Introduction to JULES

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JULES Training Workshop
University of Exeter
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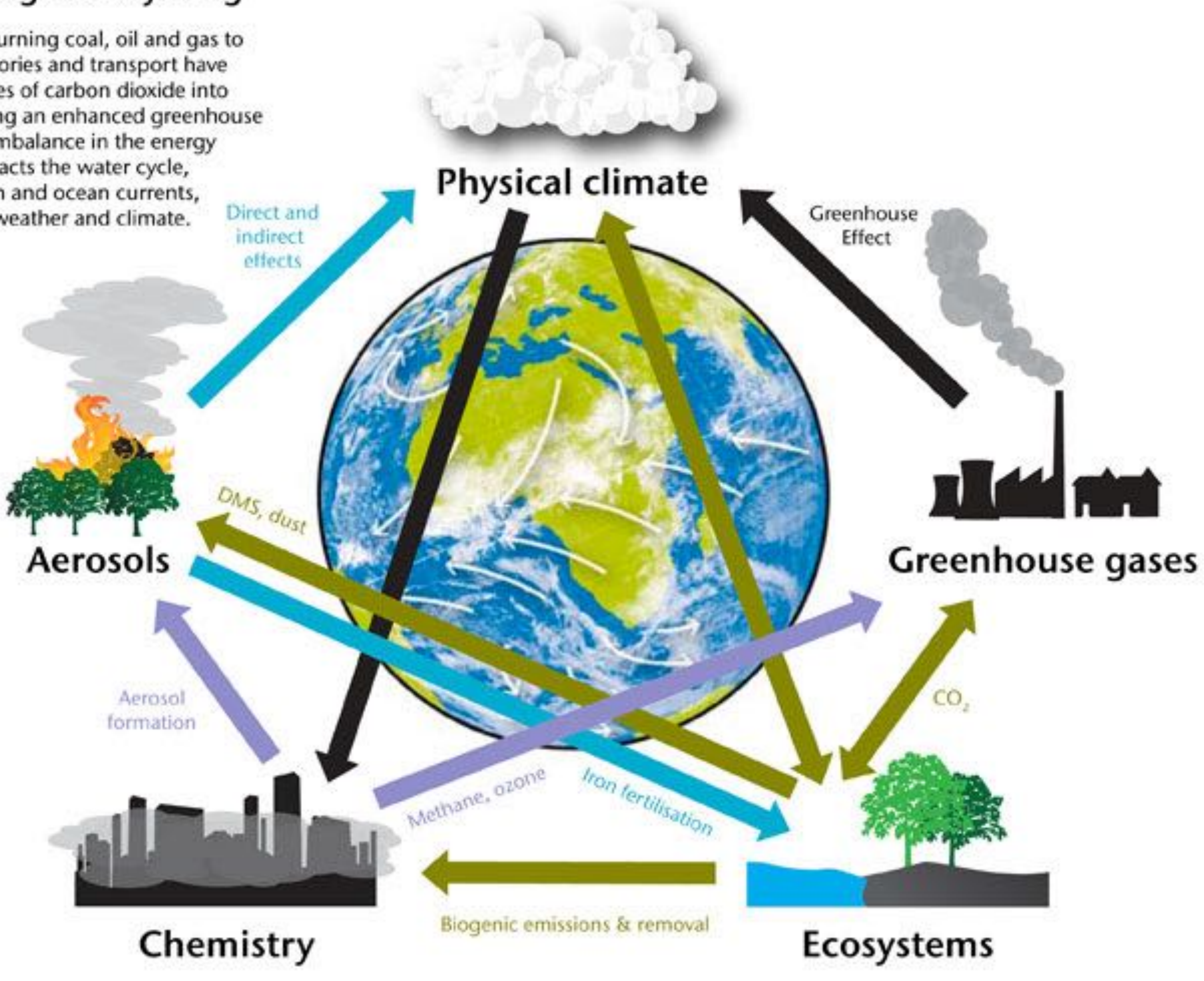
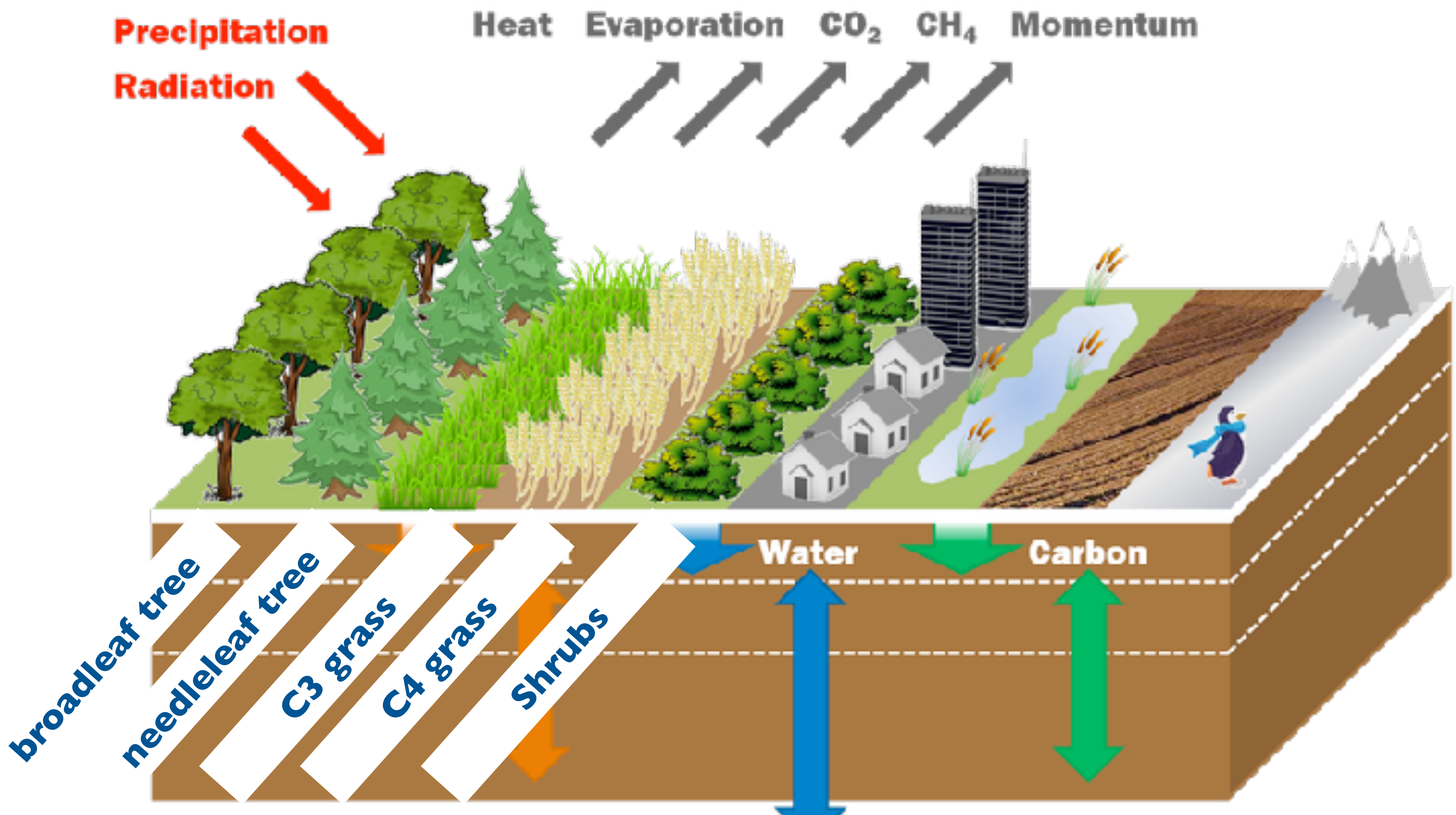
The Earth System

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.



JULES



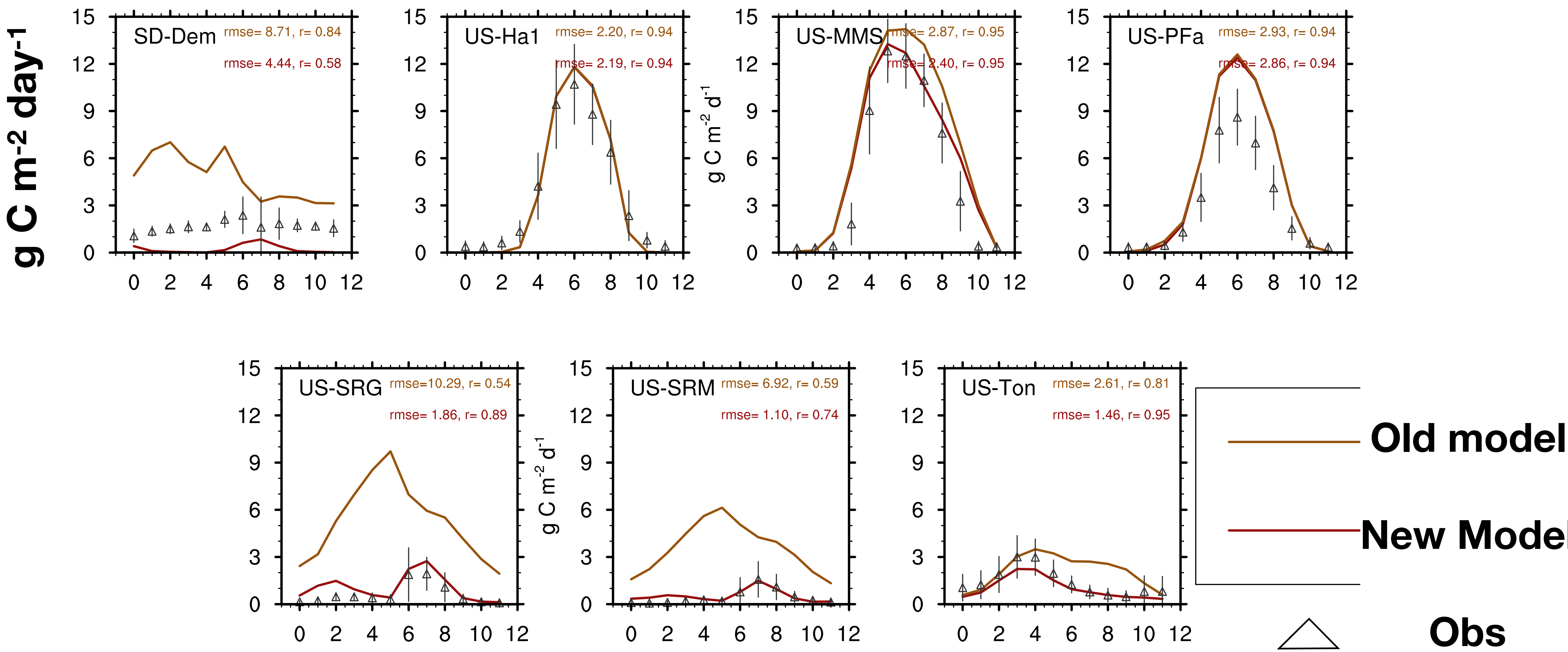
Based on MOSES, Cox et al. 1999, Climate Dynamics.

Clark et al. 2011 and Best et al. 2011; *Geosci. Mod. Dev.,*

Harper et al. 2016, 2018 *Geosci. Mod. Dev.*

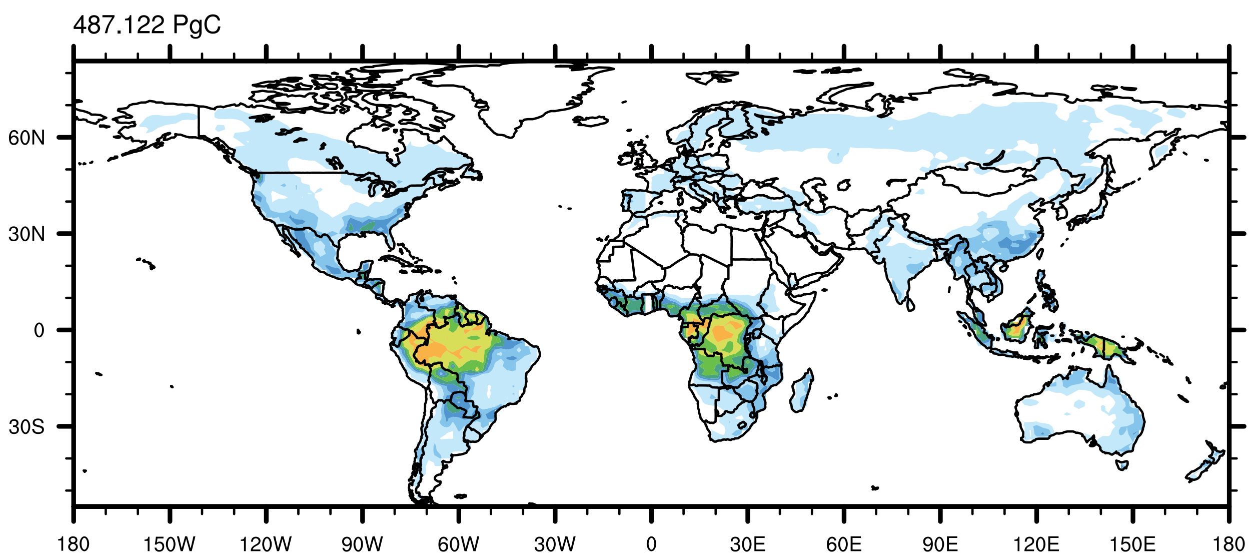
JULES can be run at a single point …

Photosynthesis at sites where carbon fluxes are measured

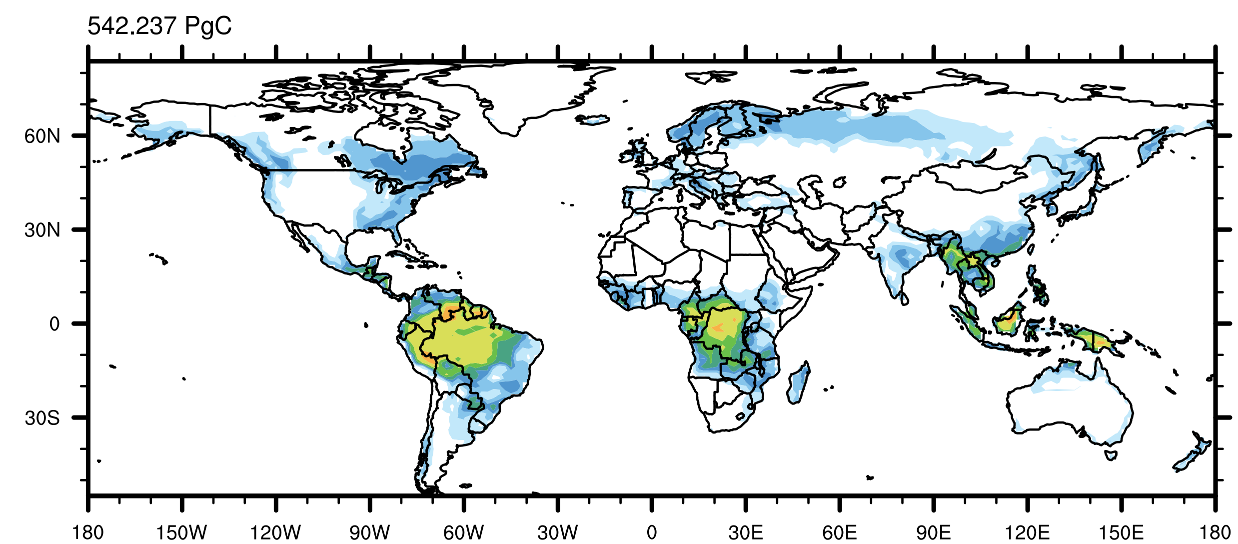


Or globally ....

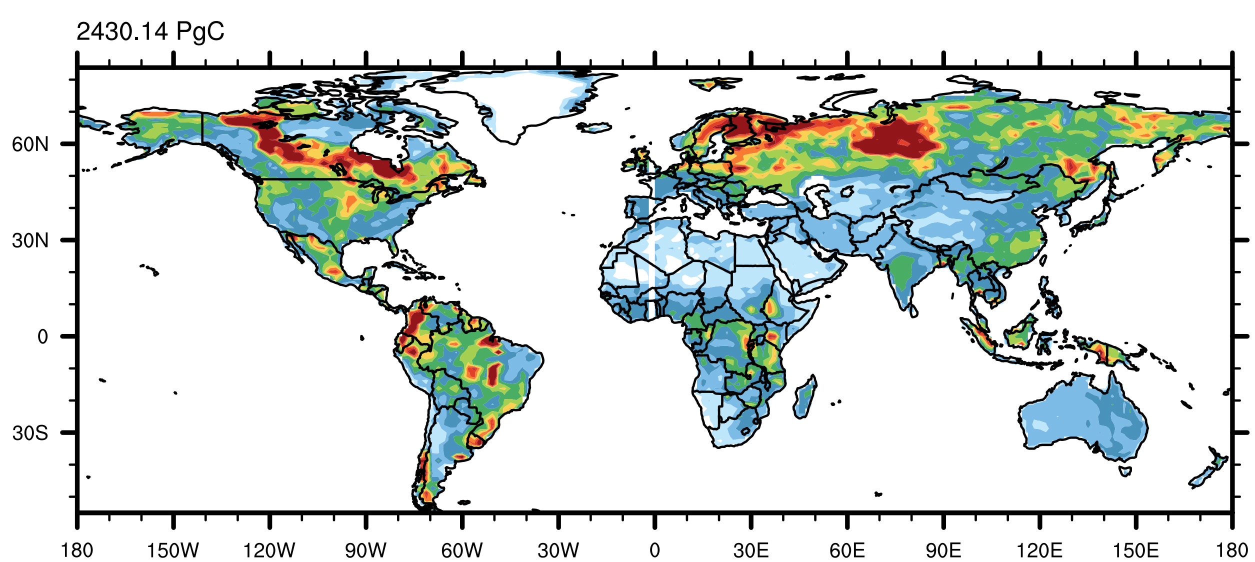
Observed carbon in vegetation



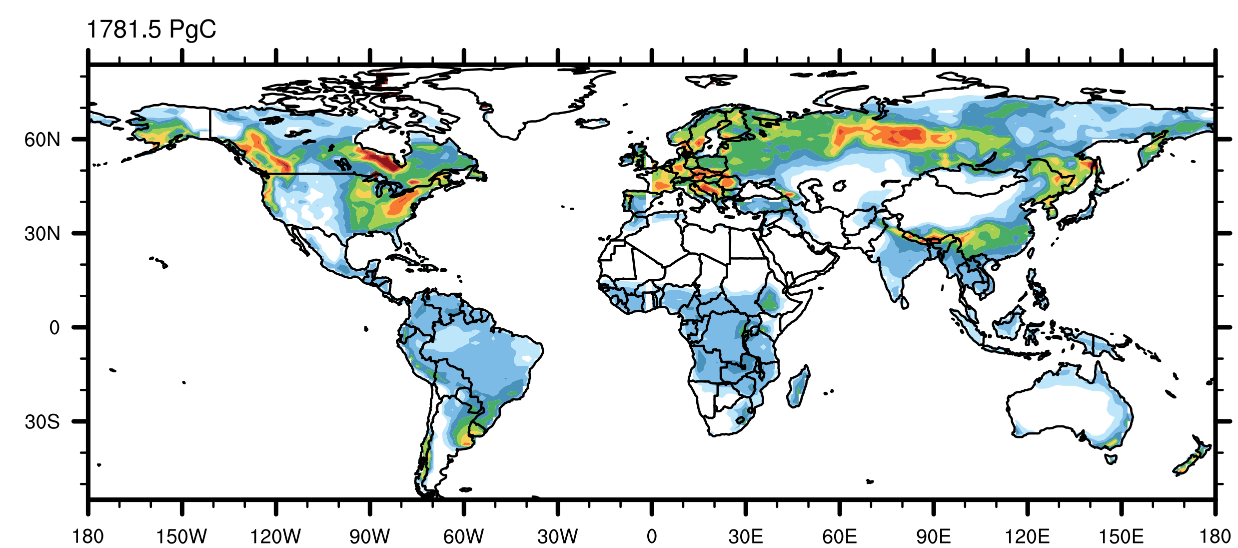
Modelled carbon in vegetation



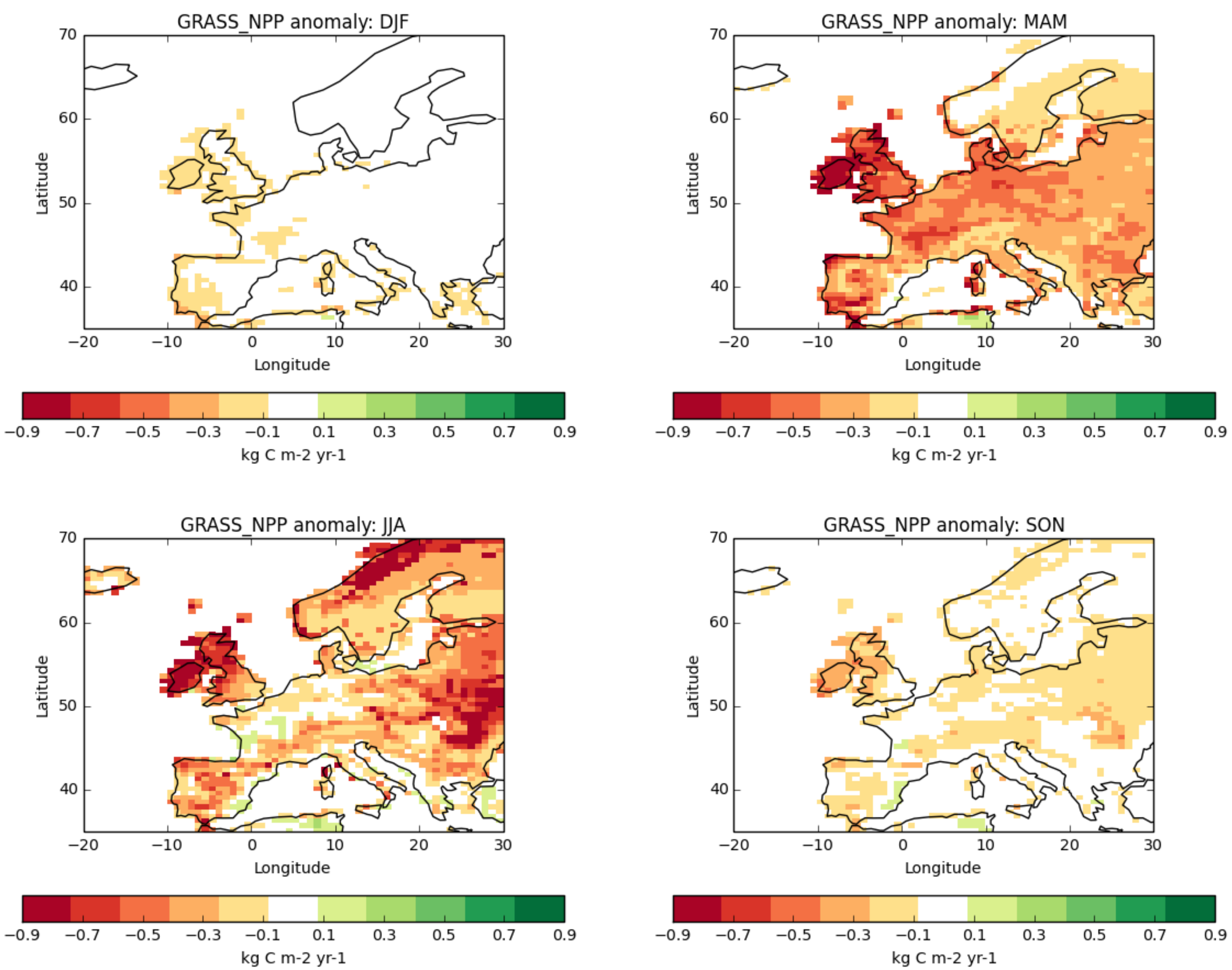
Observed carbon in soils



Modelled carbon in soils



Or regionally …



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Analysis by Mark Williamson based on simulations by Jackson et al. (2015) Climate Dynamics

JULES can be used for many purposes …

- Terrestrial water balance
- River runoff
- Crops
- Permafrost
- Surface energy fluxes
- Coupled carbon cycle-climate

But let's back up

What is a land surface model?

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

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

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

Net radiation=

Latent heat flux

+ Sensible heat flux

+ Ground heat flux

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

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- Something that solves the energy and water budgets:
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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

What is a land surface model?

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

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

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

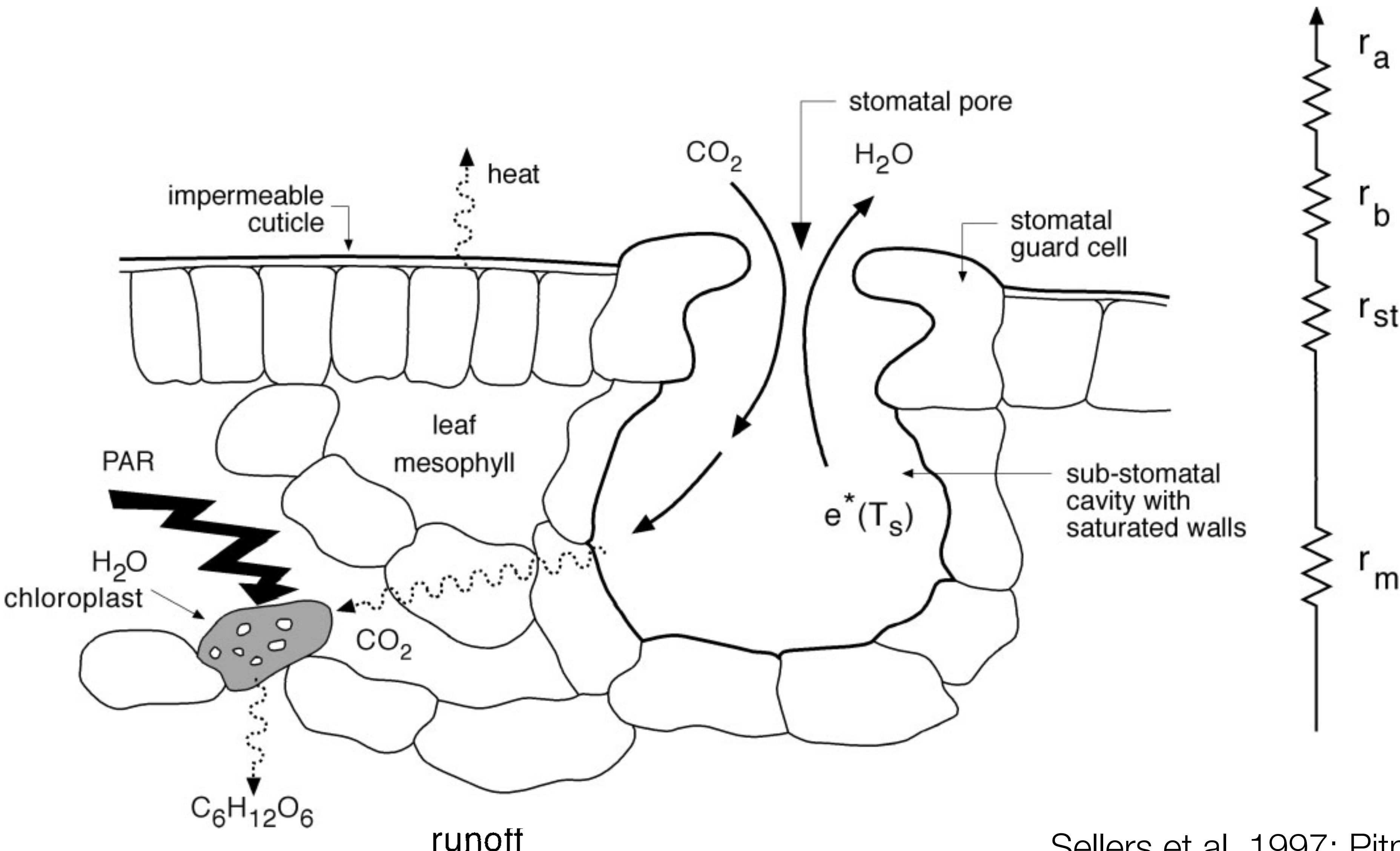
- Later generations added carbon budgets

Evolution of LSMs

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

Second generation
- Stomatal conductance
- "Big Leaf" representation of vegetation

1980 **1990**



Calculations of photosynthesis and stomatal conductance

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

Evolution of LSMs

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Third generation

- Photosynthesis
- Carbon cycle

1980 **1990**

- Scale from leaf to canopy
- Net primary production of plants input carbon into land, respiration removes it —> representation of terrestrial carbon cycle

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

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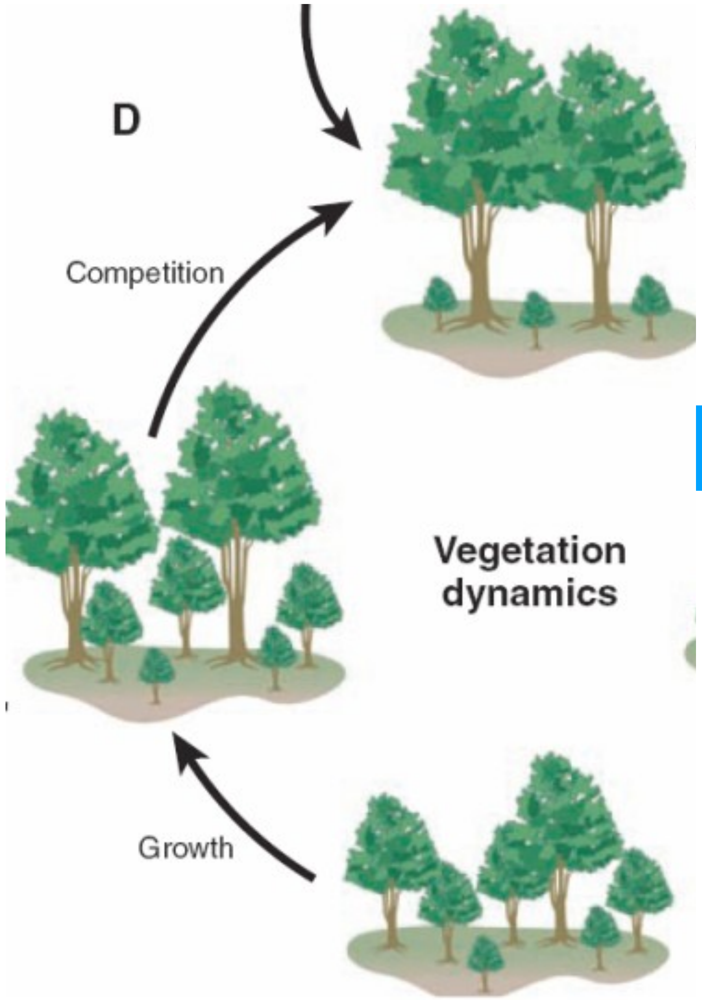
1980 **1990**

Fourth generation
- Biogeography
- vegetation dynamics

2000s



So what about JULES?

So what about JULES?

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

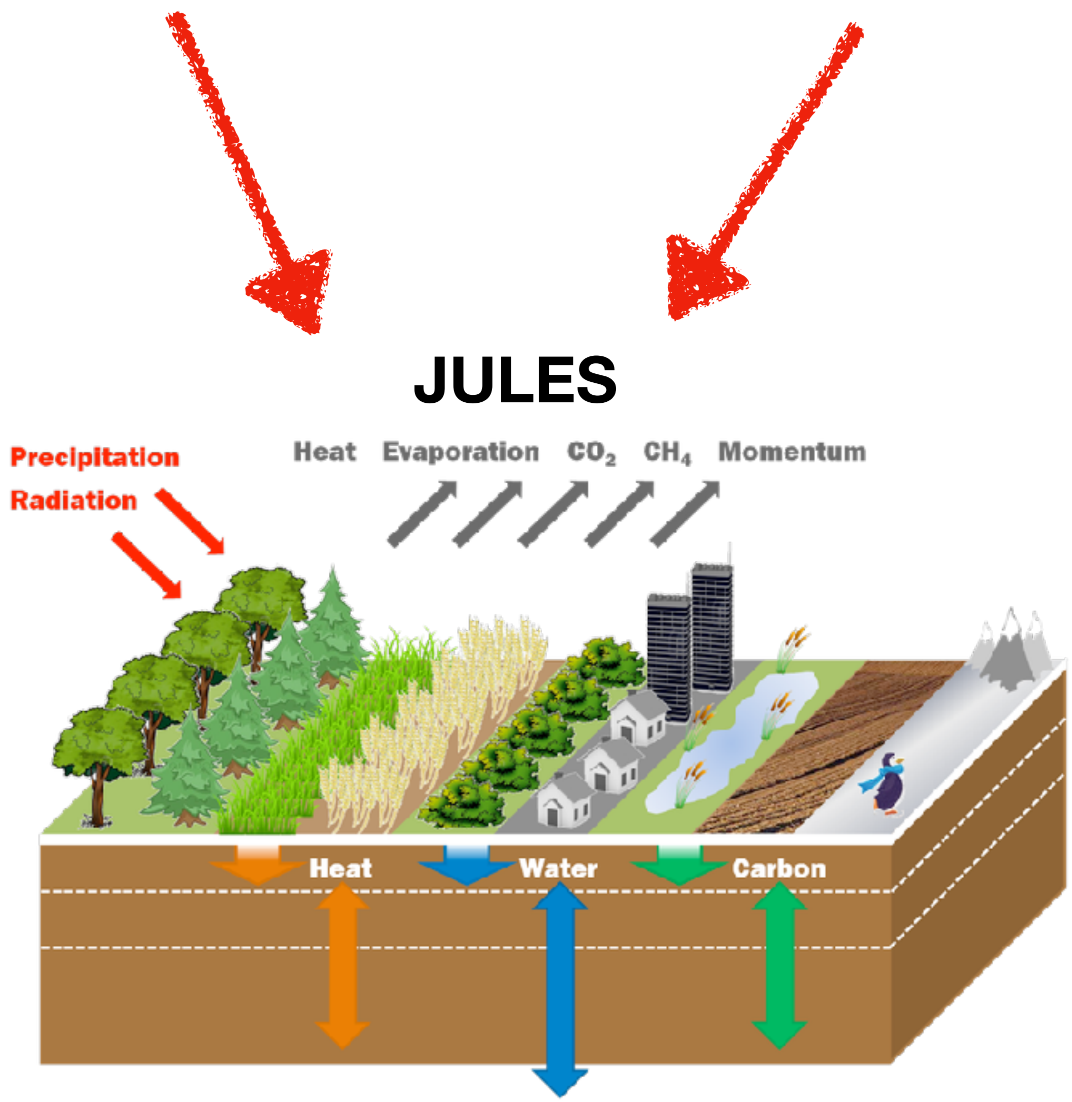
Hadley Centre, Met Office, London Road, Bracknell, Berks R12 2SY, UK
pmcox@meto.gov.uk

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]

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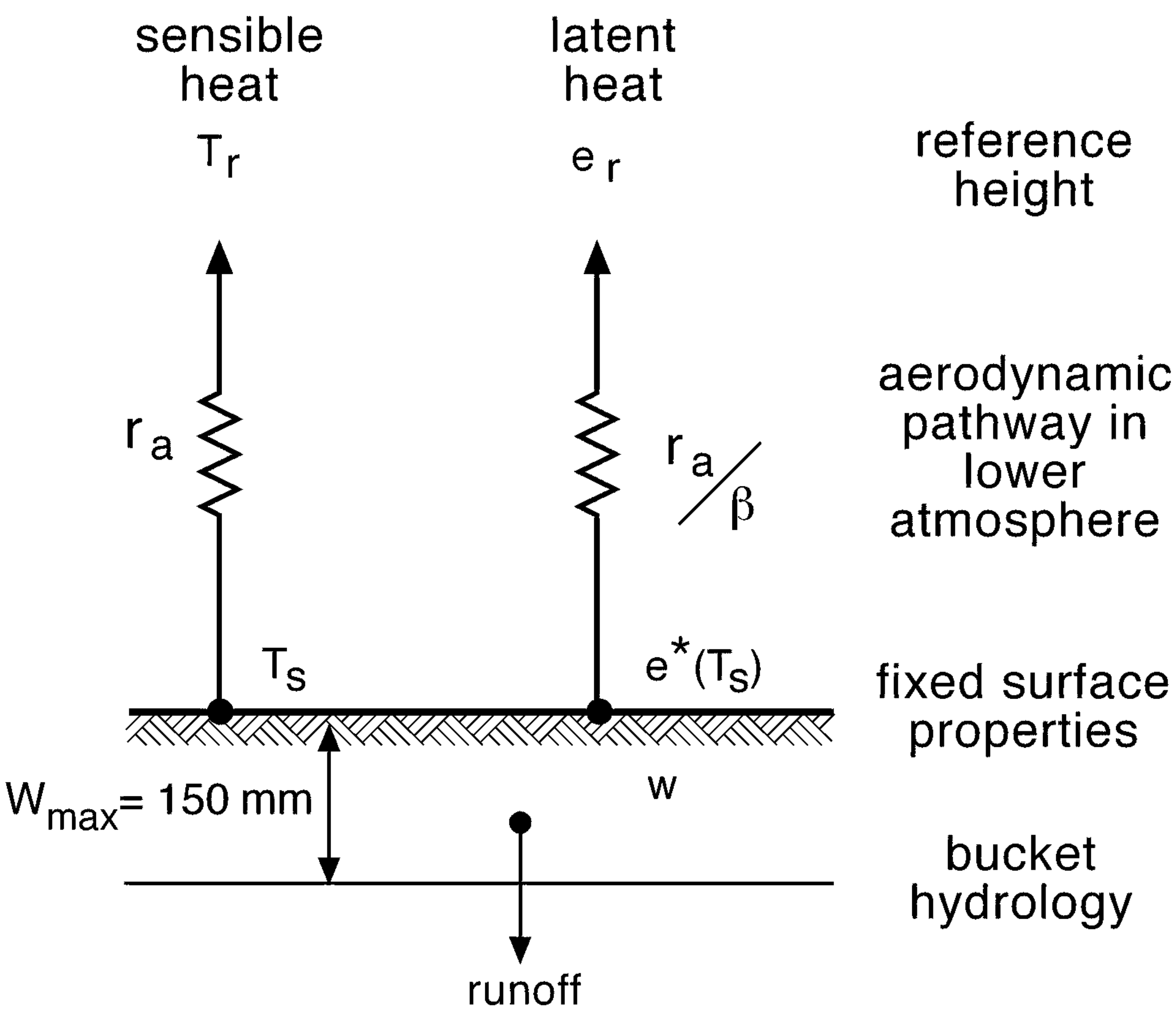

$$H = \frac{\rho c_p}{r_a}(T_* - T_A)$$

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

From Best et al. 2011

In the surface part of JULES <u>code</u>

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

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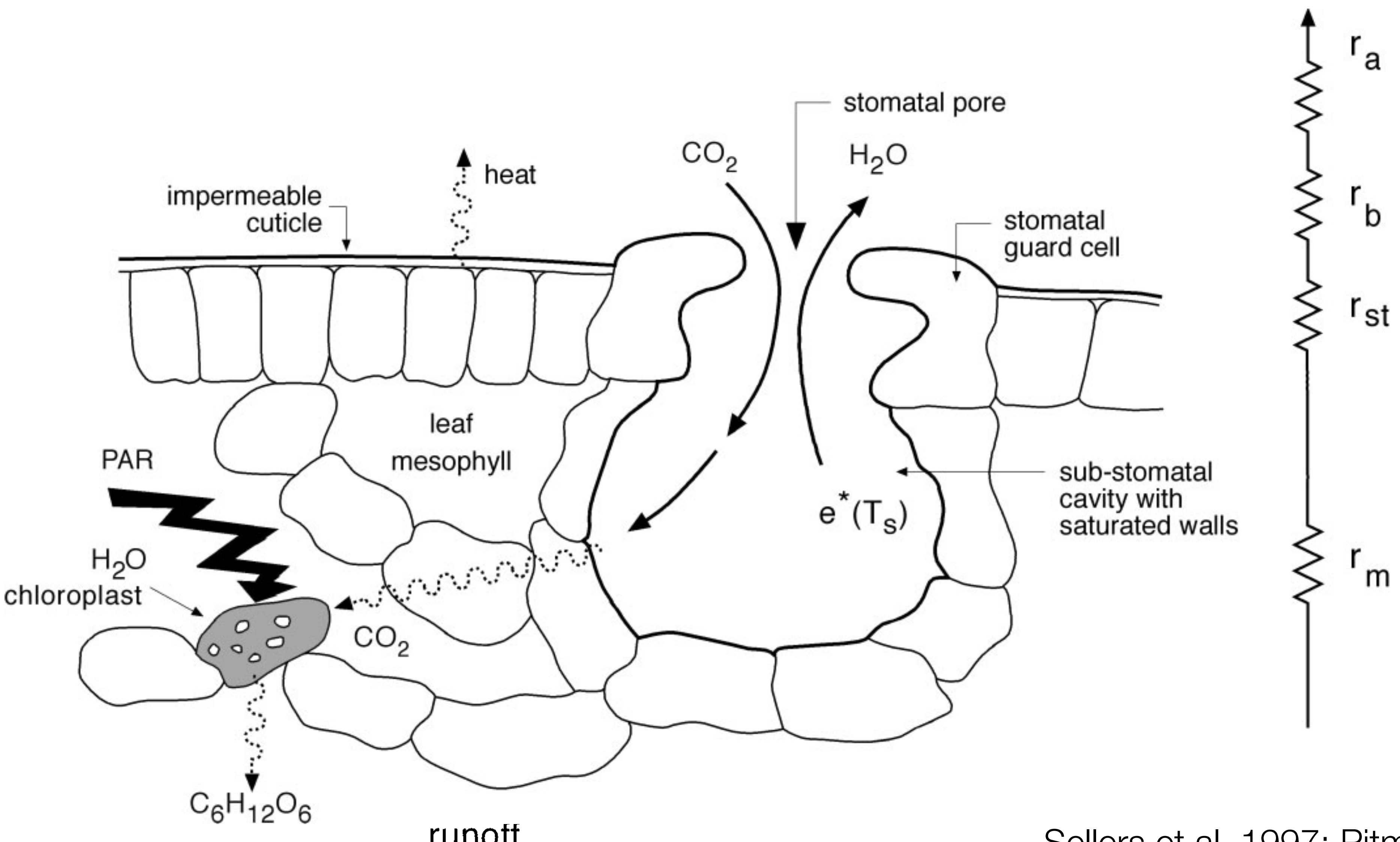

In the subroutine sf_stom

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

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

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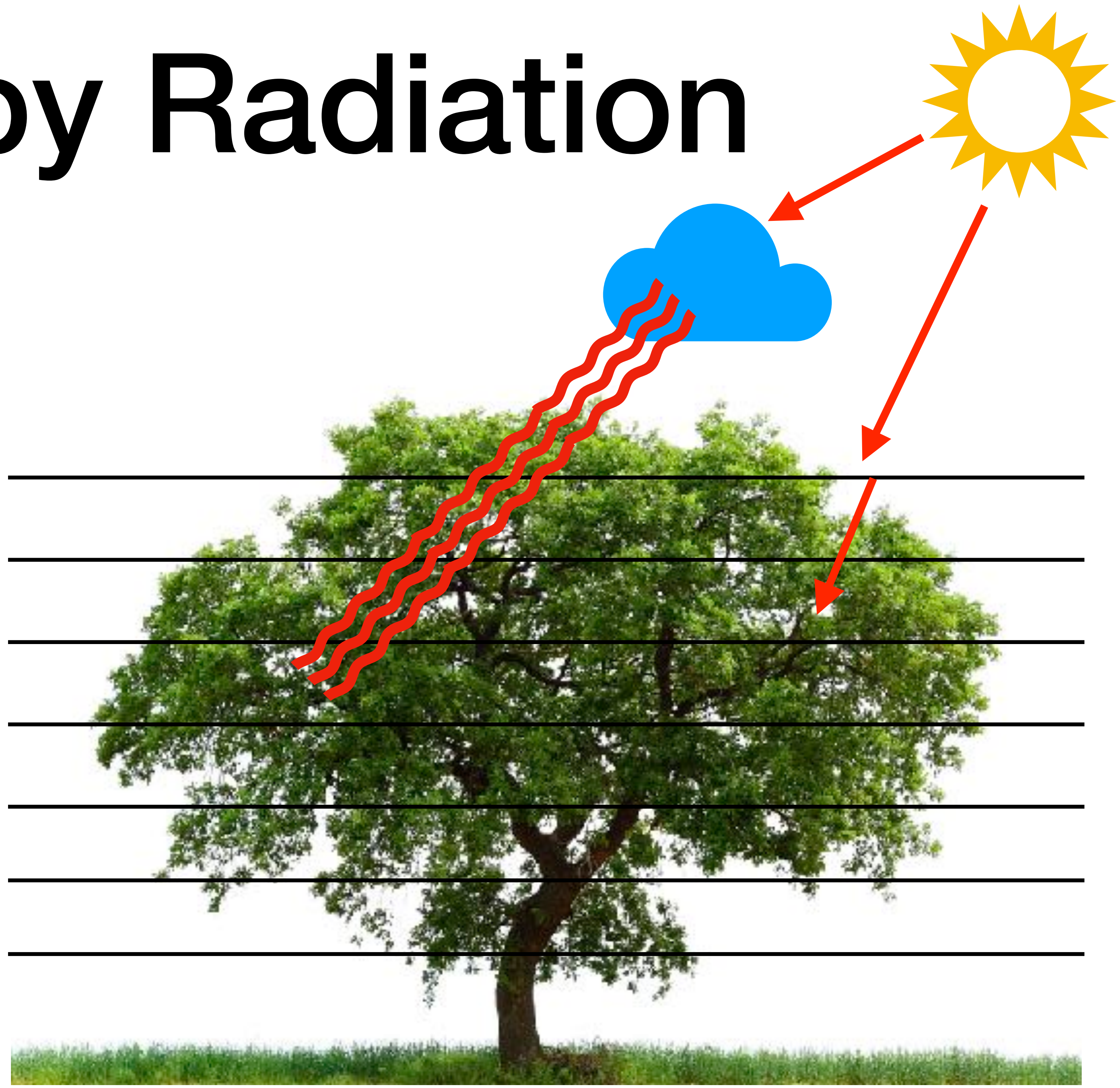
- Scale from leaf to canopy **(depends on canopy radiation scheme)**
- Net primary production of plants input carbon into land, respiration removes it —> representation of terrestrial carbon cycle

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

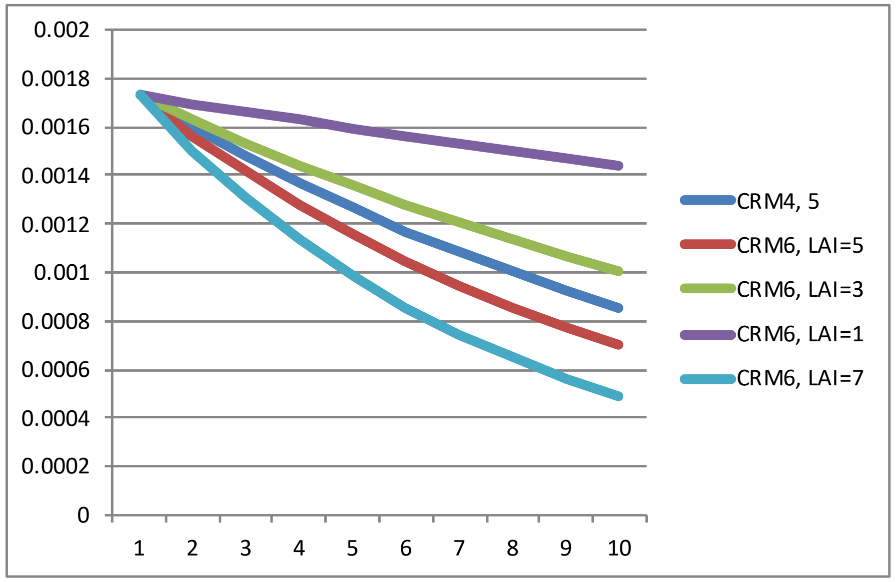


<u>CanRadMod = 1</u>

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**



These factors determine net photosynthesis of the plant

CanRadMod6: See Harper et al. 2018

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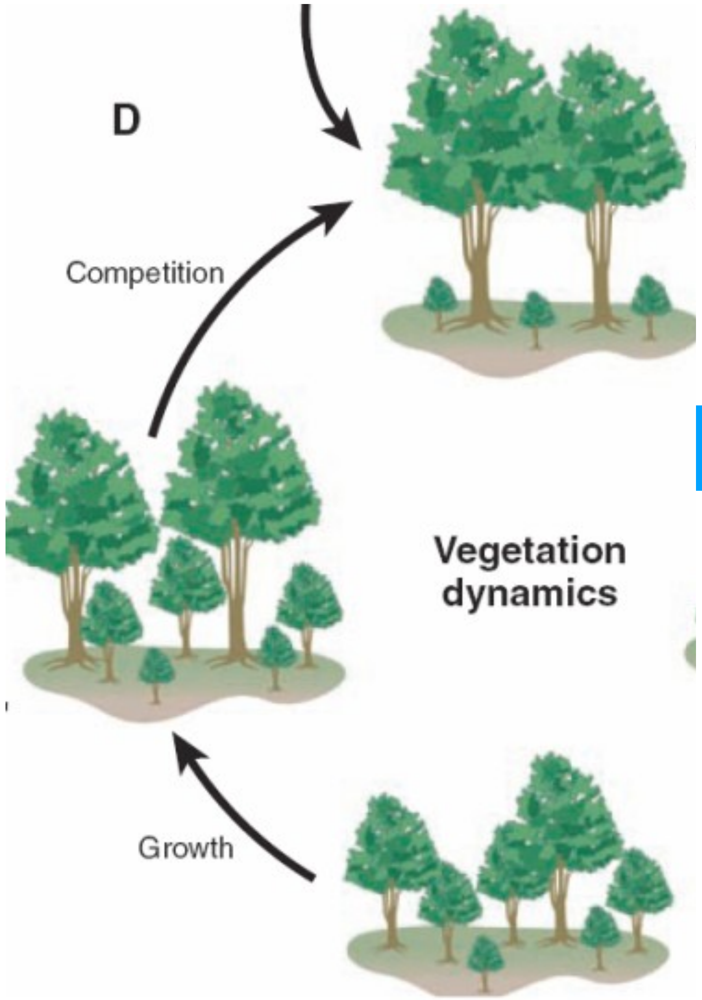
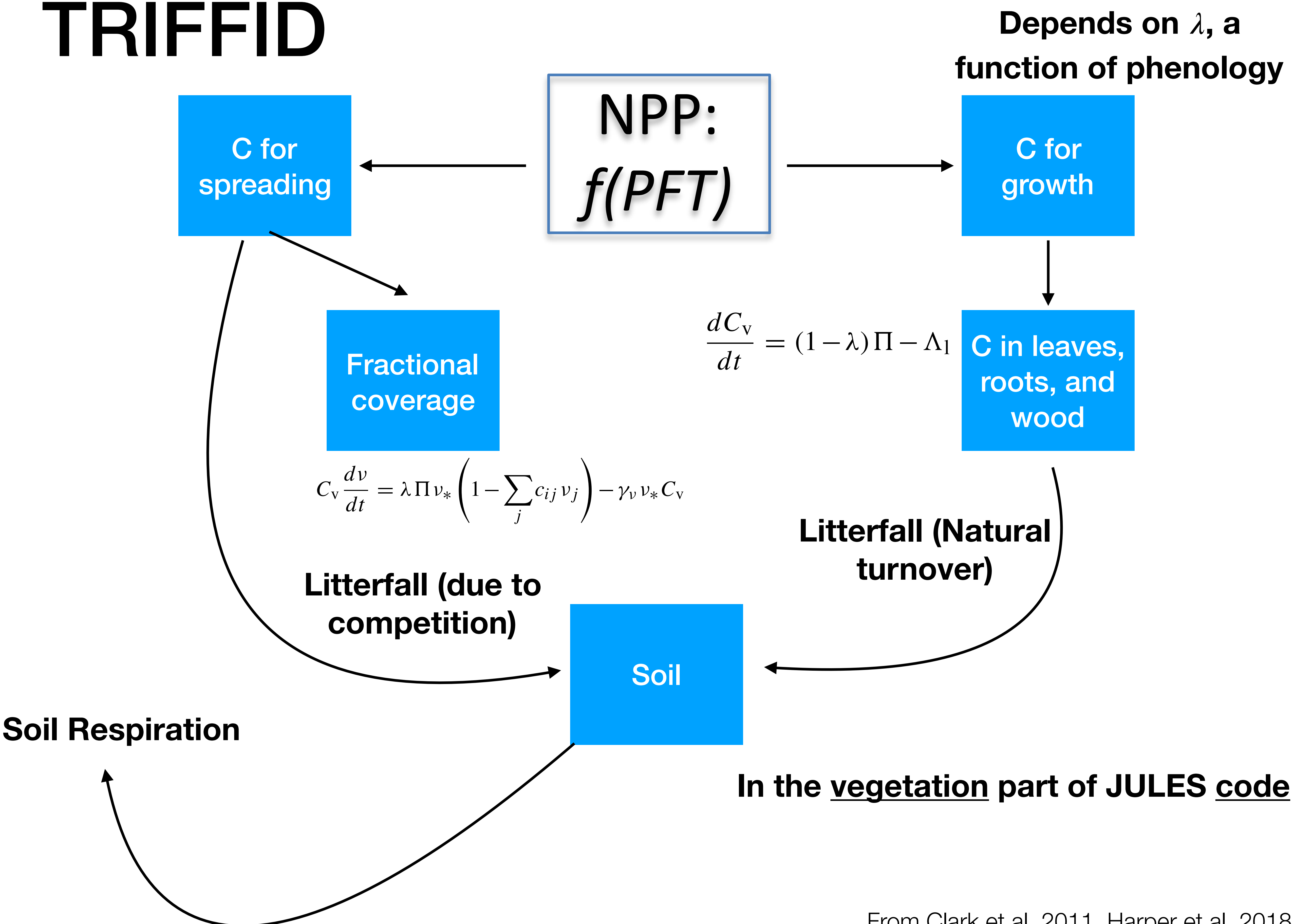


TRIFFID



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

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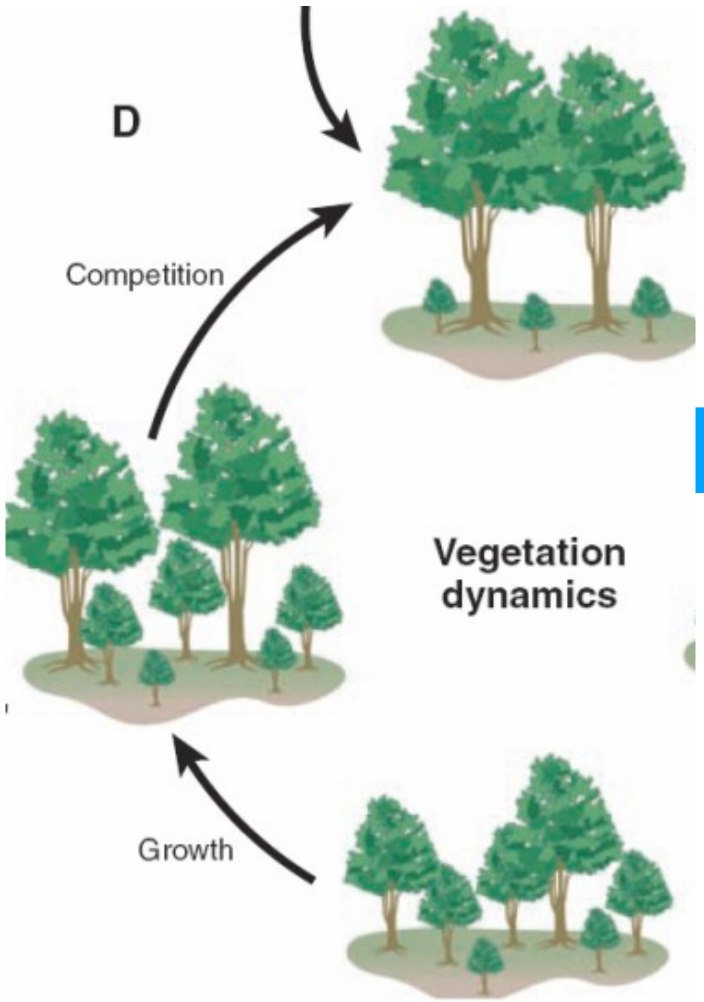

Some other things I haven't mentioned …
- Hydrology
- Soil physics
- Snow processes
- Rivers, inundation, runoff
- Phenology
- N cycle
- Fires
- Land use and agriculture

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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