Developing a new generation land surface model, ORCHIDEE-CAN, featuring dynamic canopy structure for regional climate research

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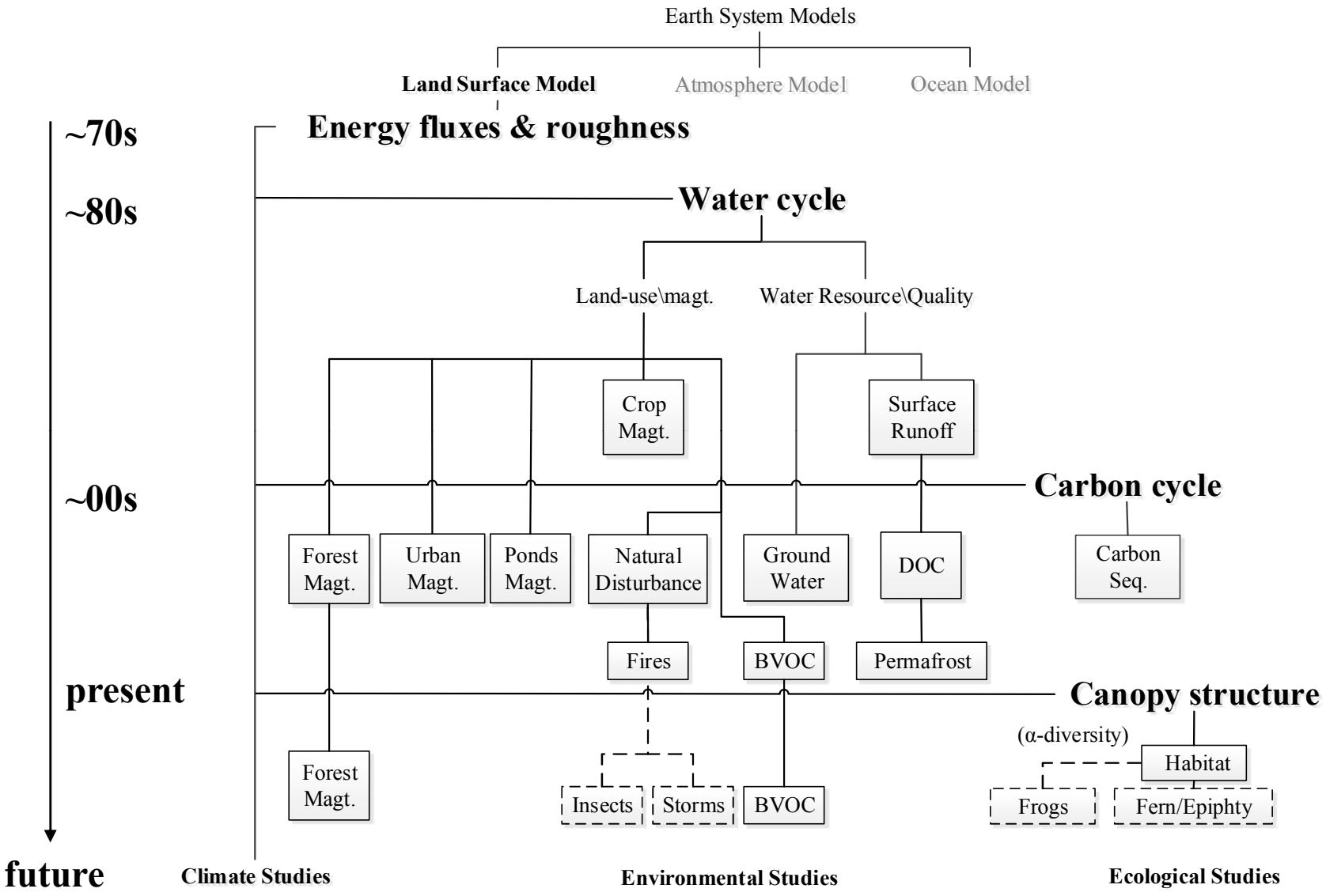
中華民國 一百零五年 一月十一日 中央氣象局科技中心

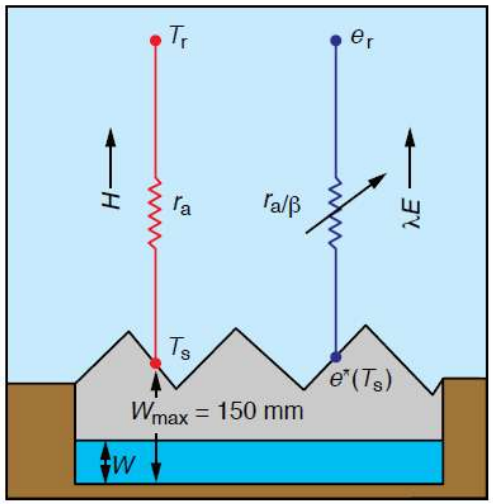
Introduction – Evolution\application of the land surface model (LSM)



Adjusted from Pitman et al., 2003

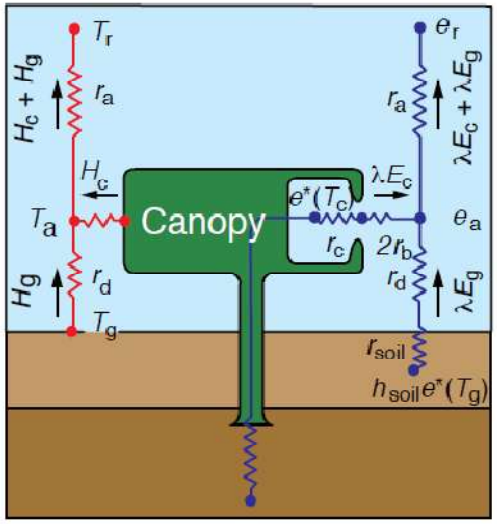
Introduction – Evolution of the land surface models (LSM)

The First Generation



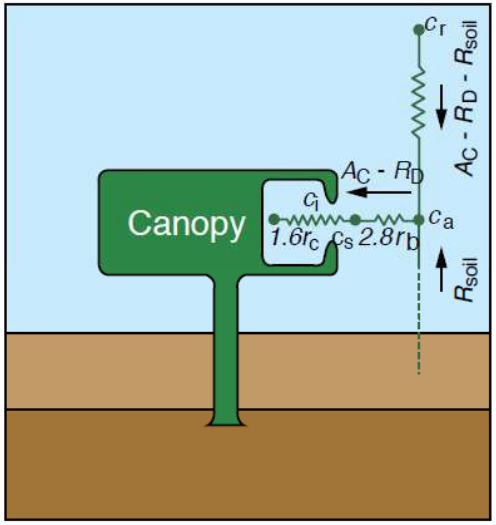
Bucket model

The Second Generation



Big-leaf (SVAT)
Soil Vegetation Atmosphere Transfer

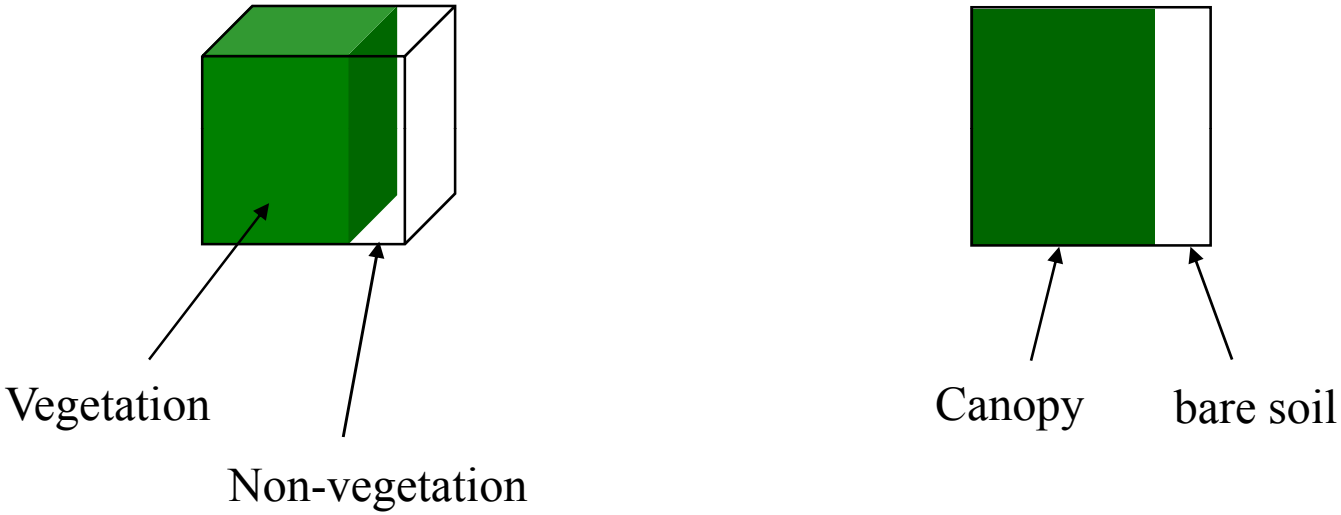
The Third Generation



Big-leaf + CO_2

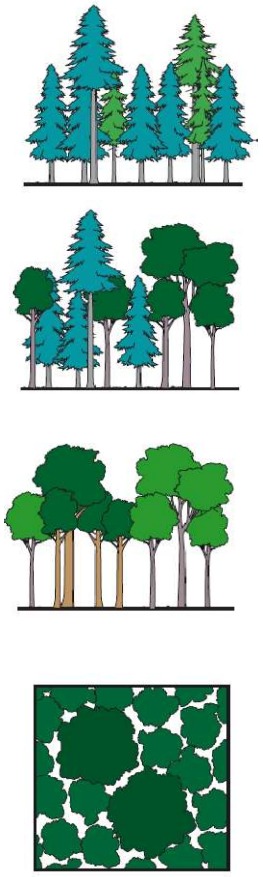
Sellers et al., 1997

Introduction – Forests in the model (big-leaf assumption)

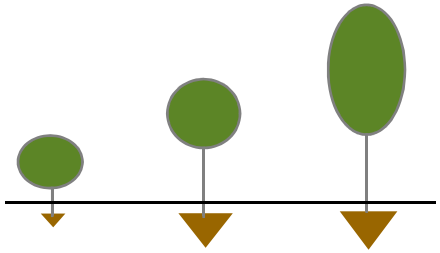


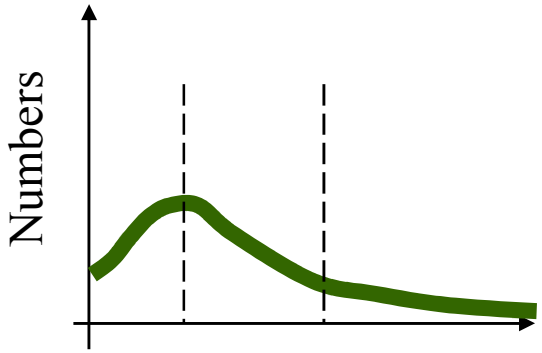
Introduction – Managed forests & canopy structure

Managed forests

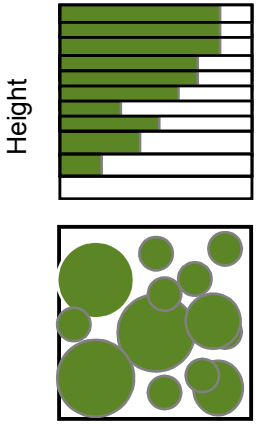


3 Circumference classes for each PFT





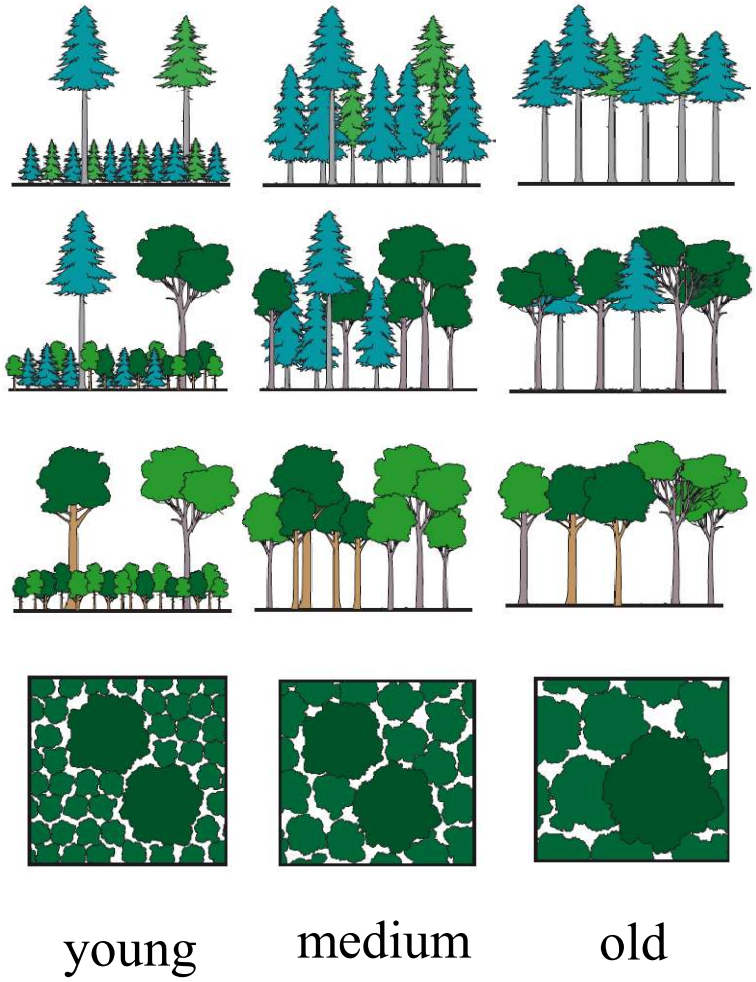
Heterogeneity of roughness



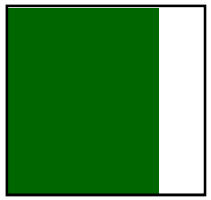
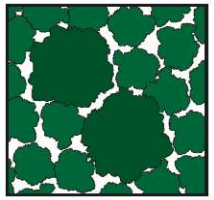
Borner, A., Bellassen, V. & Luyssaert, S. 2010; Naudts et al, 2015

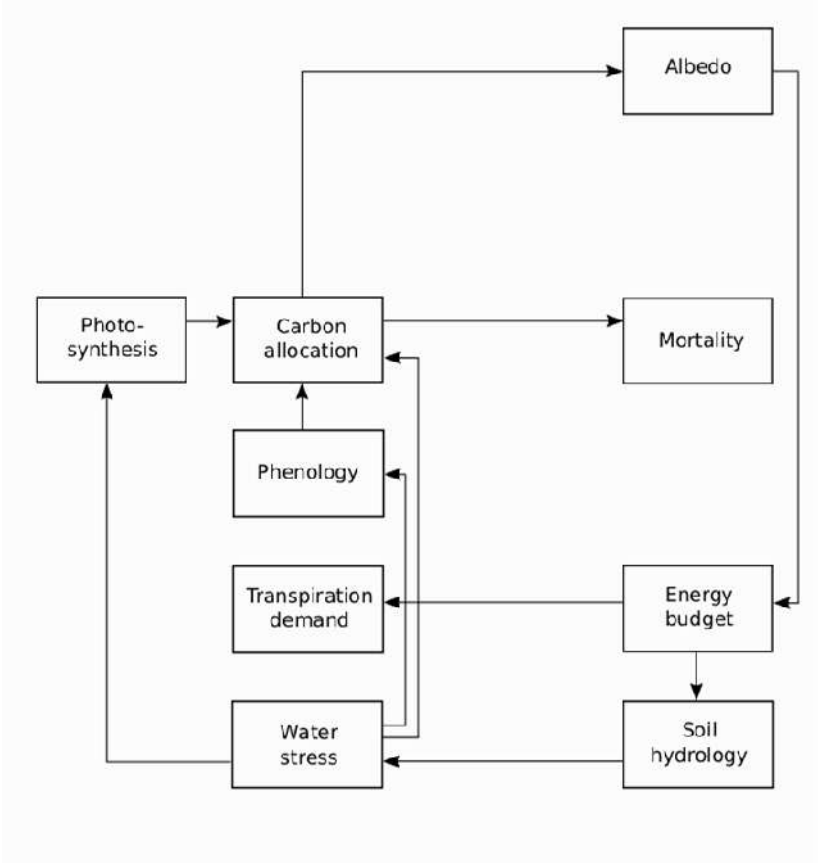
Introduction – Excepted new canopy structure in the model

Managed forests



Capacity building for a land-atmosphere model, ORCHIDEE

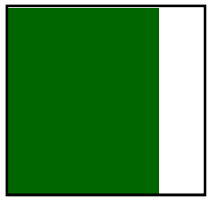
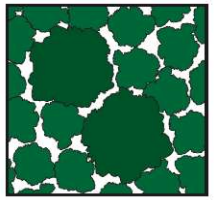
If we want to change this  to 



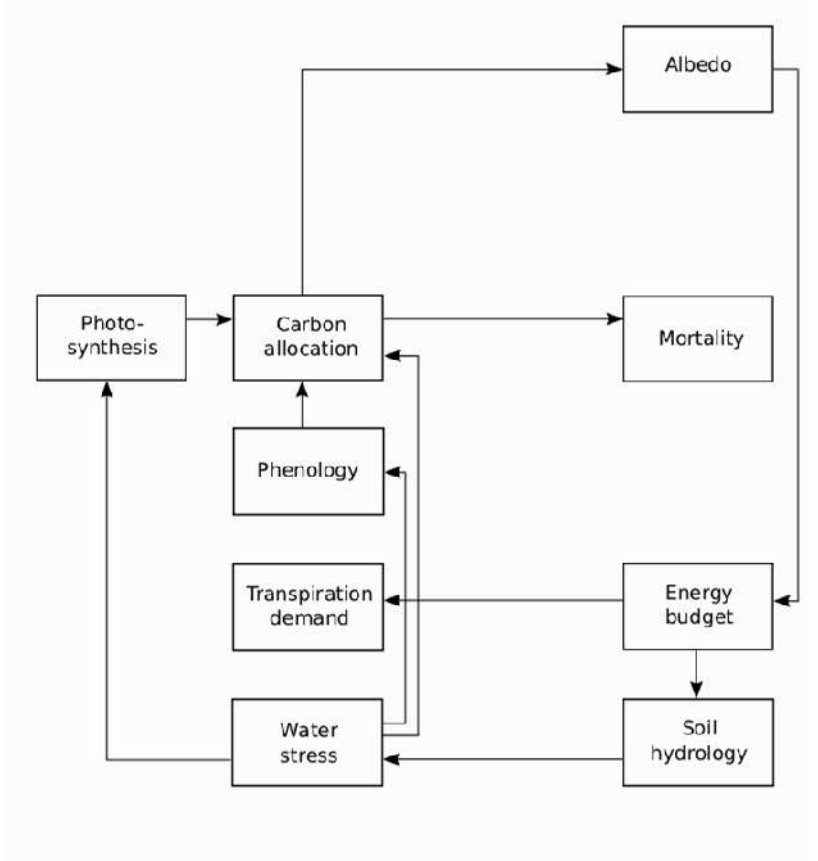
ORCHIDEE

Naudts et al., 2015

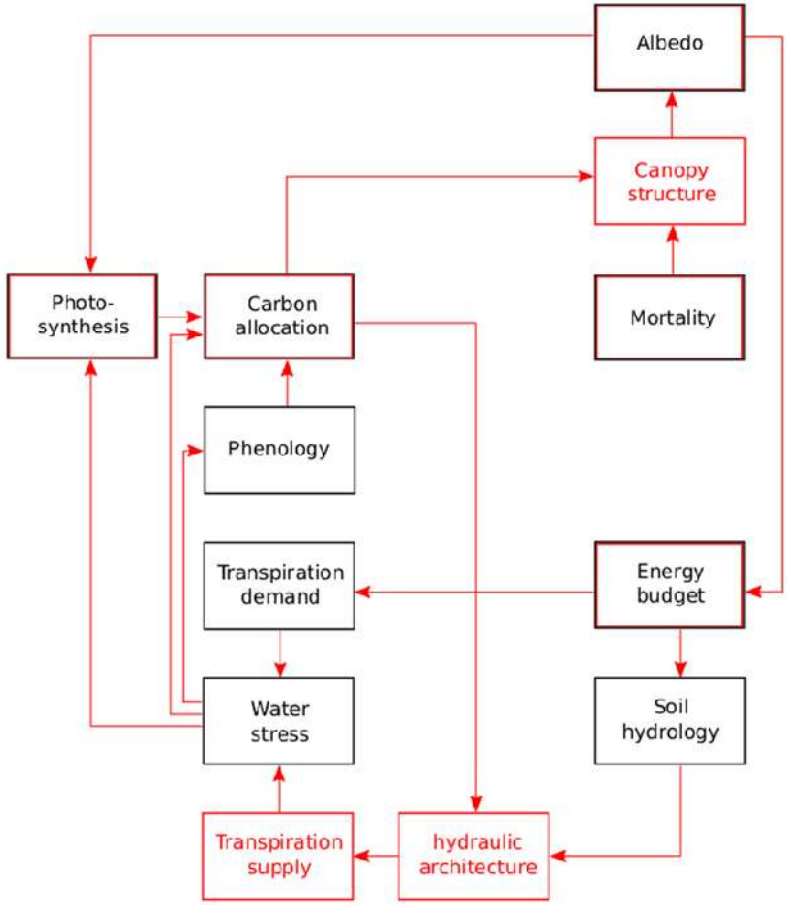
Capacity building for a land-atmosphere model, ORCHIDEE

If we want to change this  to 

We need to add/modify these modules (color in red)



ORCHIDEE

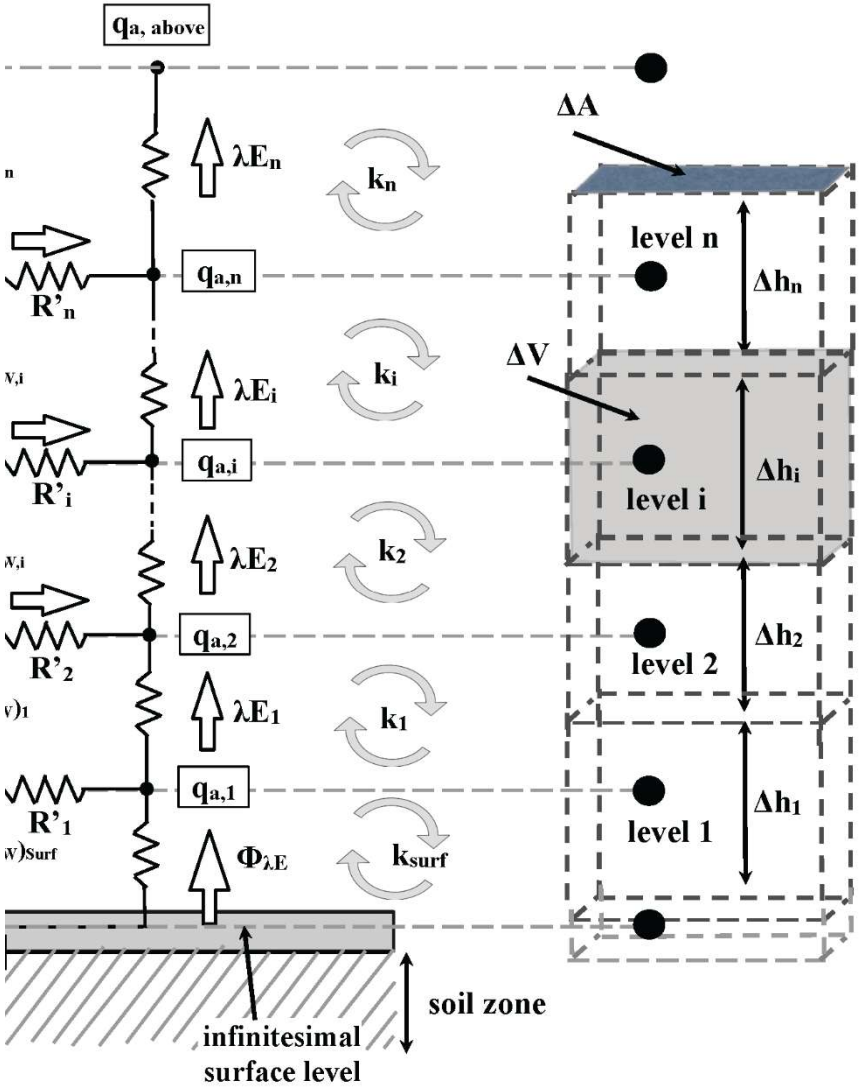


ORCHIDEE-CAN

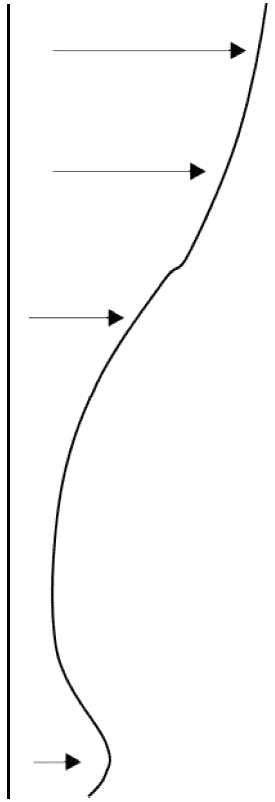
Naudts et al., 2015

ORCHIDEE-CAN, multi-layer energy budget : Parameterisation

Eddy diffusivity



Wind Profile



Ryder et al., 2015

ORCHIDEE-CAN, multi-layer energy budget : Eddy diffusivity

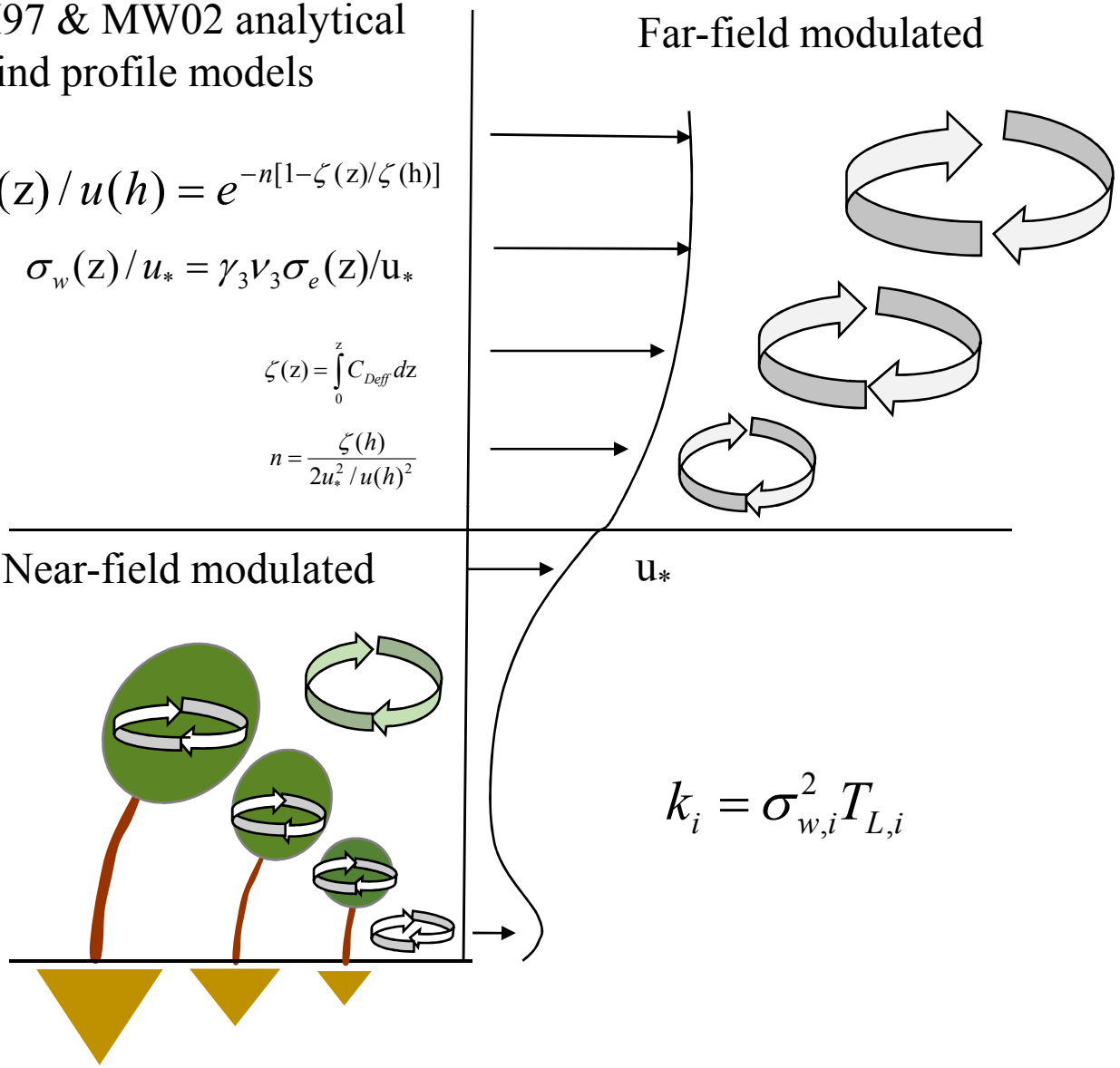
M97 & MW02 analytical wind profile models

$$u(z)/u(h) = e^{-n[1-\zeta(z)/\zeta(h)]}$$

$$\sigma_w(z)/u_* = \gamma_3 \nu_3 \sigma_e(z)/u_*$$

$$\zeta(z) = \int_0^z C_{Deff}\, dz$$

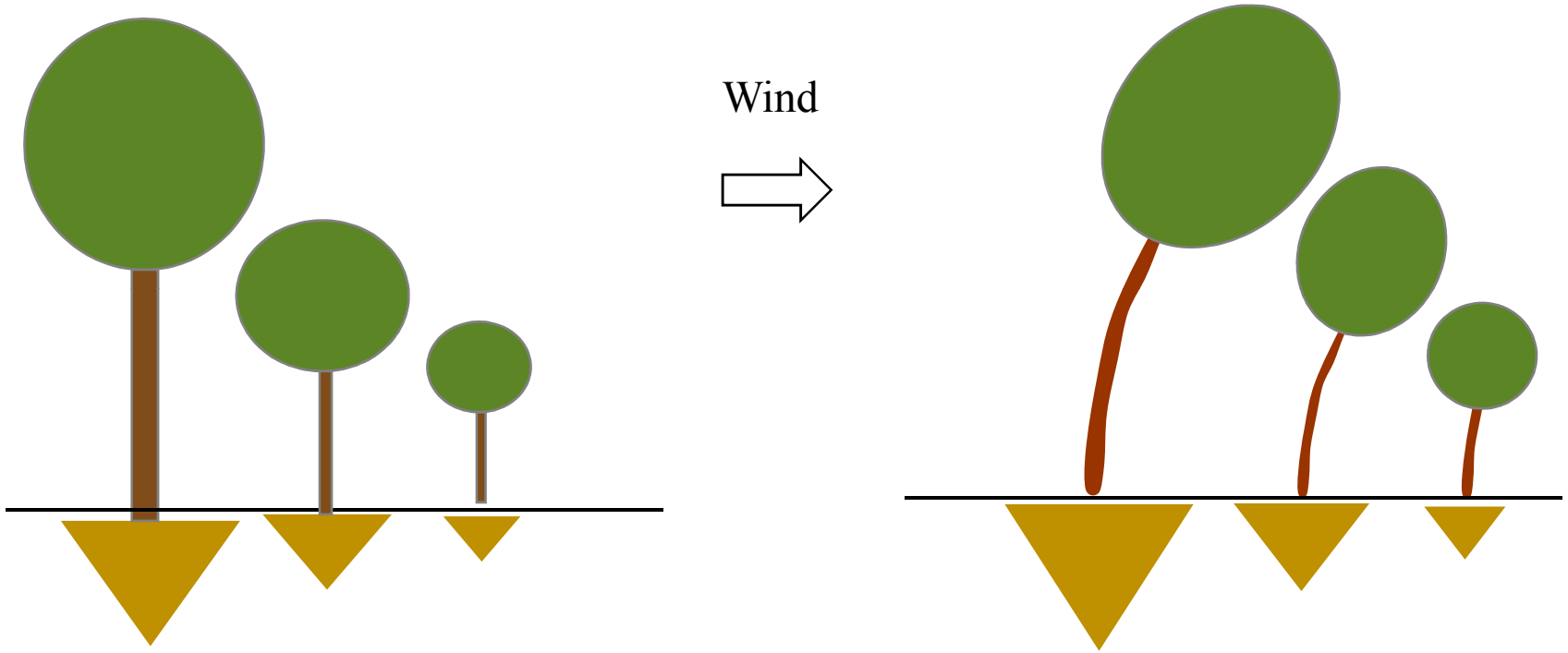
$$n = \frac{\zeta(h)}{2u_*^2/u(h)^2}$$



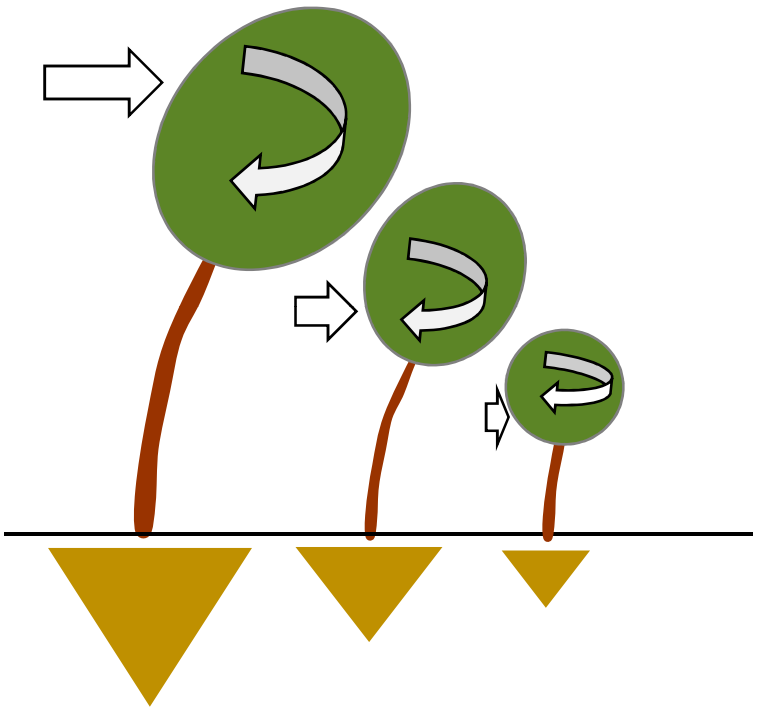
$$k_i = \sigma_{w,i}^2 T_{L,i}$$

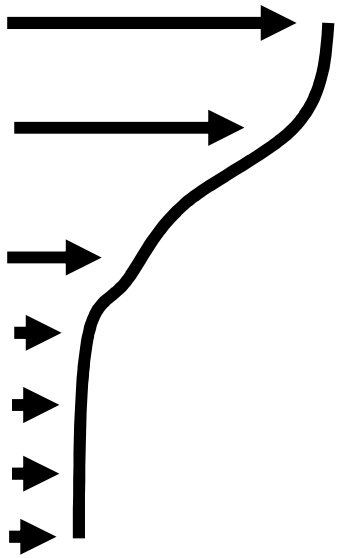
Massman, 1997; Massman and Weil, 2002

ORCHIDEE-CAN, multi-layer energy budget : Effective drag coefficient

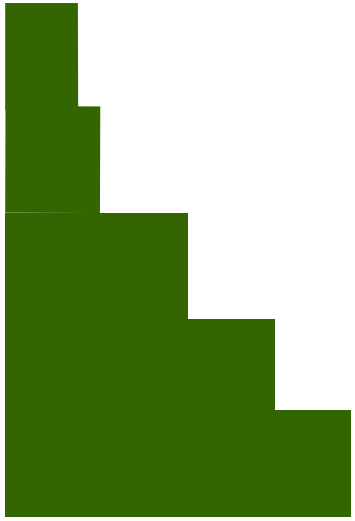


ORCHIDEE-CAN, multi-layer energy budget : Effective drag coefficient





Effective drag



Cumulative LAI

$$C_{Deff,i} = a_1^{-LAI_{cum,i}/a_2} + a_3^{-LAI_{cum,i}/a_4} + a_5$$

Wohlfahrt and Cernusca, 2002

ORCHIDEE-CAN, multi-layer energy budget : Eddy diffusivity

M97 & MW02 analytical wind profile models

$$u(z)/u(h) = e^{-n[1-\zeta(z)/\zeta(h)]}$$

$$\sigma_w(z)/u_* = \gamma_3 \nu_3 \sigma_e(z)/u_*$$

$$\zeta(z) = \int_0^z C_{Deff}\, dz$$

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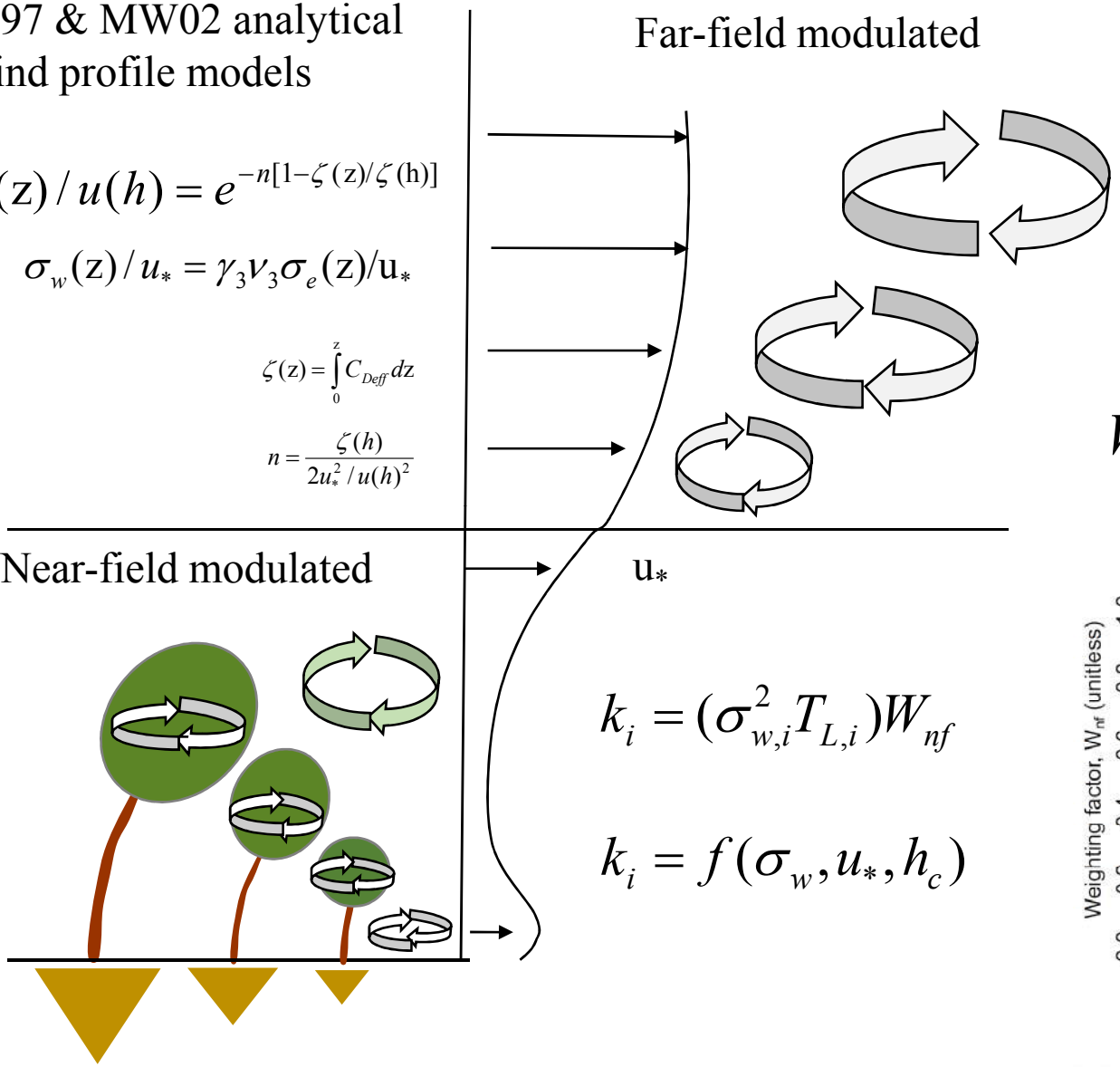
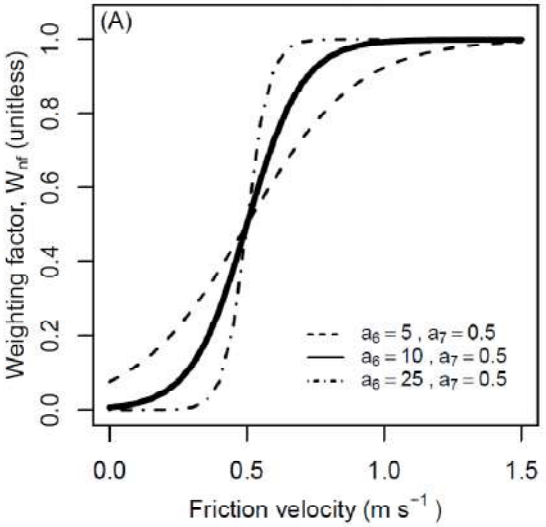


$$k_i = (\sigma_{w,i}^2 T_{L,i}) W_{nf}$$

$$k_i = f(\sigma_w, u_*, h_c)$$

$$W_{nf} = \frac{1}{1 + e^{(-a_6(u_* - a_7))}}$$



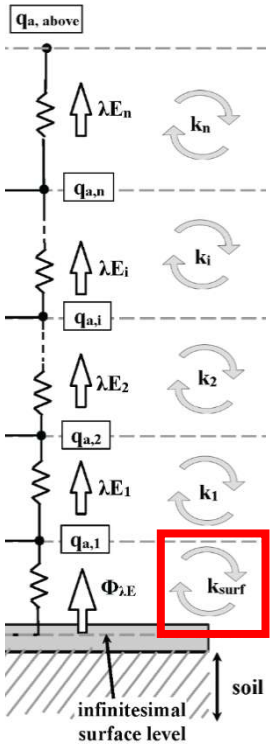
Massman, 1997; Massman and Weil, 2002; Chen et al. to be submitted

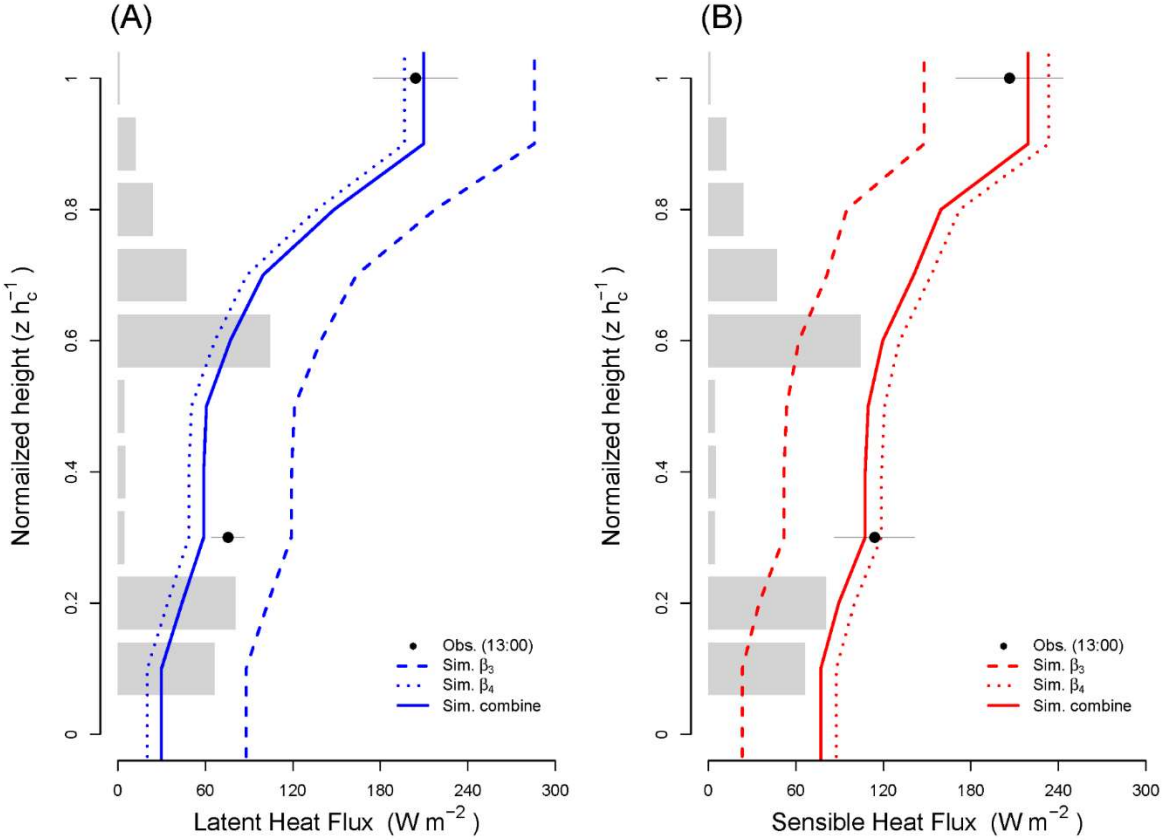
ORCHIDEE-CAN, multi-layer energy budget : Soil-atmosphere interface

$$k_{surf} = \beta_4 \left(u_1 C_{Deff,1} \right) \quad dotline$$

$$k_{surf} = \beta_3 \left(u_1 C_{Deff,1} \right) \quad dashline$$

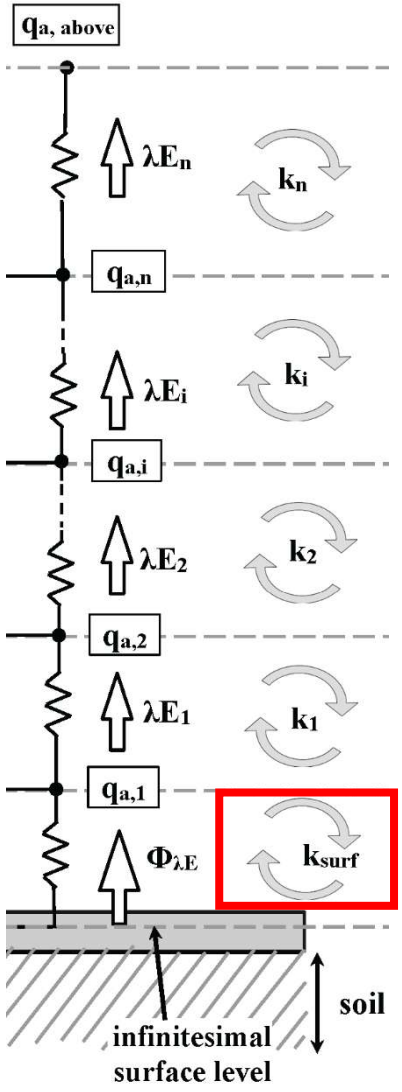
$$k_{surf} = \left(W_{sf} \beta_4 + (1 - W_{sf}) \beta_3 \right) \left(u_1 C_{Deff,1} \right) \quad solidline$$





Chen et al., to be submitted

ORCHIDEE-CAN, multi-layer energy budget : Soil-atmosphere interface



Sparse

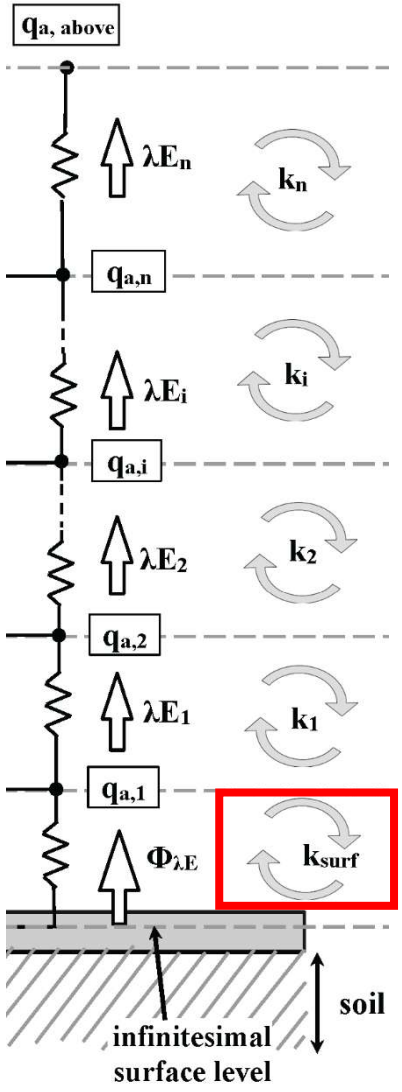
Dense

Summer

Fall

Chen et al., to be submitted

ORCHIDEE-CAN, multi-layer energy budget : Soil-atmosphere interface



Sparse

Dense

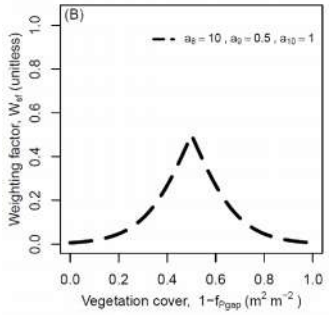
Summer

Fall

$$k_{surf} = \left(W_{sf}\beta_4 + (1-W_{sf})\beta_3\right)u_1 C_{Deff,1}$$

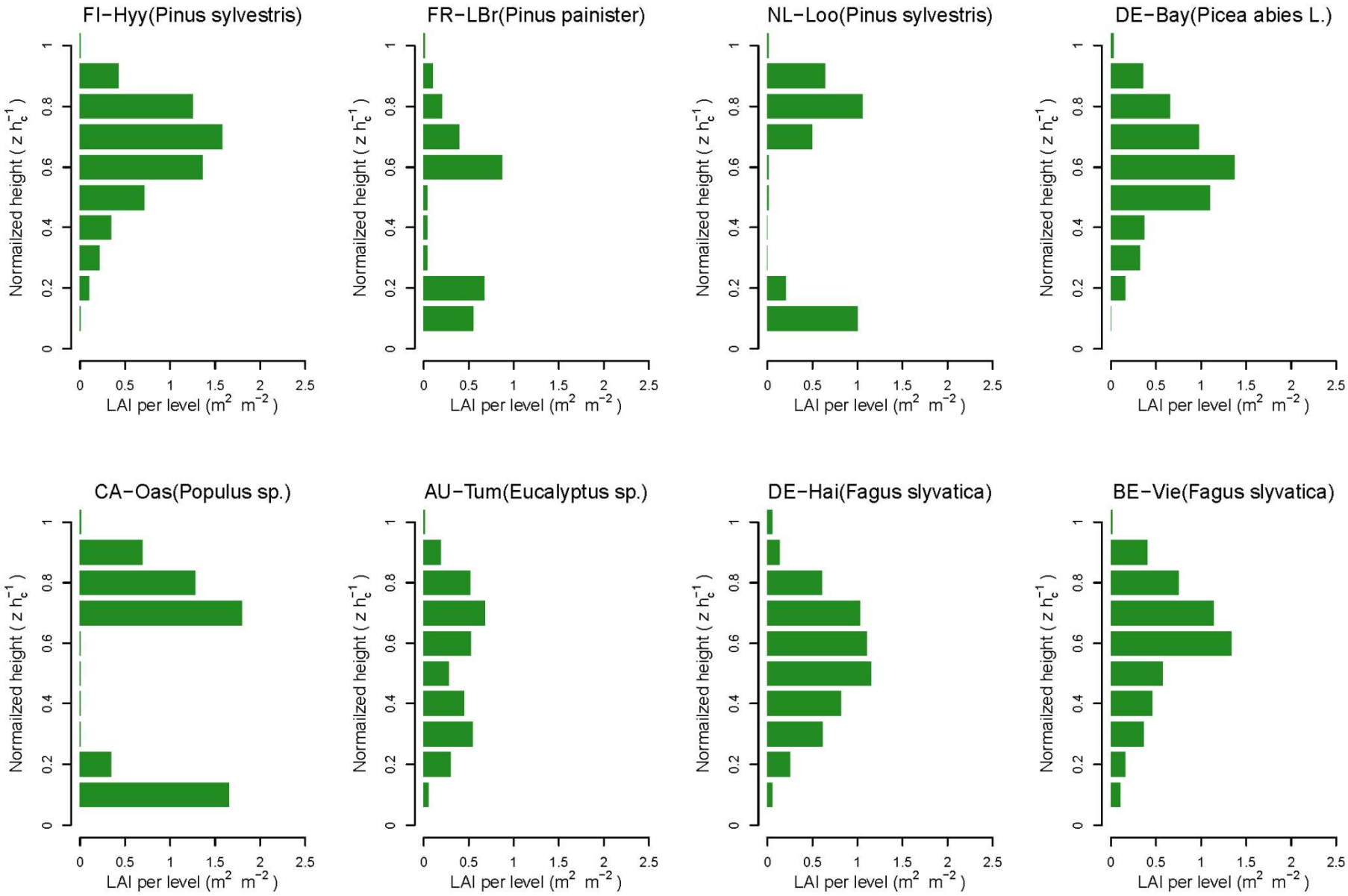
$$\begin{cases} W_{sf} = \beta_0 & when \quad (1-f_{Pgap}) > a_9 \\ W_{sf} = (1-\beta_0) & when \quad (1-f_{Pgap}) \le a_9 \end{cases}$$

$$\beta_0 = \begin{cases} \dfrac{a_{10}}{(1+\dfrac{298.15-\overline{T_a}}{15}) + e^{\left(-a_8(1-f_{Pgap})-a_9\right)}} & when \quad \overline{T_a} \le 298.15 \\ \dfrac{a_{10}}{(1+e^{\left(-a_8(1-f_{Pgap})-a_9\right)}} & when \quad \overline{T_a} > 298.15 \end{cases}$$



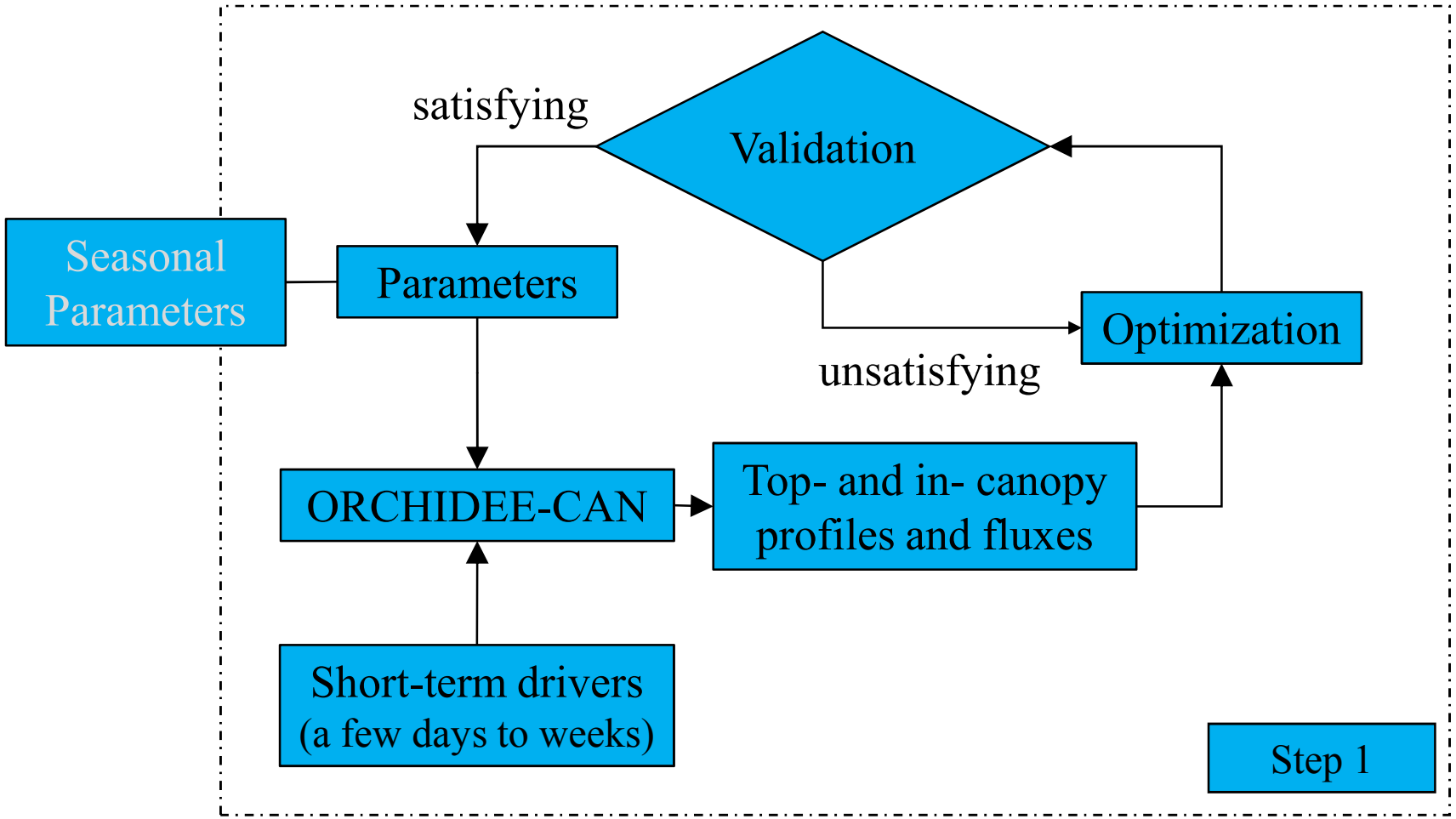
Chen et al., to be submitted

ORCHIDEE-CAN, multi-layer energy budget : Multiple sites validation



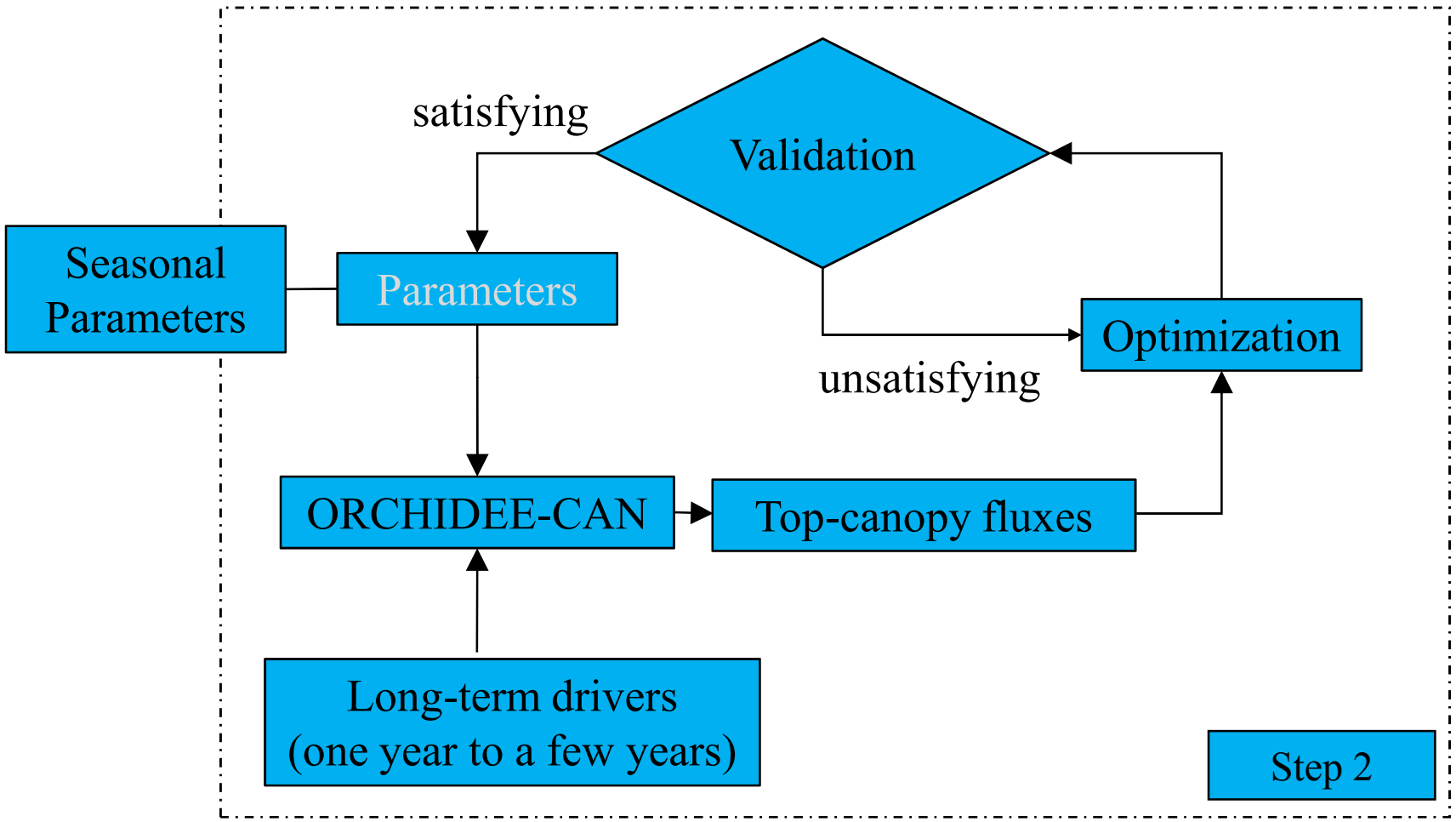
Chen et al., to be submitted

ORCHIDEE-CAN, multi-layer energy budget : Optimization and validation



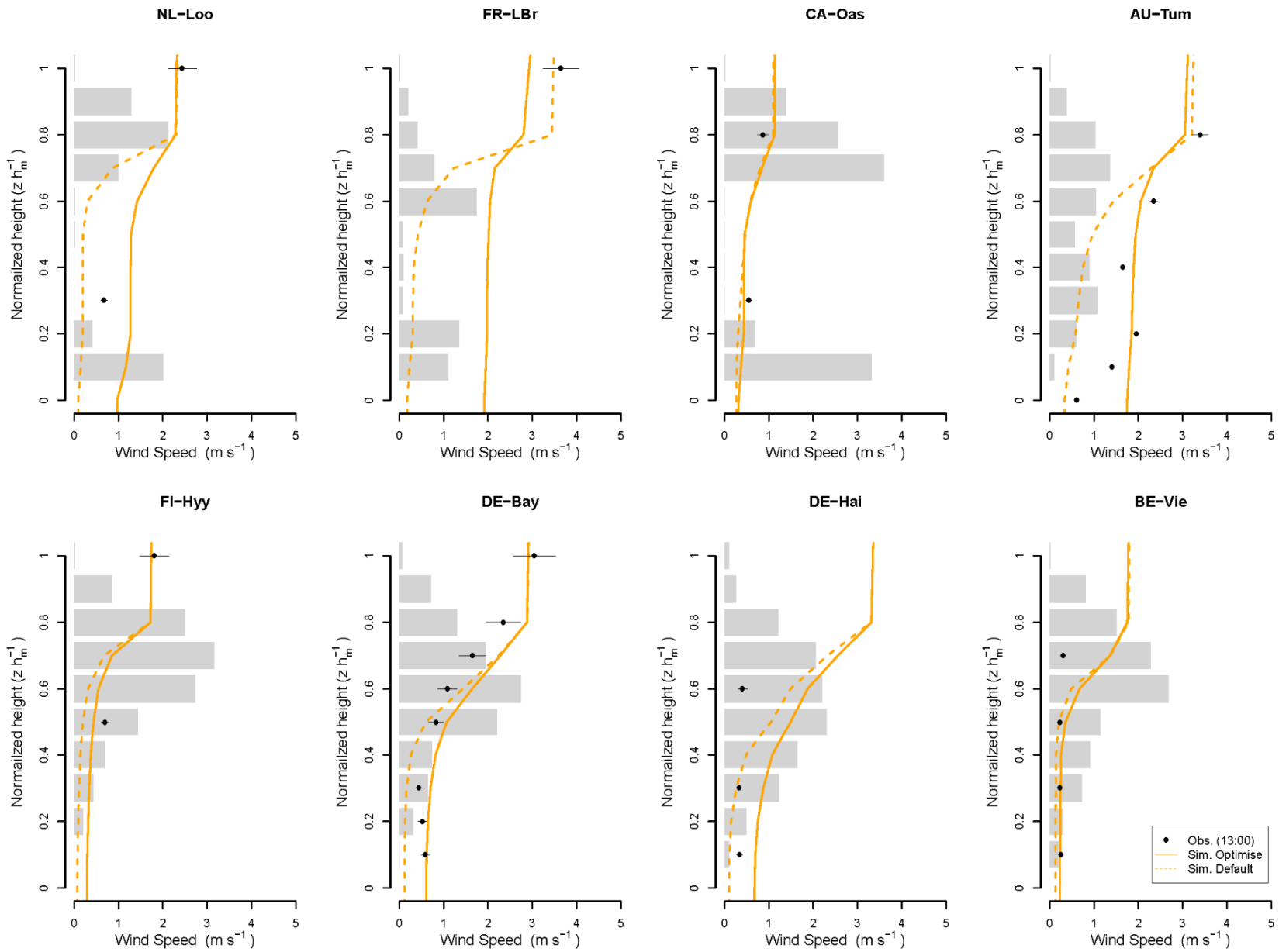
Chen et al., to be submitted

ORCHIDEE-CAN, multi-layer energy budget : Optimization and validation



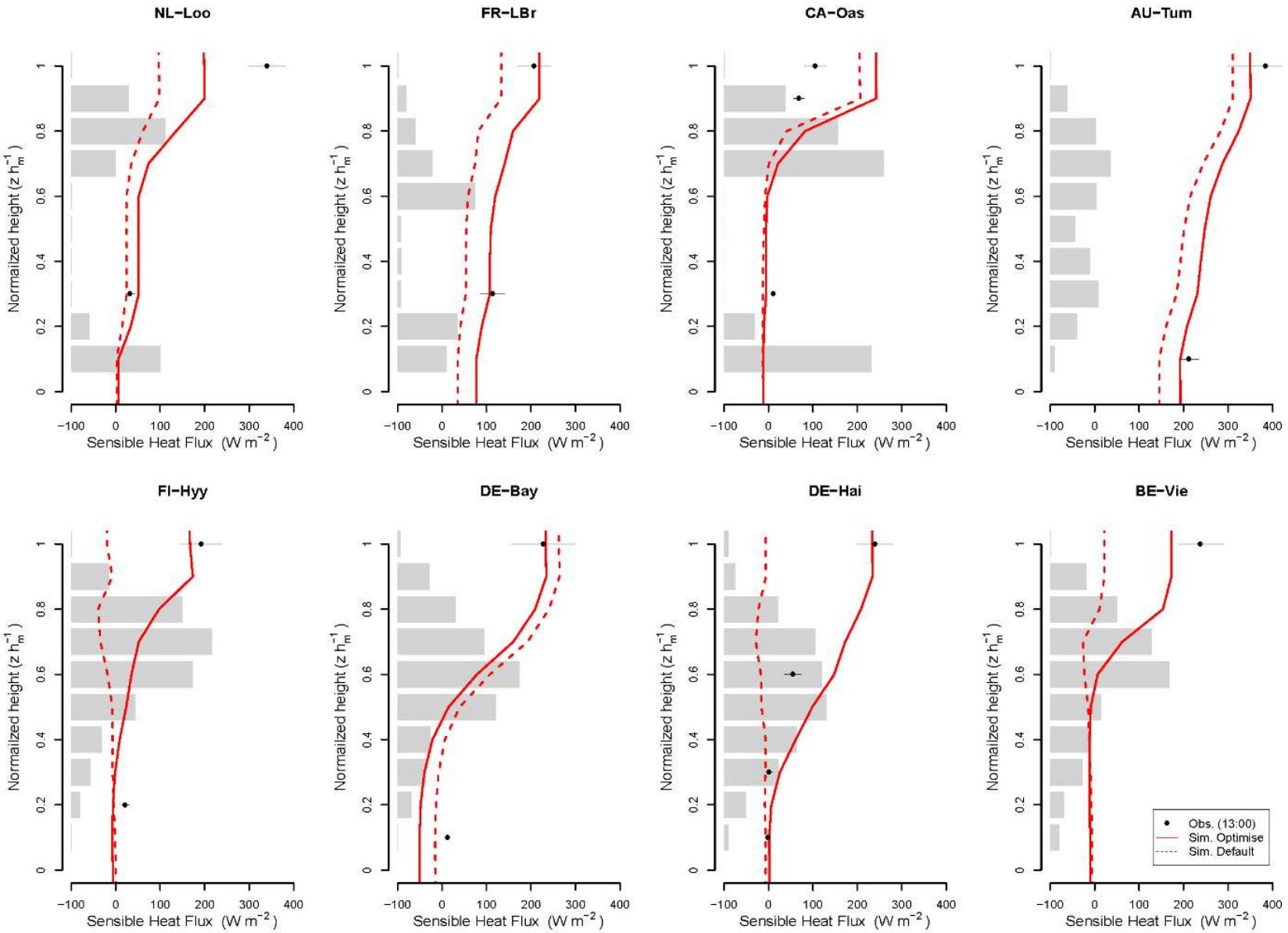
Chen et al., to be submitted

ORCHIDEE-CAN, multi-layer energy budget : Wind profiles



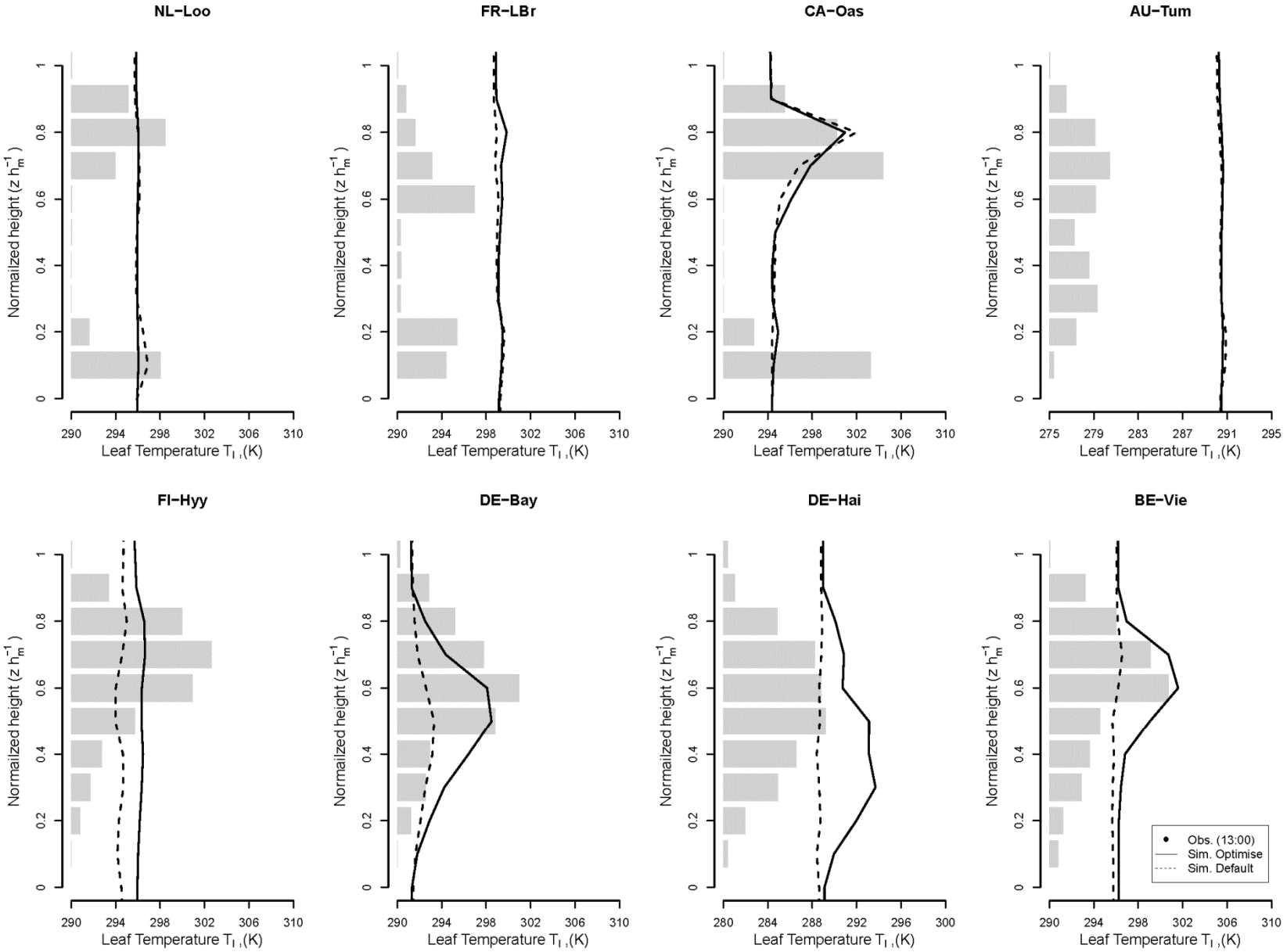
Chen et al., to be submitted

ORCHIDEE-CAN, multi-layer energy budget : Sensibel heat flux profiles



Chen et al., to be submitted

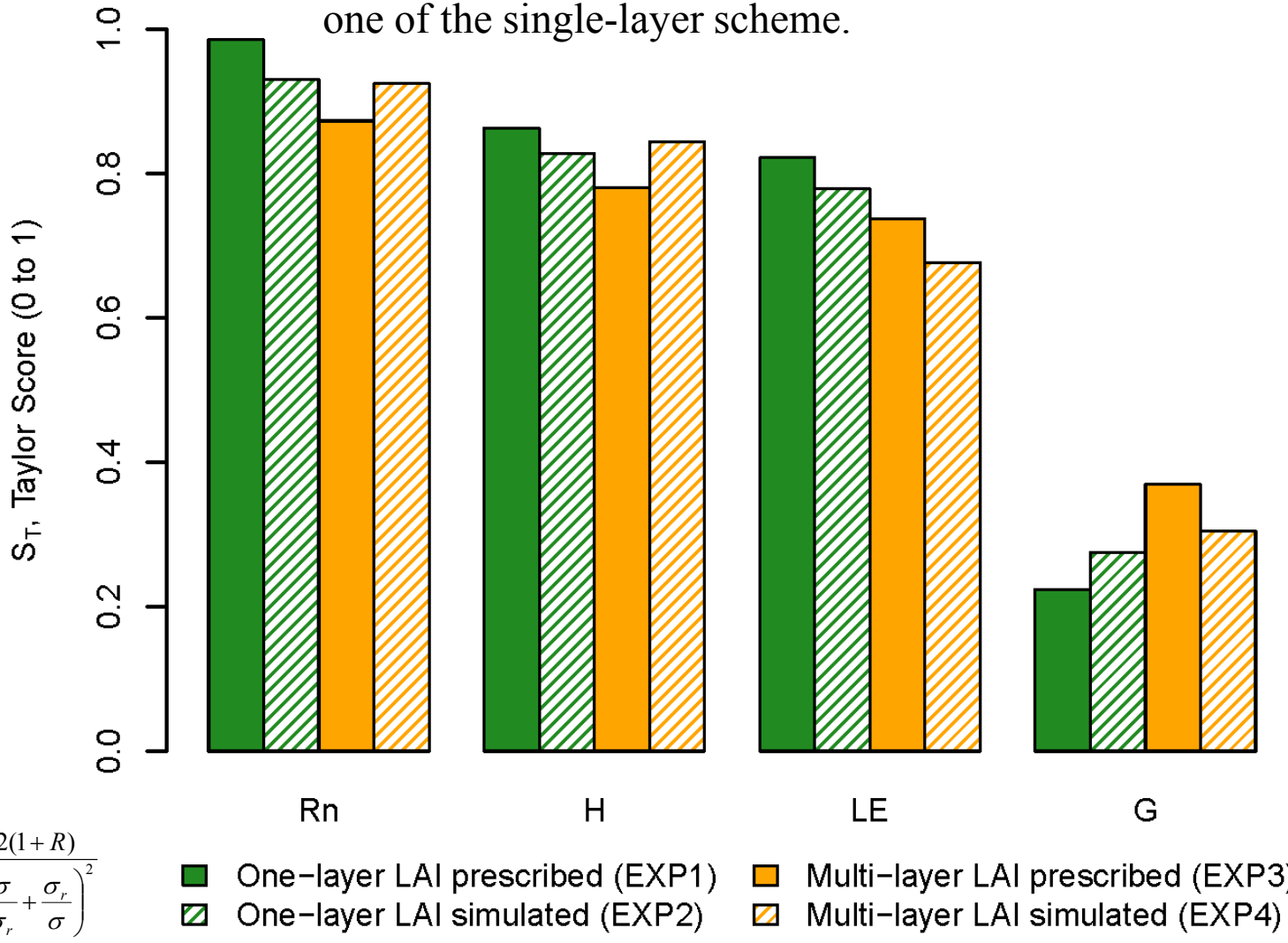
ORCHIDEE-CAN, multi-layer energy budget : Leaf temperature profiles



Chen et al., to be submitted

Single- and multi- layer energy budget : Long-term performance

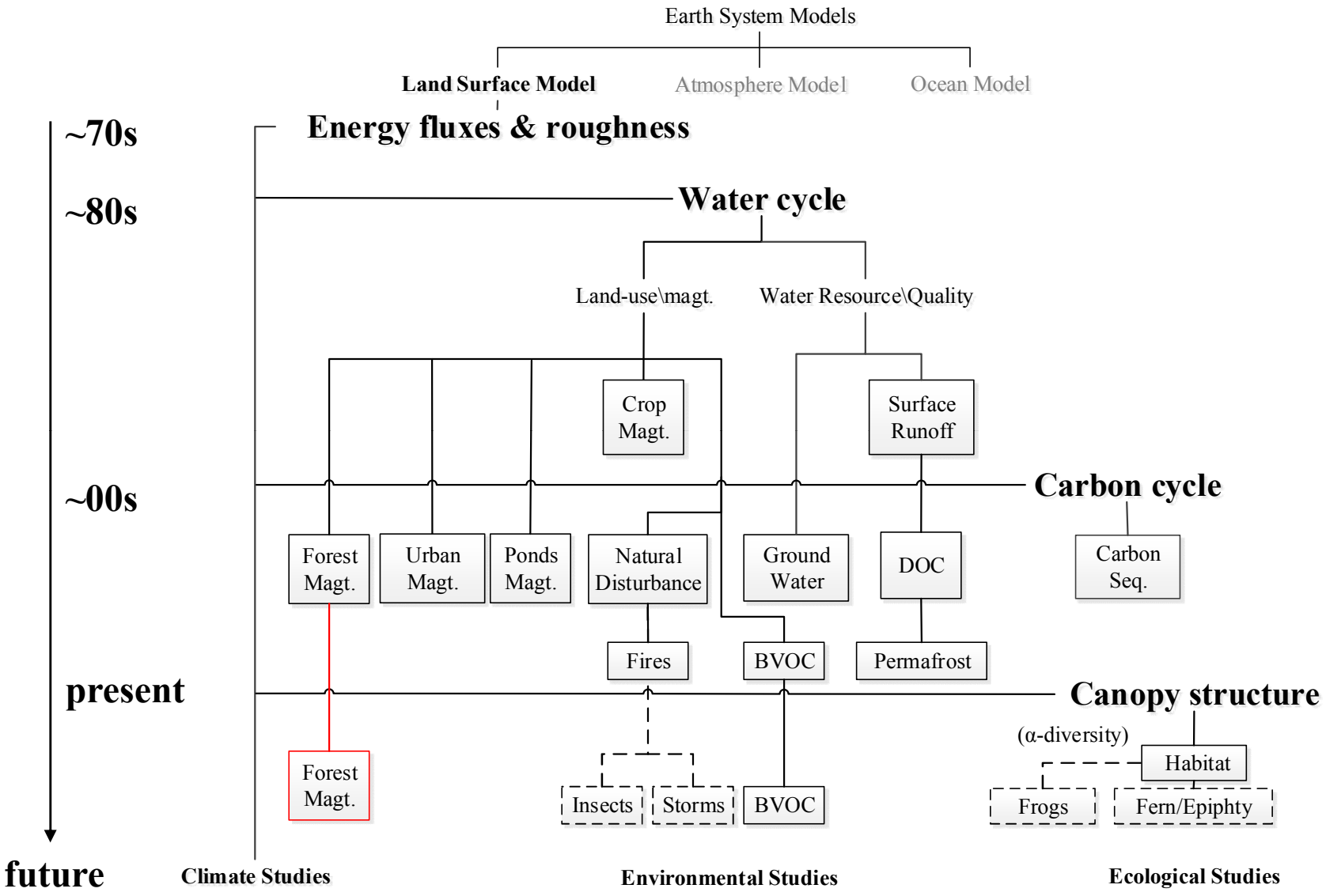
The performance of multi-layer scheme is as well as the one of the single-layer scheme.



$$S_T = \frac{2(1+R)}{\left(\frac{\sigma}{\sigma_r} + \frac{\sigma_r}{\sigma}\right)^2}$$

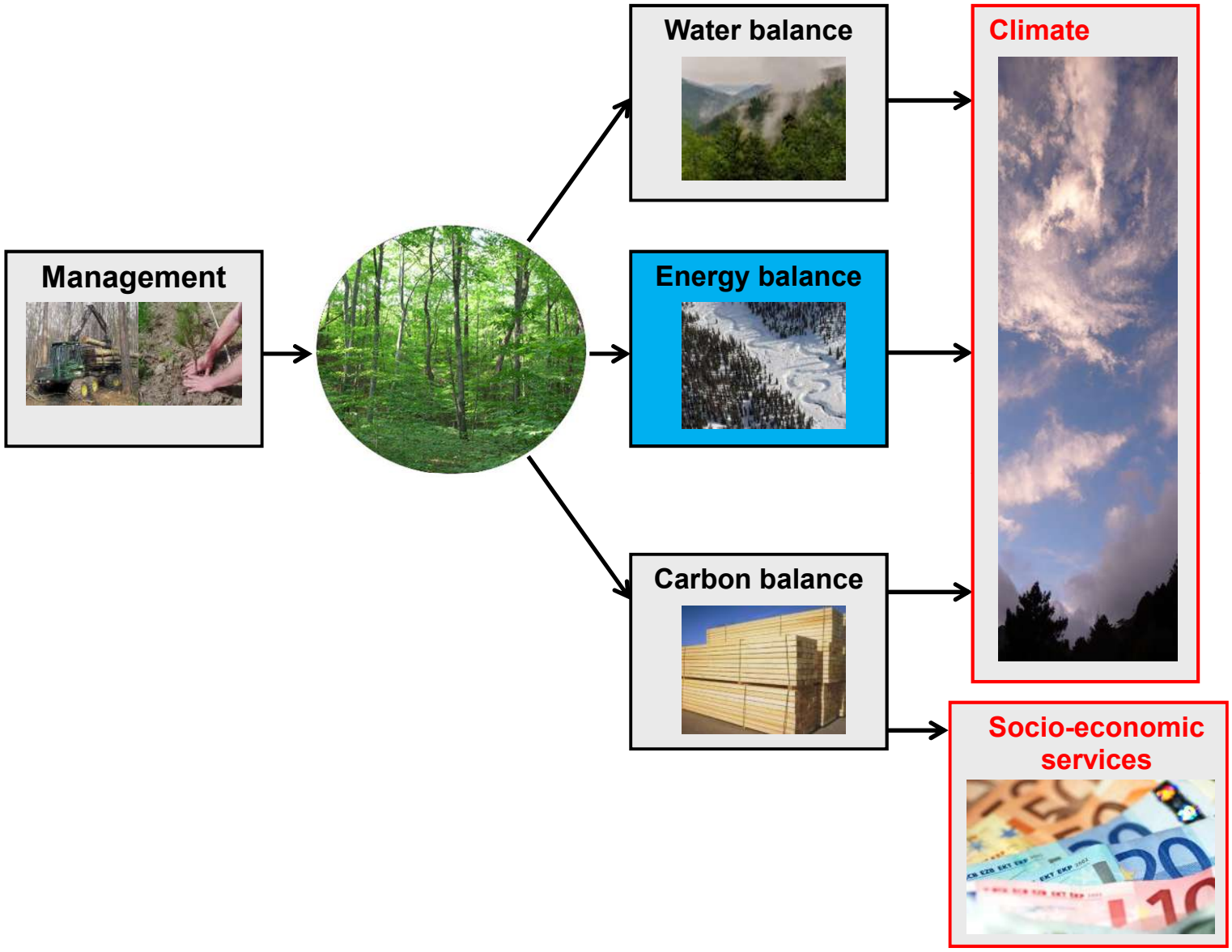
Chen et al., to be submitted

Application of the land surface model (LSM)



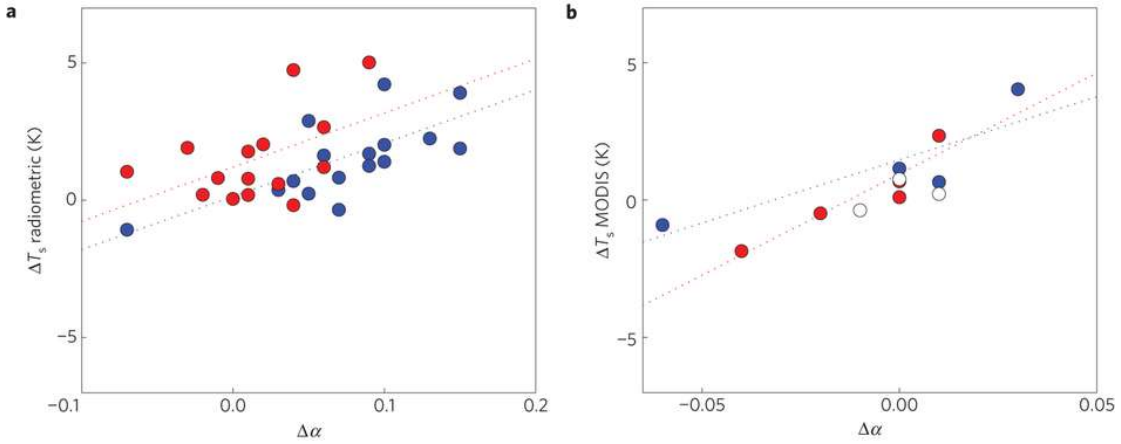
Adjusted from Pitman et al., 2003

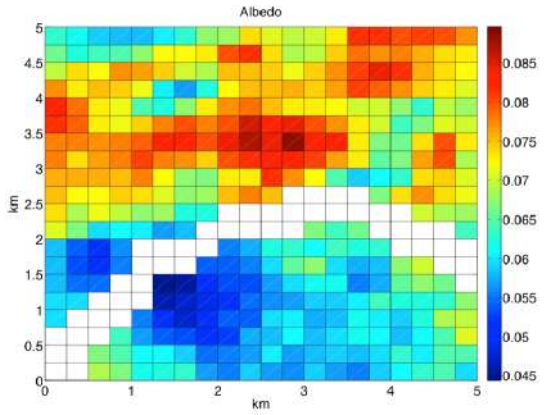
Application – ORCHIDEE-CAN: Effects of forest management

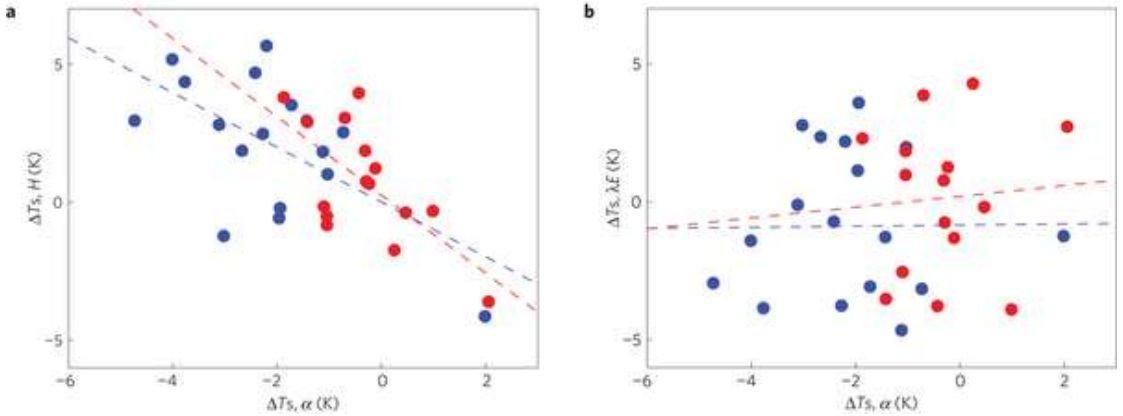


Eddy covariance fluxes and MODIS temperature\albedo observations

Land Management and **Land-cover Change** have impacts of similar magnitude on surface temperature



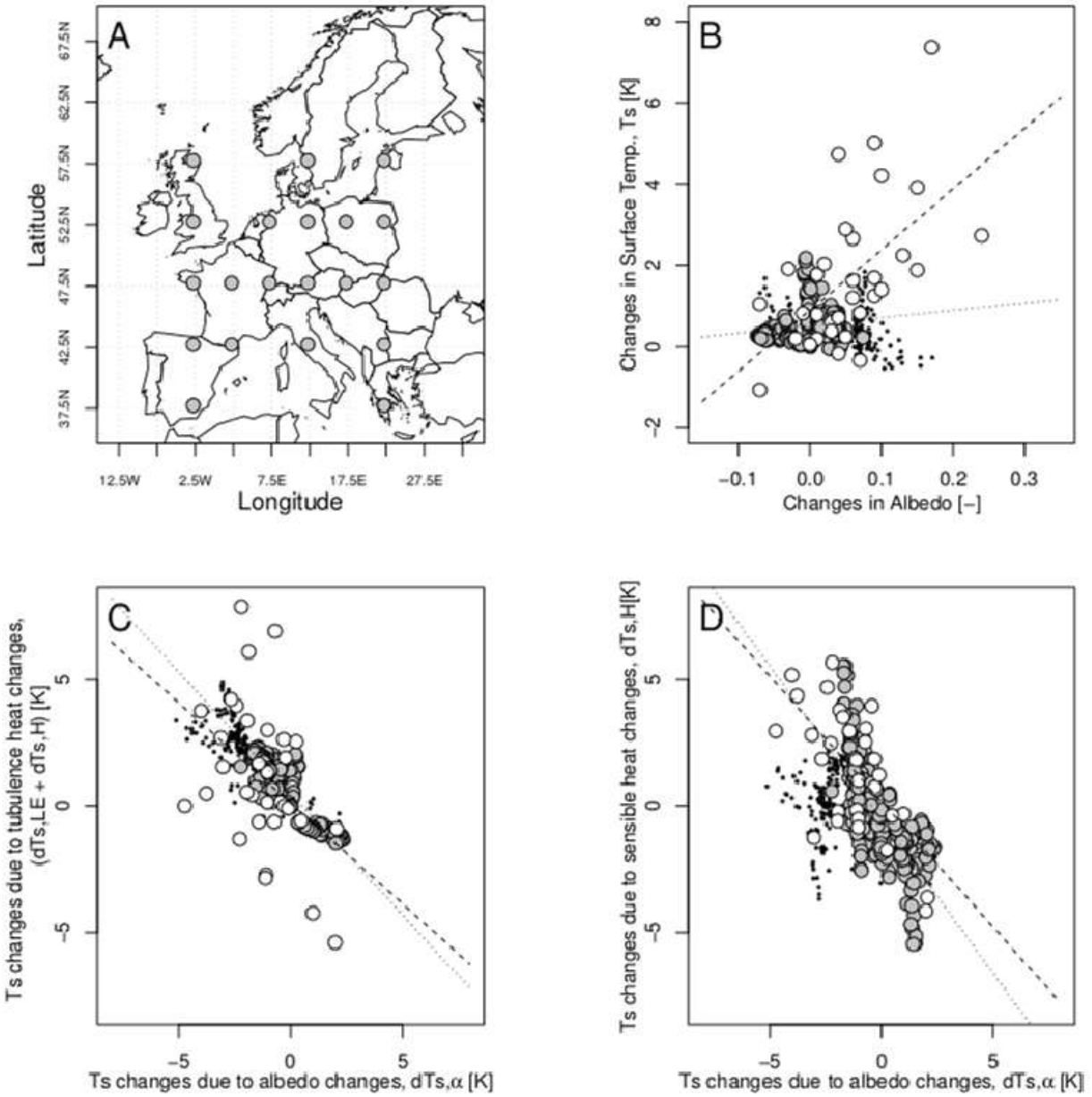




Caption: Biophysical effects of land cover change (blue) or land management (red).

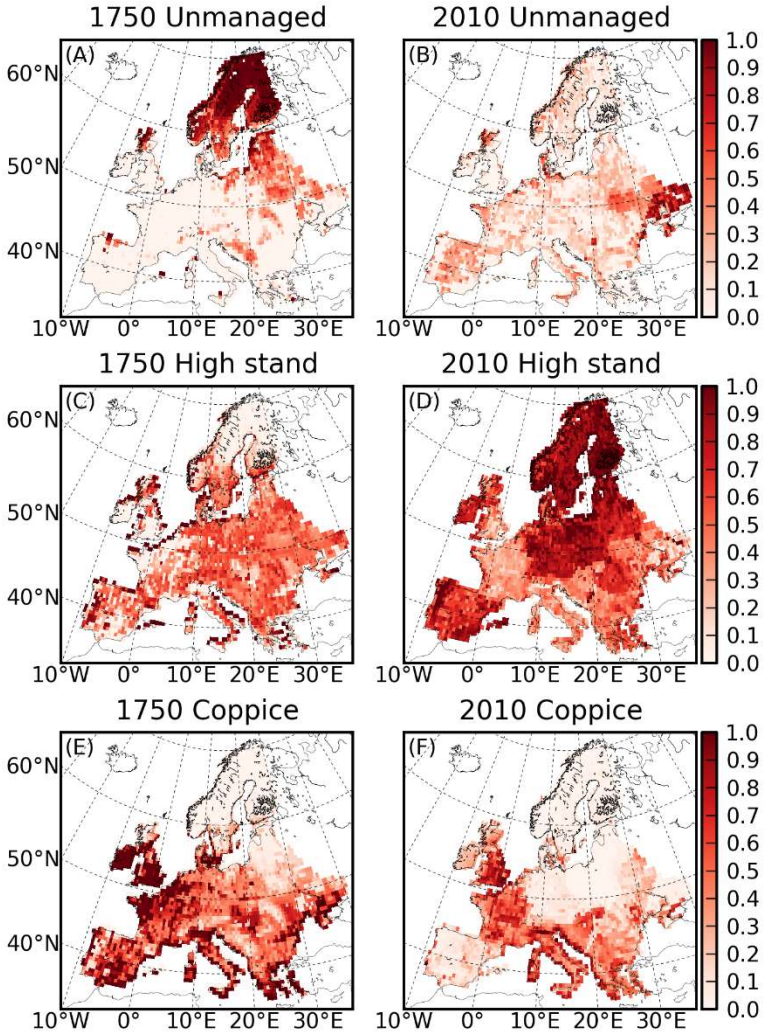
Luyssaert et al, 2014

Application – Capacity building for land-atmosphere models

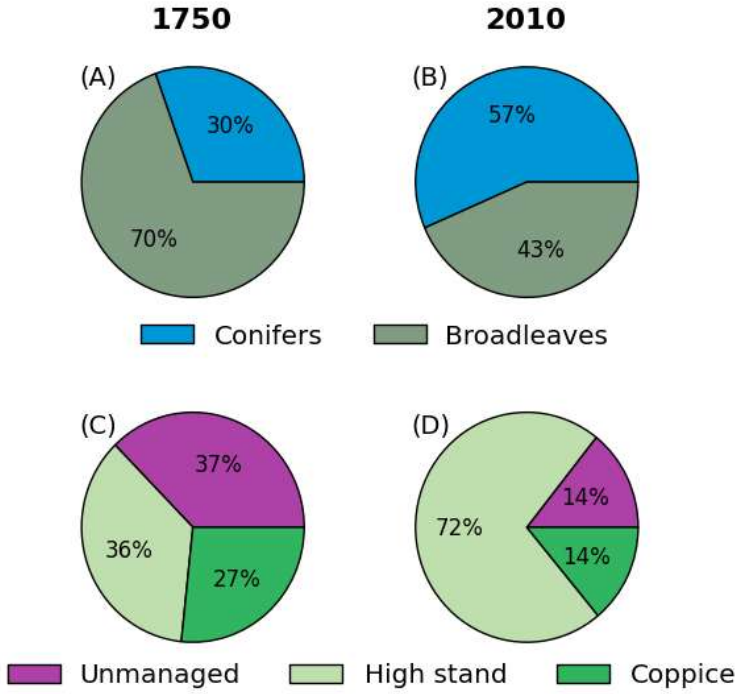


Naudts et al., 2016; Luyssaert et al., 2014

Application – Effects of forest management



European's FM from 1750 to 2010 for factorial simulation setup



McGrath et al., 2015

Application – Effects of forest management (model configuration)

LMDzOR-CAN

Global (118x128x39L) / Europe (80x80x39L)

Wind field nudged by 60 min outside Europe
by 10 days inside Europe
(ERA 1990 to 2010 mean)

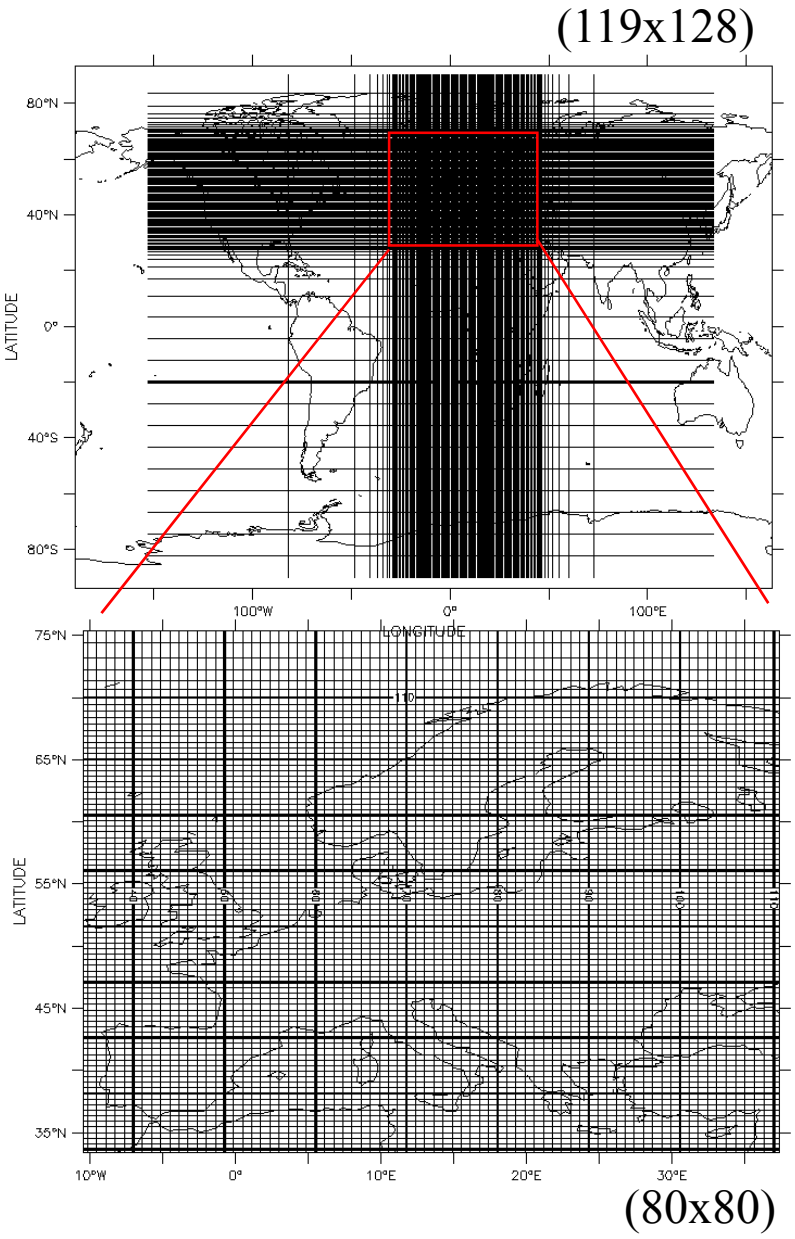
Ocean

A swamp ocean model, ocean, sea ice have surface temperature, but no heat storage and release

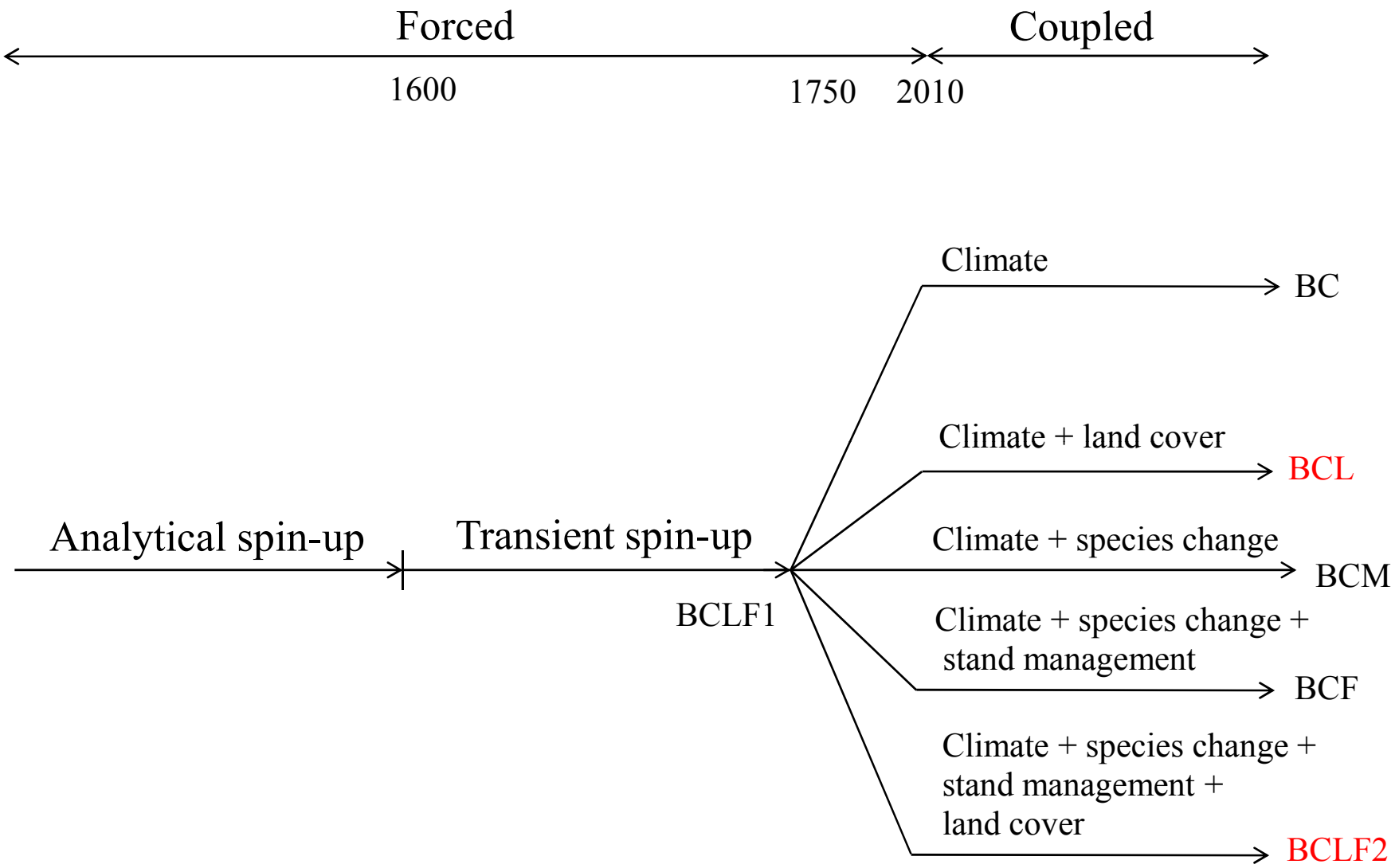
Atmosphere composition

O_3, CO_2, O_2, N_2O, CH_4, CFC11 and CFC12

80 nodes run in parallel: 1year simulation ~ 4hrs (119x128x39)



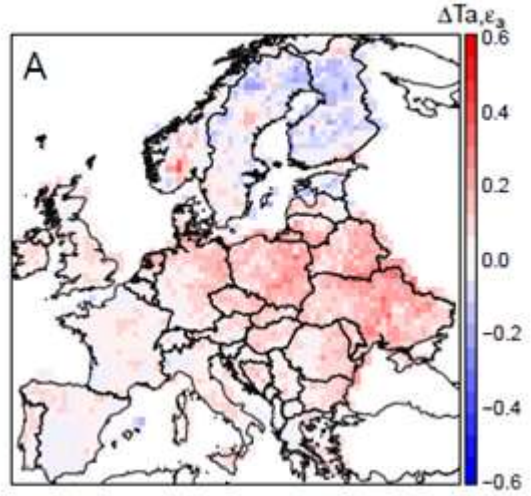
Application – Climate effects of 250-years of forest management

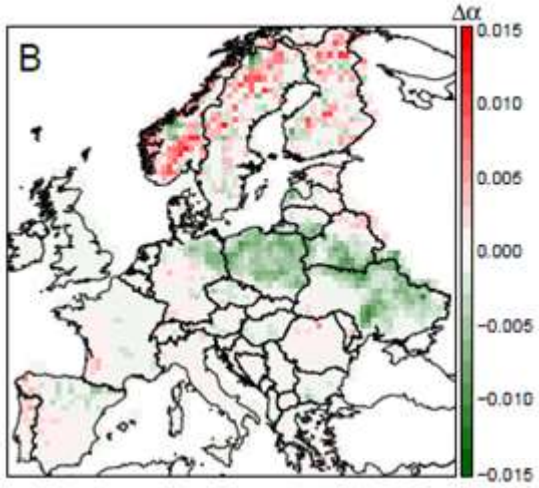


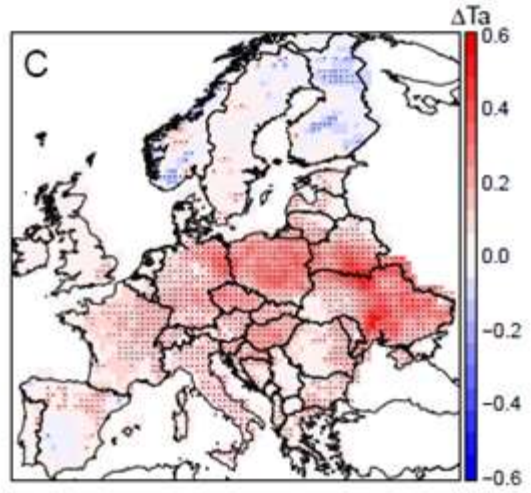
Naudts et al., 2016

Application – Effects of forest management (biophysical effect)

BCLF2-BCL = Forest Management (Species change + Stand Magt.)



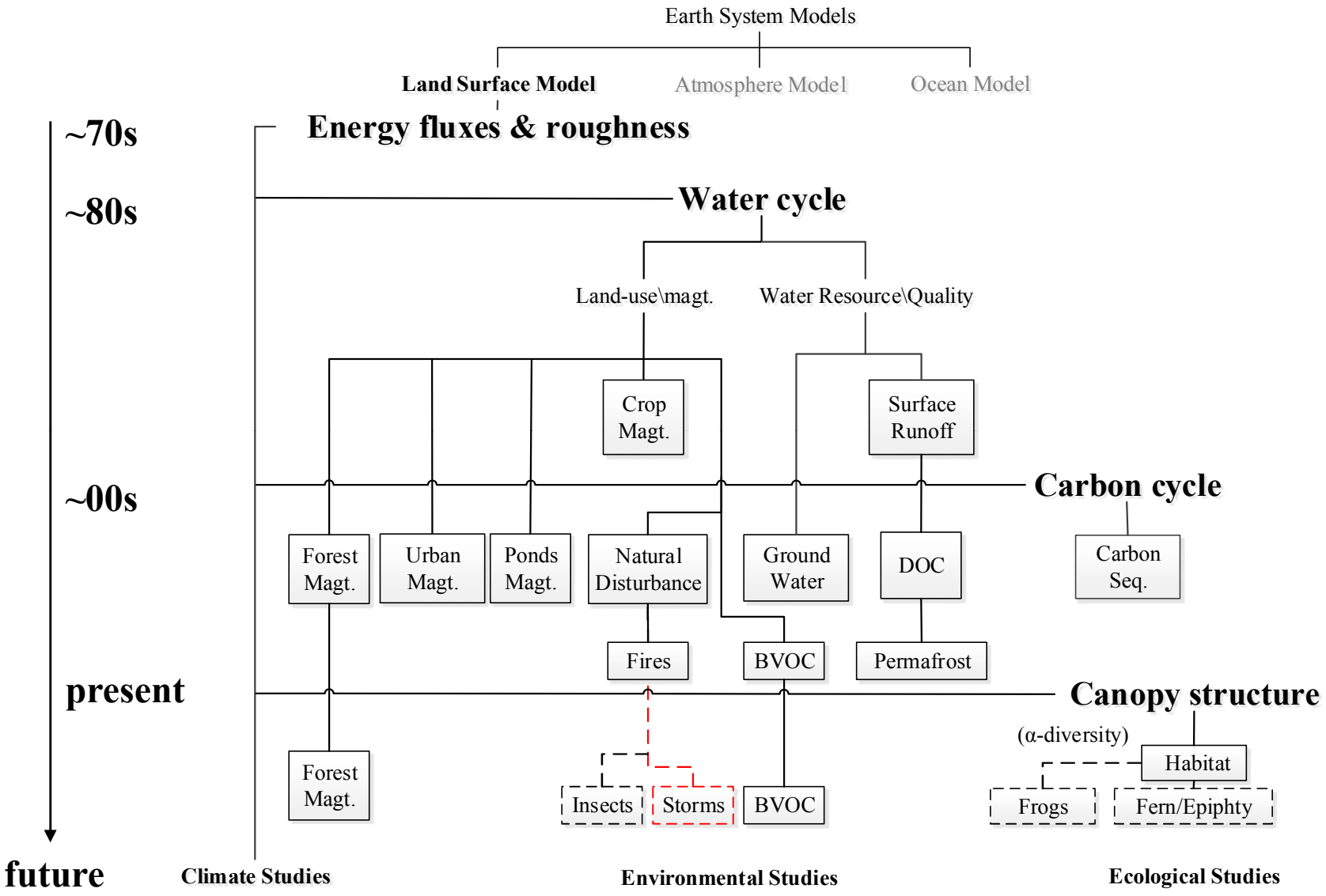




$$\Delta T_a = \frac{1}{4\varepsilon_a \sigma T_a^3} \begin{bmatrix} R_{si}\Delta\alpha \\ -(1-\alpha)\Delta R_{si} \\ +\Delta LE \\ +\Delta H \\ +\Delta G \\ -(\sigma T_a^4)\Delta\varepsilon_a \end{bmatrix}$$

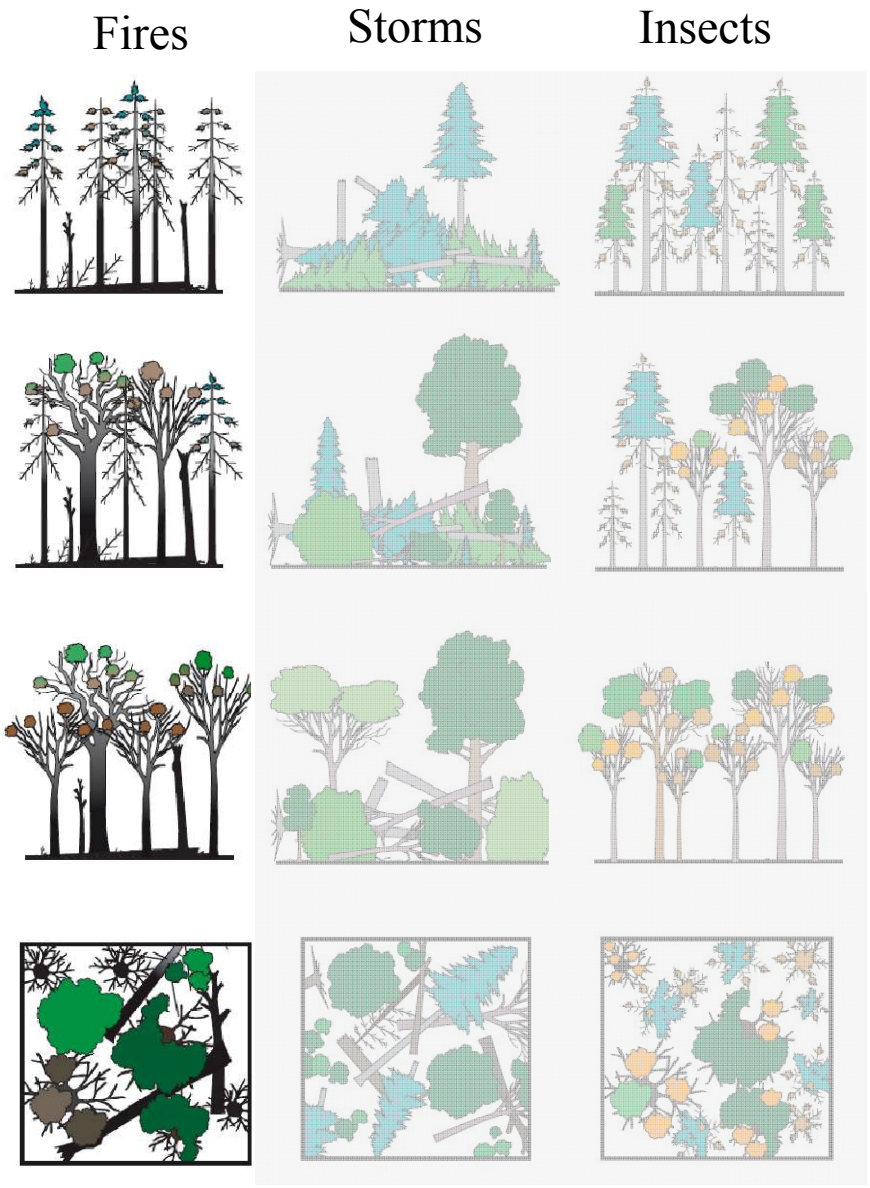
Naudts et al., 2016

Introduction – Evolution\application of the land surface model (LSM)



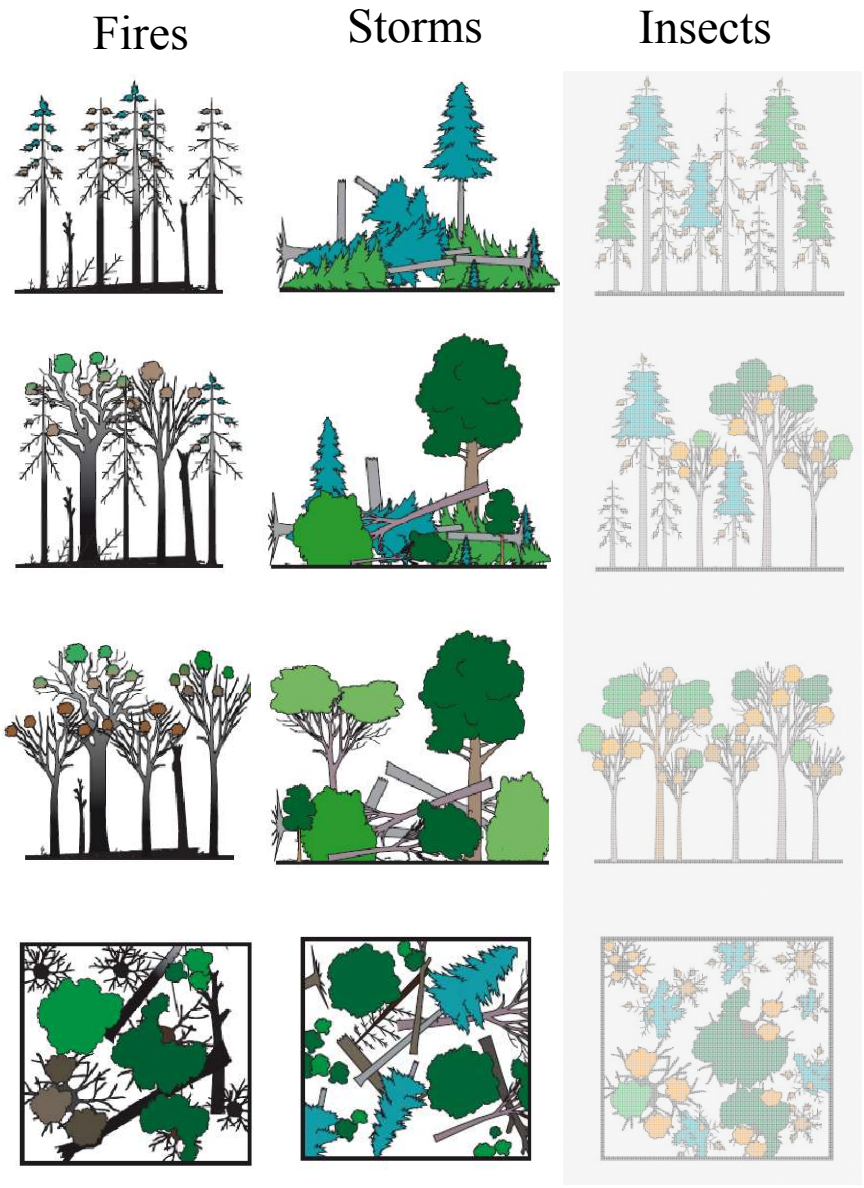
Adjusted from Pitman et al., 2003

Future development – Natural disturbances in the forest



Borner, A., Bellassen, V. & Luyssaert, S. 2010. Forest Management Cartoons.

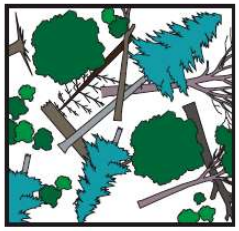
Future development – Natural disturbances in the forest

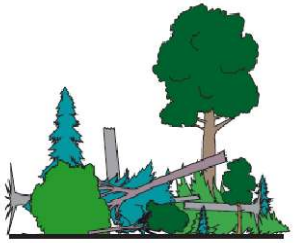


How ?

Borner, A., Bellassen, V. & Luyssaert, S. 2010. Forest Management Cartoons.

Future development – Visiable & invisible effects





Typhoon\Storm Disturbance

- Uprooting
- Stem breakage
- Branch damage
- Foliage damage
- Root damage
- Xylem damage

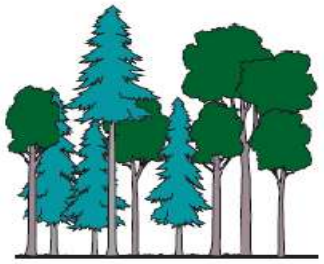
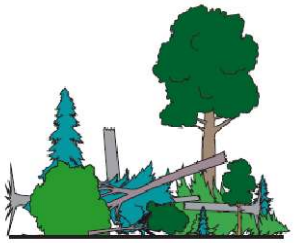
Structural Effects

- Productivity
- Regeneration
- Stand composition

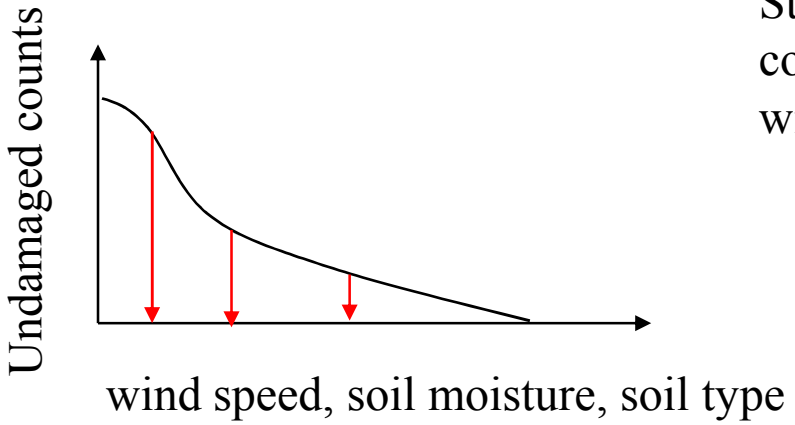
Functional Effects

- Allocation
- Heterotrophic respiration
- Weathering
- Runoff

Future development – windfall module

from  to 

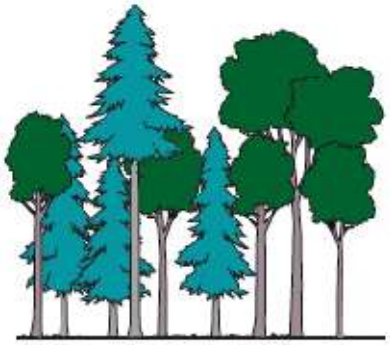
Using the critical wind speeds to determining which tree needs to be killed in the grid.



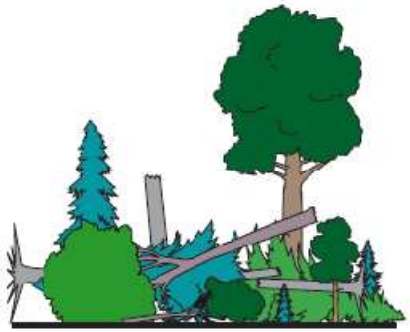
Statistical downscaling of wind filed from coarse spatial scale to fine spatial scale (fitting with satellite disturbance observations)

Site observation and terrain analysis
Grid scale wind forcing data will apply a statistical downscaling approach to capture within grid wind distribution (one peak or multiple peaks).

Applications – Creating a habitat map



Typhoon disturbance

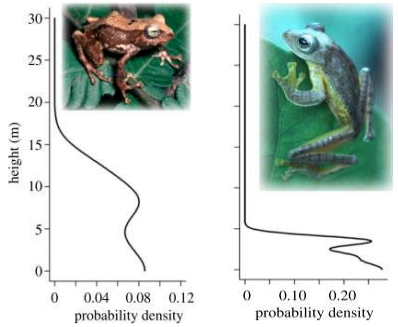


Micro-environmental conditions

Ecological model

Habitat studies

frog species



Woolbright et al., 1991; Scheffers et al., 2013

Conclusions

1. A multi-layer energy and water budget has been implemented, calibrated and validated with in-canopy fluxes, profiles and top-canopy fluxes at site level scale.

2. Land surface model is a powerful state-of-the-art tool to study the biophysical and biochemical effects of environmental changes such as land-use, land management on climate

3. The innovative land surface model is able to provide the micro-environmental conditions for different types of land covers, as well as the simulated leaf temperature and humidity profiles for the ecological studies such as habitat for frogs, fern or epiphyte community.

Outlook :

- A more realistic canopy structure has been built up in the next generation of land surface model for the climate\environmental research, such as the change of typhoon intensities or frequencies might be able to enhance or decrease the regional climate system such as Asia monsoon ISO.

- Incorporating the natural disturbance induced by Typhoons in the model and representation of top-canopy and sub-canopy with different PFTs will be the next model developing work.