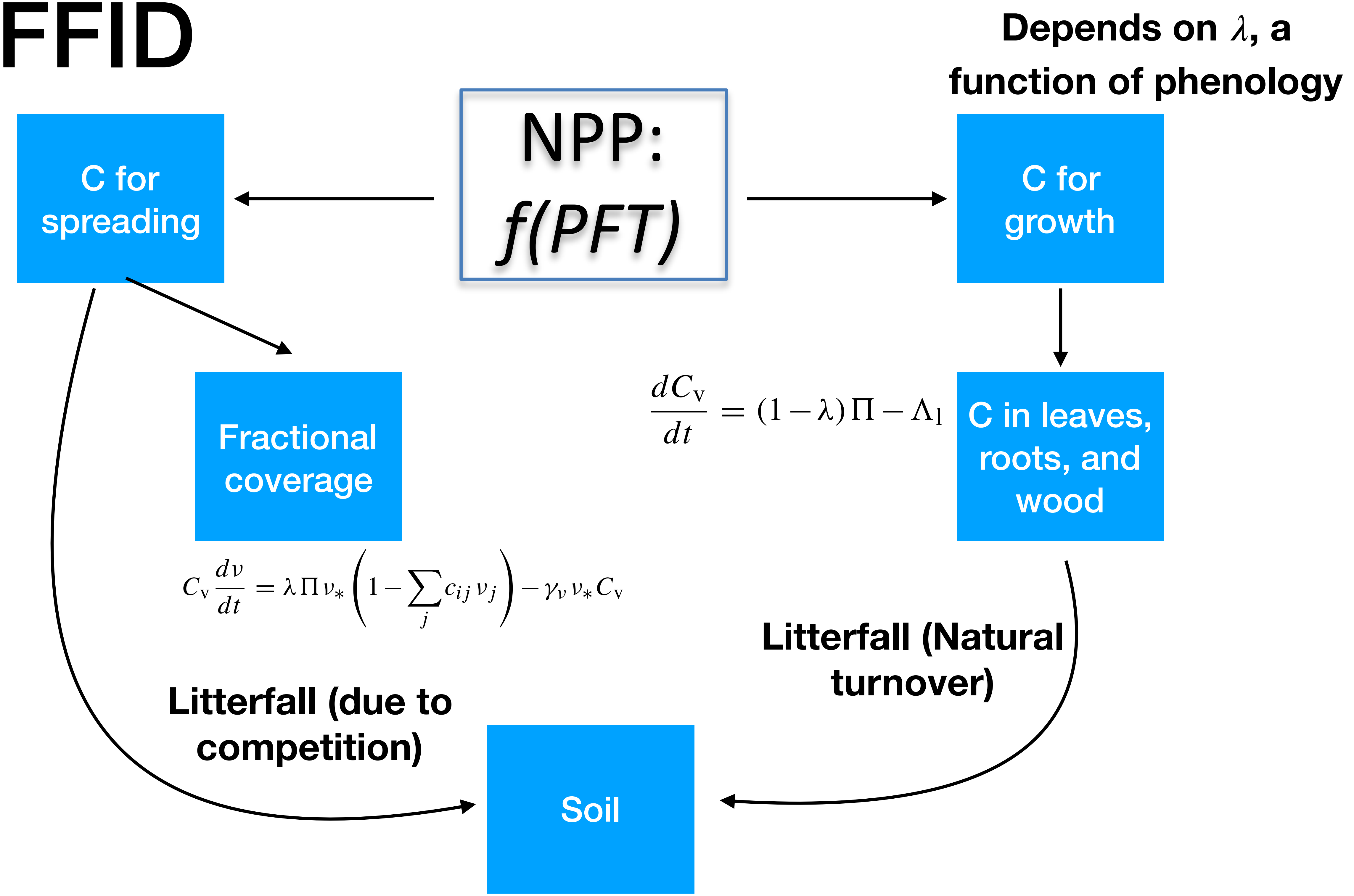

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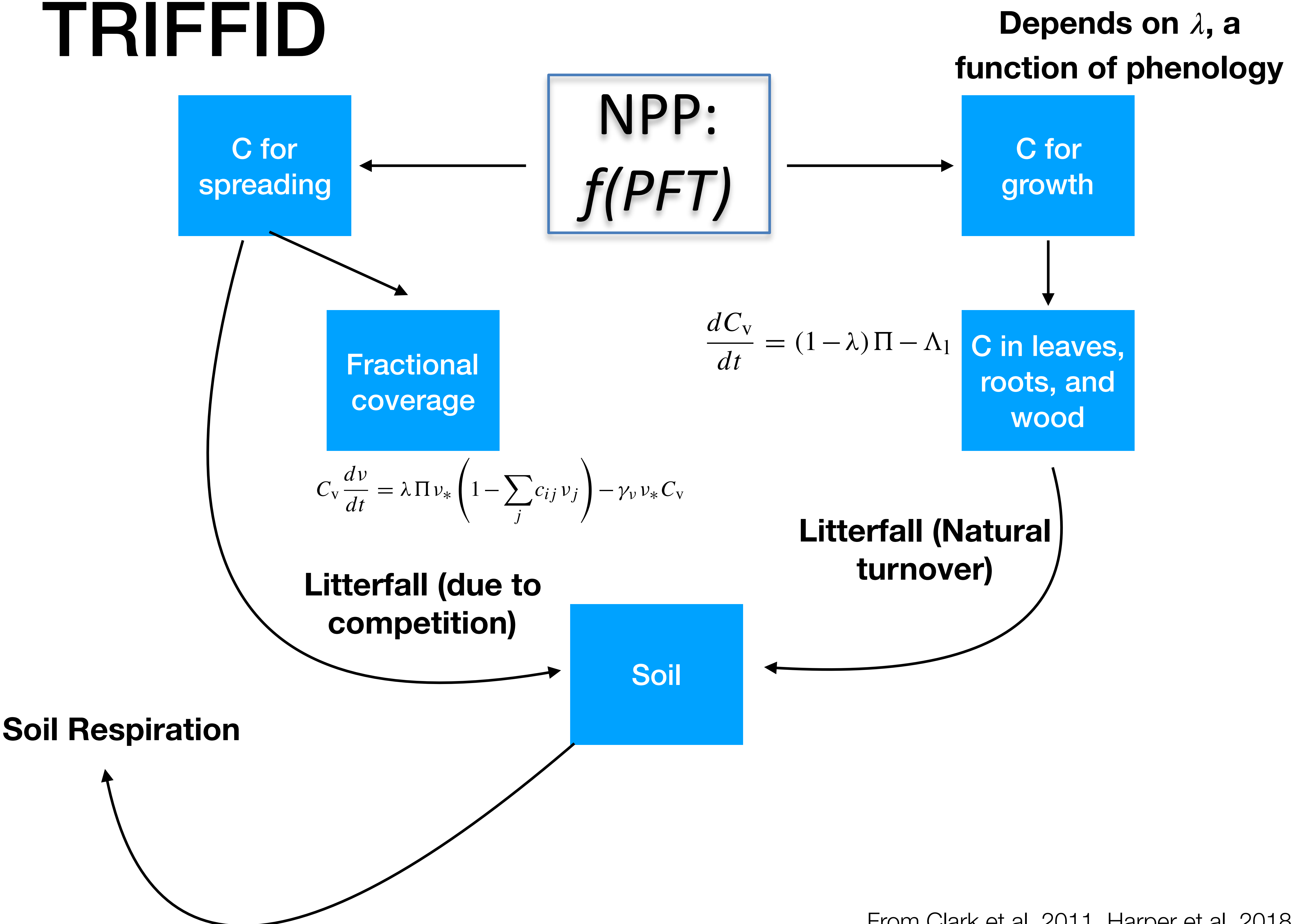

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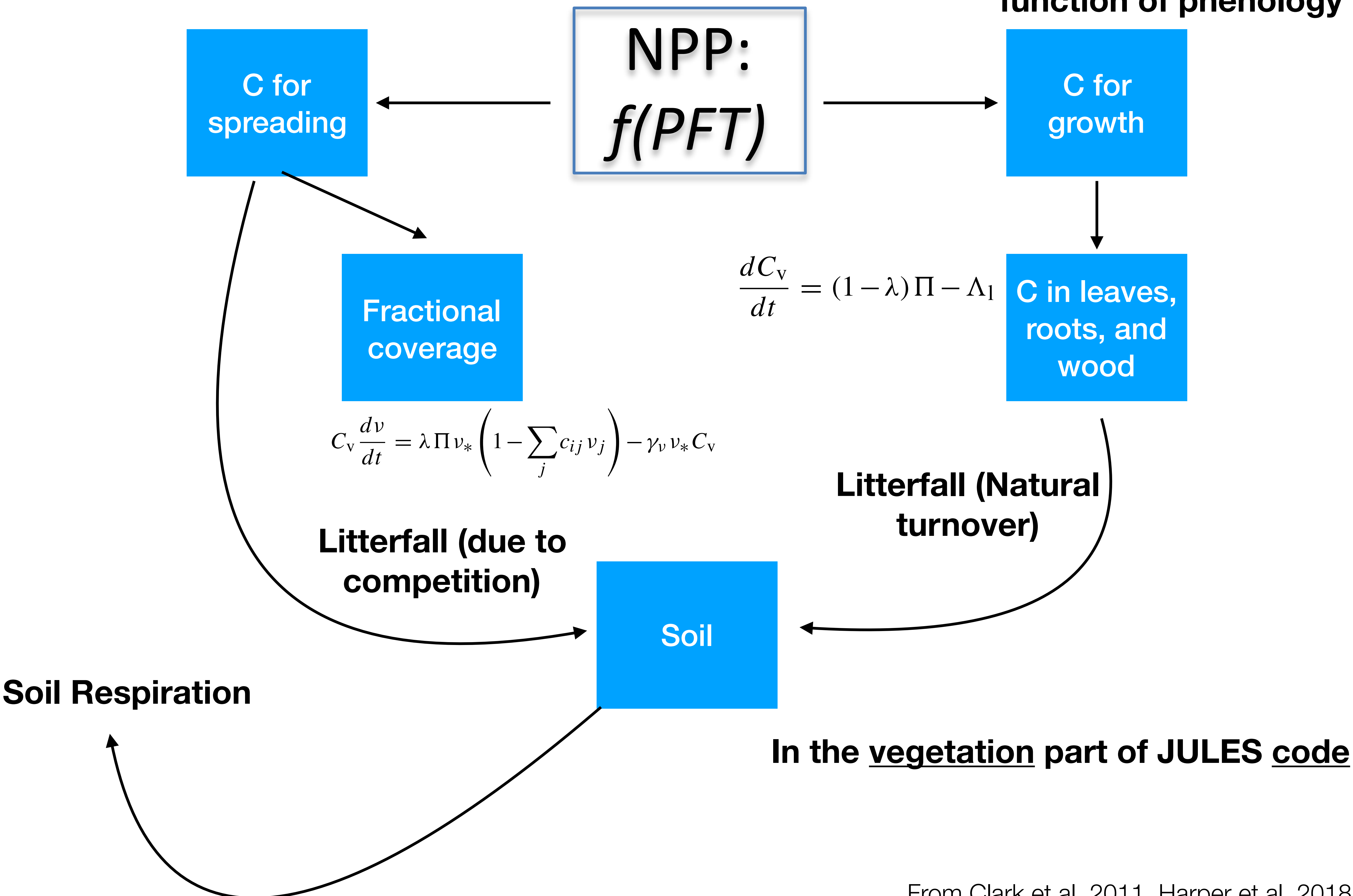

From Clark et al. 2011, Harper et al. 2018

Within vegetation part of code:

- First, in control/shared/surf_couple_extra_mod: either veg2 (TRIFFID+phenology) or veg1 (phenology only) is called.
- Veg2 first calls phenology
- Next it calls TRIFFID
    - Vegcarb: calculates local litterfall, change to vegetation C, which can be limited by N
    - Lotka competition (Equilibrium or Dynamic, can be called multiple times depending on land use settings & excludes land for agriculture or burnt area)
        - In between Lotka and soilcarb, the litter is diagnosed based on changes to PFT fractions and vegetation C. The TRIFFID harvesting is applied.
    - soilcarb
    - Wood prod

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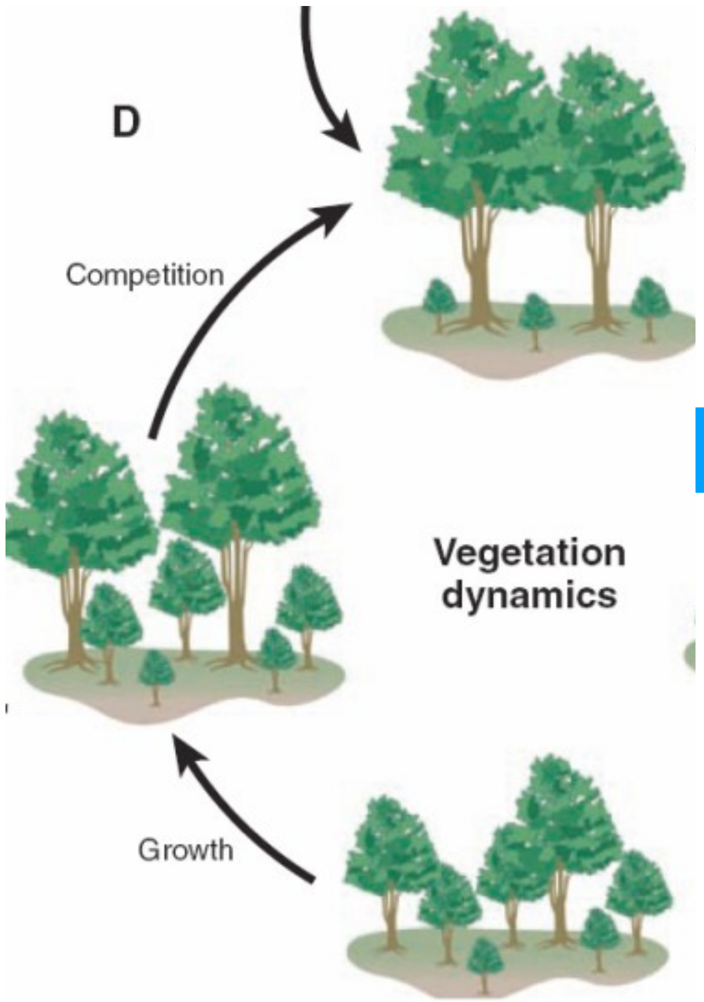

Some other things I haven't mentioned …
- Hydrology
- Soil physics
- Snow processes
- Rivers, inundation, runoff
- Phenology
- N cycle
- Fires
- Land use and agriculture

See http://jules.jchmr.org/content/about for more info or ask one of us.

References

- Best et al. 2011, The Joint UK Land Environment Simulator (JULES), model description - Part 1: Energy and water fluxes, *Geoscientific Model Development*
- Clark et al. 2011, The Joint UK Land Environment Simulator (JULES), model description - Part 2: Carbon fluxes and vegetation dynamics, *Geoscientific Model Development*
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- Cox et al. 1999, The impact of new land surface physics on the GCM simulation of climate and climate sensitivity, *Climate Dynamics*
- Cox et al. 2001, Description of the “TRIFFID” dynamic global vegetation model, *Hadley Centre Technical Note 24*
- Harper et al. 2016, Improved representation of plant functional types and physiology in the Joint UK Land Environment Simulator (JULES v4.2) using plant trait information, *Geoscientific Model Development*
- Harper et al. 2018, Vegetation distribution and terrestrial carbon cycle in a carbon cycle configuration of JULES4.6 with new plant functional types, *Geoscientific Model Development*
- Jackson et al. 2015, Global and European climate impacts of a slowdown of the AMOC in a high resolution GCM, *Climate Dynamics*
- Mercado et al. 2007, Improving the representation of radiation interception and photosynthesis for climate model applications, *Tellus B*
- Pitman 2003, The evolution of, and revolution in, land surface schemes designed for climate models; *J. Of International Climatol.*
- Sellers et al. 1997, Modelling the exchanges of energy, water and carbon between continents and the atmosphere, *Science*