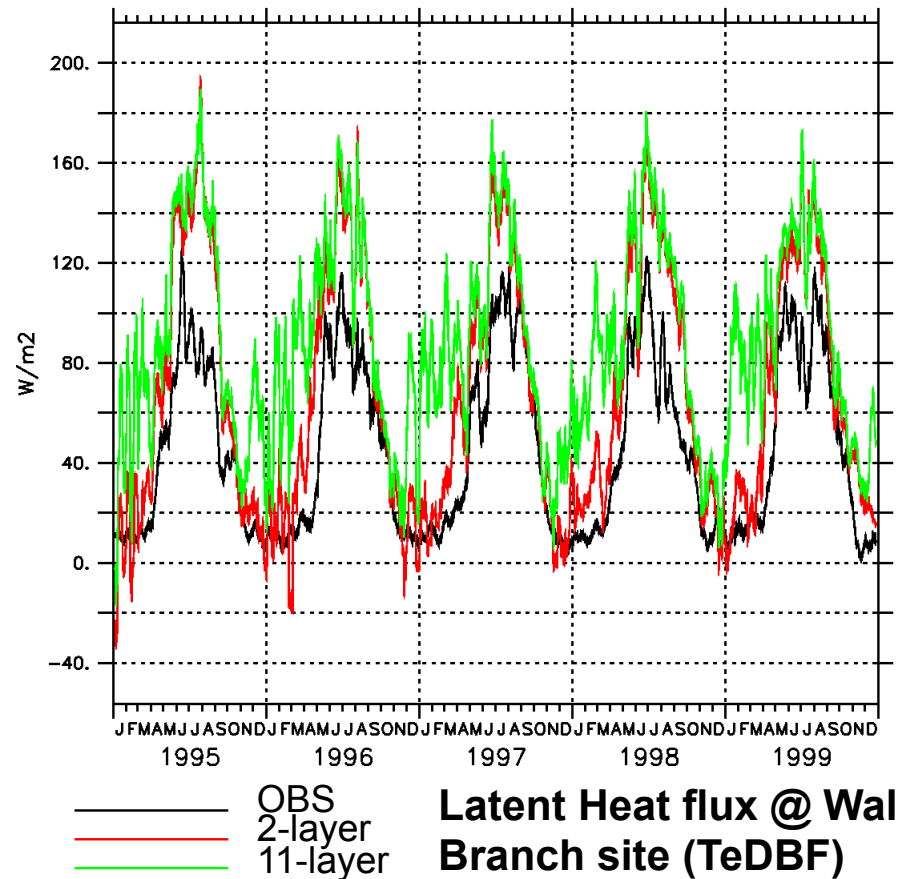


# Modification of the aerodynamic resistance formulation

# Context

- Shifting from the 2-layer hydrological scheme to the 11-layer one increases latent heat flux for some PFT's

- That is due to the evaporative component
- It acts at winter time for deciduous trees when no canopy coverage



## How evaporation is represented ?

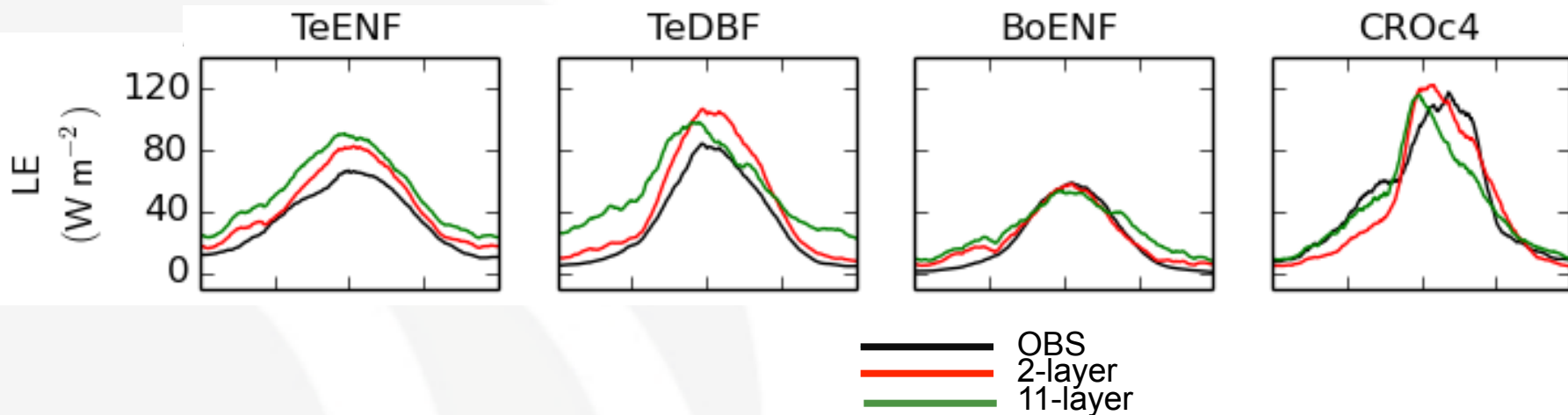
- In the 2-layer scheme, there is an explicit soil resistance to evaporation
- In the 11-layer scheme, the potential evapotranspiration is the flux set as a boundary condition to the diffusion scheme.
  - Either the potential evapotranspiration can be supplied
  - Either a minimal evaporation flux is defined by setting the soil water content of the first layer to the residual

⇒ ***Different schemes, no direct comparison***

## Many sources of uncertainties

- Only measurements of the evapotranspiration, no direct measurements of evaporation
- Evaporation and transpiration components are driven by the LAI which is computed by ORCHIDEE  
⇒ Differences between observed and modelled LAI
- Observed Energy budget is not closed by approx. 15-20%

# Latent heat flux on different vegetation types



- Good performance of the 11-layer scheme over cropland sites, even during bare soil periods (only evaporation, no transpiration)

# Searching for possible processes ...

- That may explain the bias on evaporation
- Modelled differently for crops and forests PFT within ORCHIDEE

⇒ ***Aerodynamic resistance and the parameterization of the roughness height***

$$r_a = \frac{1}{\kappa^2 u_a} \left[ \ln \left( \frac{z - d_0}{z_{0m}} \right) \ln \left( \frac{z - d_0}{z_{0v}} \right) \right]$$

**where**

- z is measurement height (m)
- $u_a$  is wind speed ( $\text{ms}^{-1}$ )
- k von Karman's constant
- $d_0$  is displacement height
- $z_{0m}$  and  $z_{0v}$  the roughness heights for momentum and water vapor transfer

# Roughness height calculation in ORCHIDEE

- Calculation of the averaged  $z_0$  for a grid point
  - For true bare soil and “bare soil” of vegetated PFTs  
 $z_0 = 0.01 \text{ m}$  *weighted by tot\_baresoil*
  - For grass and crops  
 $z_0 = 1/16 * \text{height}$  *weighted by veget*
  - For trees  
 $z_0 = 1/16 * \text{height}$  *weighted by veget\_max*
- ⇒ *One assumes that the trunk and the branches impact as a full canopy coverage on  $z_0$*
- Search for literature supporting that  $z_0$  varies with LAI
  - Ershadi et al. (2015) uses the formulation of Su et al. (2001)
  - An evaluation of different  $z_0$  formulations by Liu et al. (2007)

# Formulation of Su et al . (2001)

- Roughness height for momentum transfer

$$z_{0m} = h_c \left( 1 - \frac{d_0}{h_c} \right) \exp \left( -\frac{\kappa}{\eta} \right)$$

where

–  $h_c$  is the canopy height

–  $\eta$  is the ratio of friction velocity to wind speed, defined as function of LAI

- Roughness height for water vapor transfer

$$z_{0h} = z_{0m} / \exp(\kappa B^{-1})$$

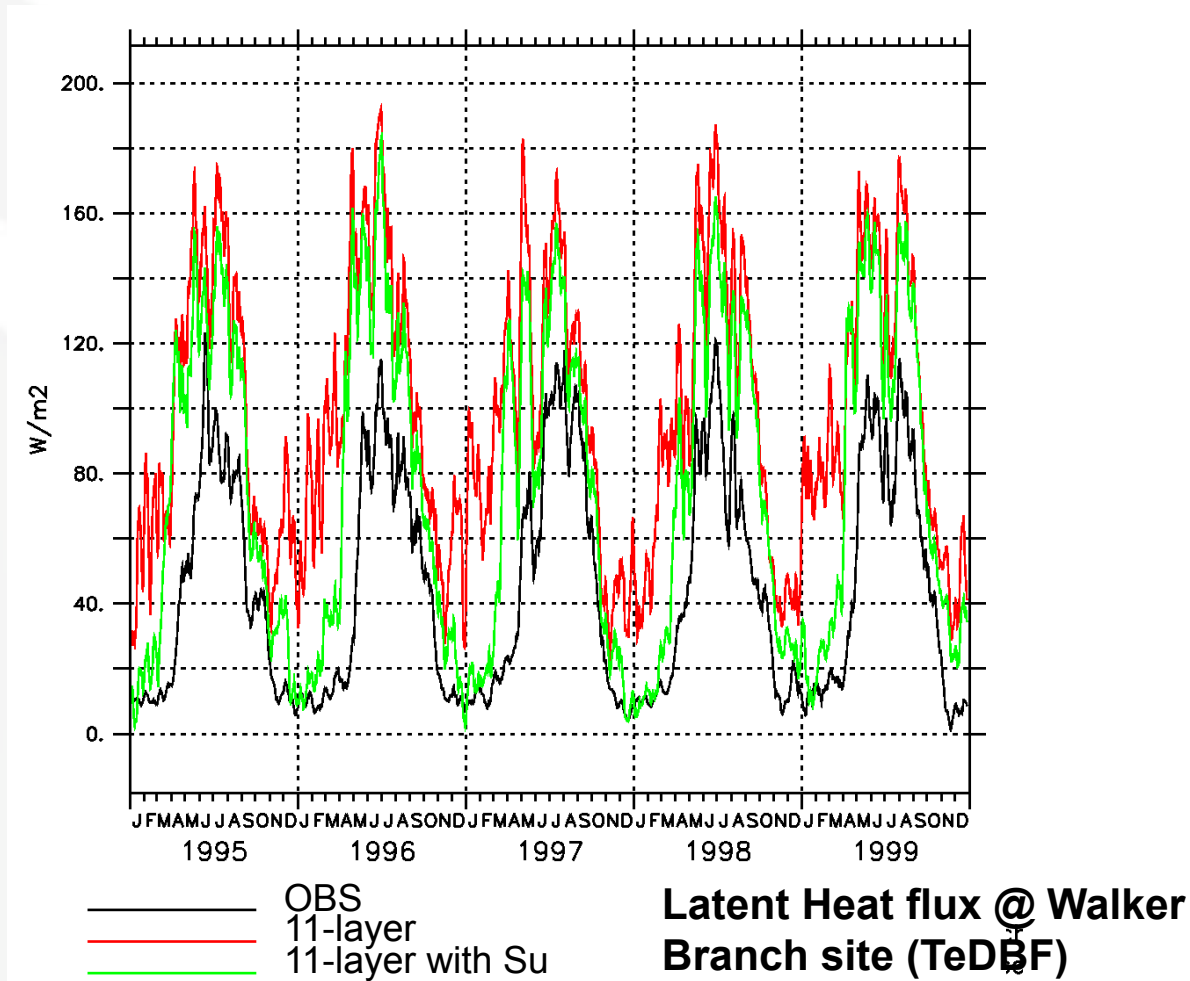
$$\kappa B^{-1} = \frac{\kappa C_d}{4C_t \beta (1 - \exp(-\frac{n_{ec}}{2}))} f_c^2 + 2f_c f_s \frac{\kappa \eta z_{0m} / h_c}{C_t^*} + \kappa B_s^{-1} f_s^2$$

where

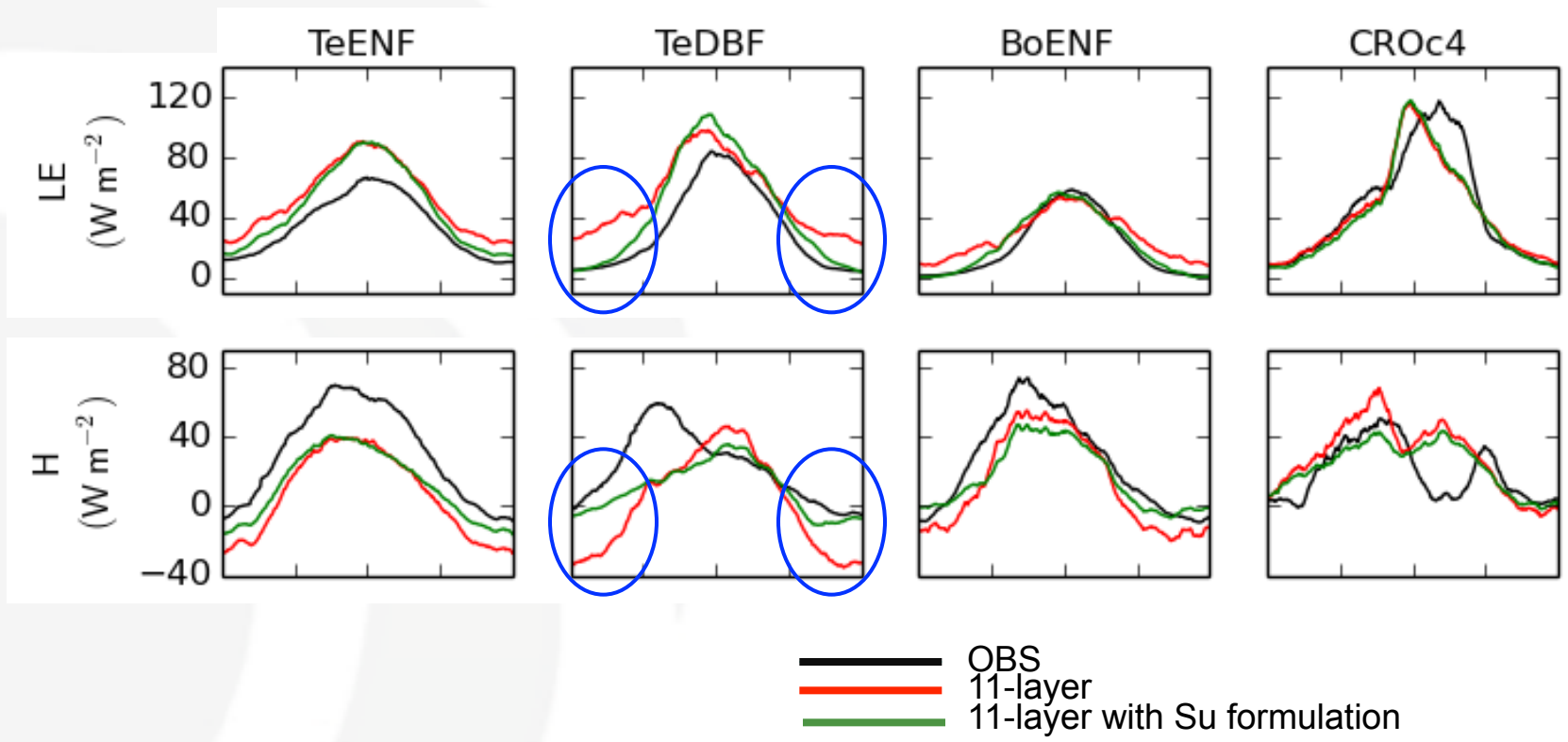
$f_c$  the fraction of canopy coverage and  $f_s$  the fraction of soil coverage



# Evaluation at site level (1)



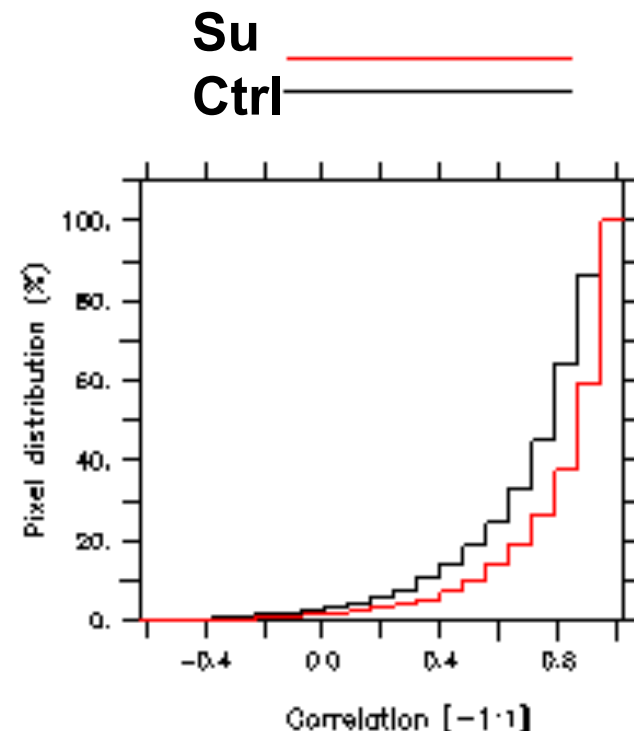
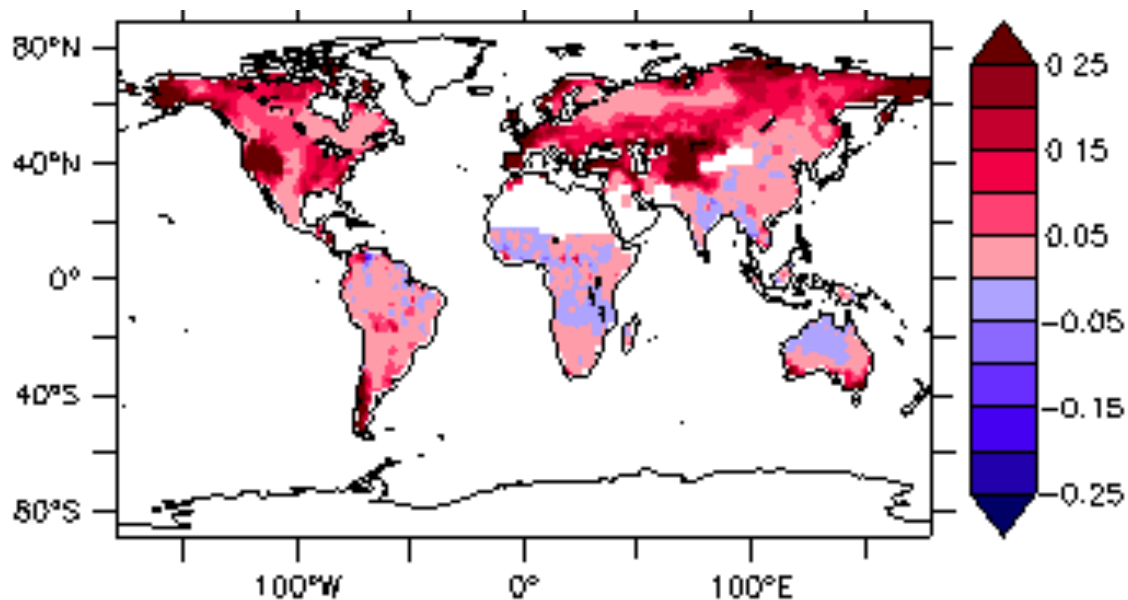
# Evaluation at site level (2)



# Tests with the Su formulation for z0

- At global level
  - Correlation of month-to-month variations of LE with Jung product increases with Su formulation

## Diff correl. Su – Ctrl



# Developments in the Photosynthesis scheme of ORCHIDEE



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ORCHIDEE-DEV meeting, 2017 December 5<sup>th</sup>



# Motivations

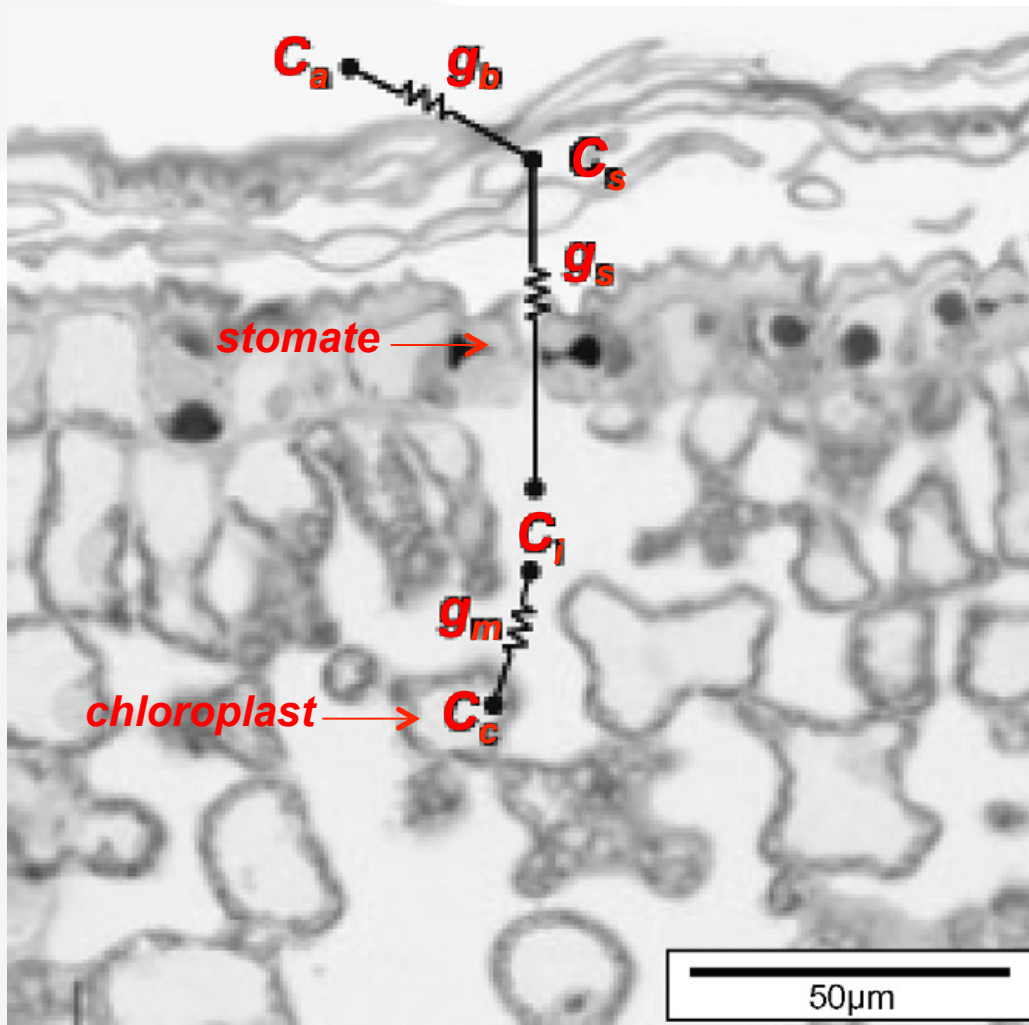
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- ① To implement an analytical solution solving jointly the assimilation, the stomatal conductance and the intercellular CO<sub>2</sub> concentration
- ② To update the parameterisation and the formalism used, in better agreement with recent experiment-based studies
- ③ To better document the overall associated module

# Three unknowns, three equations

- The rate of [CO<sub>2</sub>] assimilation,  $A$ 
  - $A = \min(A_c, A_j)$  where  $A_c$  is the Rubisco-limited rate of CO<sub>2</sub> assimilation and  $A_j$  is the e-transport-limited rate of CO<sub>2</sub> assimilation
    - Both  $A_c$  and  $A_j$  are function of  $C_i$
- The intercellular CO<sub>2</sub> partial pressure,  $C_i$ 
  - $C_i = C_a - A ( 1/g_b + 1/g_s )$  where  $C_s$  is the leaf-surface CO<sub>2</sub> partial pressure
    - $g_b$  the boundary-layer conductance
- The stomatal conductance,  $g_s$ 
  - $g_s = g_0 + ( A + R_d ) / ( C_i - C_i^* ) f_{VPD}$  where  $g_0$  is the stomatal conductance when irradiance is 0 and  $R_d$  the dark respiration

# Conductances and $[CO_2]$ within the leaf



- $C_a$  : Ambient air  $CO_2$  partial pressure
- $C_s$  : Leaf surface  $CO_2$  partial pressure
- $C_i$  : Intercellular  $CO_2$  partial pressure
- $C_c$  : Chloroplast  $CO_2$  partial pressure
- $g_b$  : Boundary-layer conductance
- $g_s$  : Stomatal conductance
- $g_m$  : Mesophyll diffusion conductance

## Solving $A$ , $g_s$ and $C_i$

- Often done by numerical iteration approach
- In ORCHIDEE, an approximate solution was calculated, using the  $C_i$  value of the former time step with a “relaxation” term
- Combining the 3 equations leads to a standard cubic equation for  $A$  :  $A^3 + pA^2 + qA + r = 0$  (more details in Baldocchi (1994))
- Yin et al. (2009) propose an analytical solution for  $C_3$  and  $C_4$  plants (All the details in the Appendix of Yin et al.)
  - Three roots, one being most suitable for solving both  $A_c$  or  $A_i$  under any combination of  $C_i$ , radiation, temperature and VPD.



# Temperature response of photosynthesis parameters

- Two types of equations are commonly used

Arrhenius function

$$f(T_k) = k_{25} \exp\left(\frac{E_a (T_k - 298)}{298RT_k}\right)$$

Function used for the all temperature-dependant parameters except  $V_{c_{max}}$  and  $J_{max}$

Peak function

$$f(T_k) = k_{25} \exp\left(\frac{E_a (T_k - 298)}{298RT_k}\right) \frac{1 + \exp\left(\frac{298\Delta S - E_d}{298R}\right)}{1 + \exp\left(\frac{T_k\Delta S - E_d}{T_k R}\right)}$$

$E_a$  : Activation energy

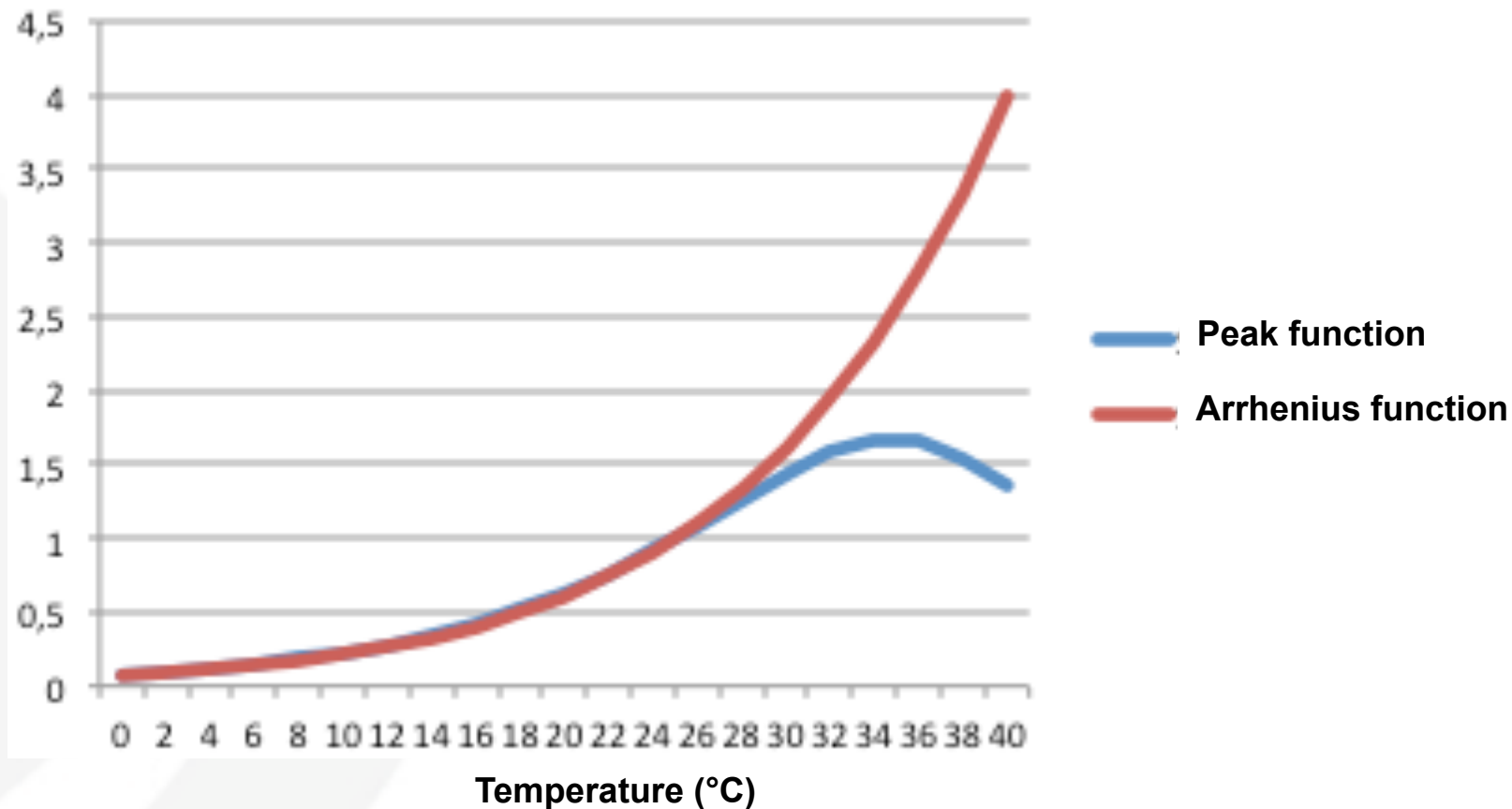
$E_d$  : Deactivation energy

$\Delta S$  : entropy factor

Function used for  $V_{c_{max}}$  and  $J_{max}$

# Temperature response of photosynthesis parameters

- **Arrhenius vs. Peak functions**



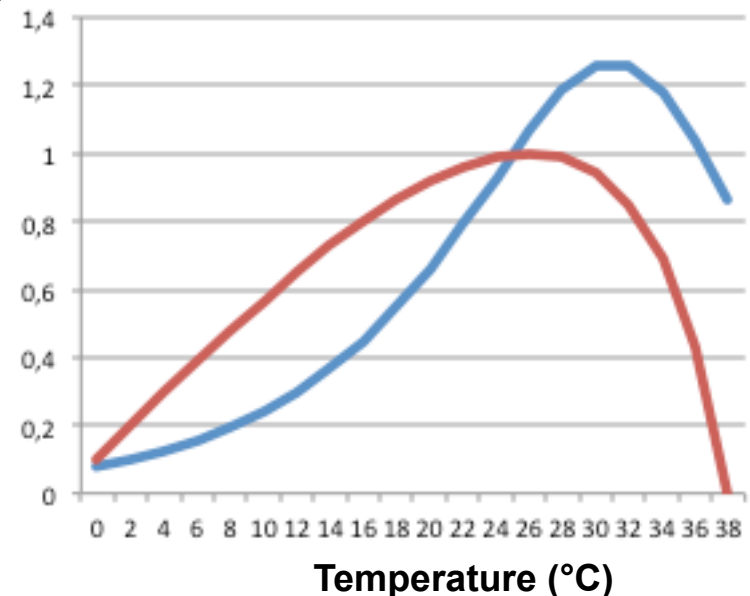
# Temperature response of photosynthesis parameters

- Formerly, in ORCHIDEE, temperature response for  $Vc_{max}$  and  $J_{max}$  (for C3 species) is defined using  $T_{min}$ ,  $T_{max}$  and  $T_{opt}$  with the following equation

$$f(T) = k_{opt} \frac{(T - T_{min})(T - T_{max})}{(T - T_{min})(T - T_{max}) - (T - T_{opt})^2}$$

— Peak function with  $E_a = 71500 \text{ J mol}^{-1}$   
 $\Delta S = 653 \text{ J mol}^{-1} \text{ K}^{-1}$   
 $E_d = 200000 \text{ J mol}^{-1}$

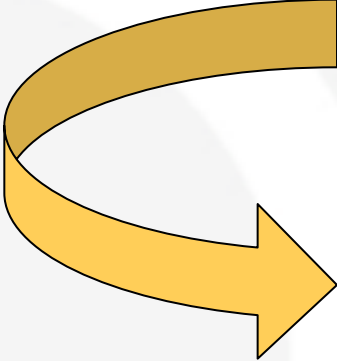
— “Old” function with  $T_{min} = -2^\circ\text{C}$   
 $T_{max} = 38^\circ\text{C}$   
 $T_{opt} = 25^\circ\text{C}$



- For C4 species, the former temperature response is a peak function => no change

# Temperature response of photosynthesis parameters

- From reference value at 25°C to reference value at  $T_{opt}$  (see Medlyn et al., 2002)



$$f(T_k) = k_{25} \exp\left(\frac{E_a(T_k - 298)}{298RT_k}\right) \frac{1 + \exp\left(\frac{298\Delta S - E_d}{298R}\right)}{1 + \exp\left(\frac{T_k\Delta S - E_d}{T_kR}\right)}$$

$$f(T_k) = k_{opt} \frac{E_d \exp\left(\frac{E_a(T_k - T_{opt})}{T_kRT_{opt}}\right)}{E_d - E_a \left(1 - \exp\left(\frac{E_d(T_k - T_{opt})}{T_kRT_{opt}}\right)\right)}$$

with  $T_{opt} = \frac{E_d}{\Delta S - R \ln\left(\frac{E_d}{(E_d - E_a)}\right)}$  in Kelvin

# Temperature acclimation

- Response to long-term temperature
- Formerly in ORCHIDEE, only for C3 grass :  $T_{min}$ ,  $T_{max}$  and  $T_{opt}$  are function of the long-term temperature
- Kattge & Knorr (2007) analysed data, searching for temperature acclimation of  $Vc_{max}$  and  $J_{max}$  related parameters

- $Vc_{max,25}$
- $J_{max,25}$
- $T_{opt}$
- $\Delta S_{Jmax}$  and  $\Delta S_{Vcmax}$
- $J_{max,25} / Vc_{max,25}$

$p = a + b \times t_{growth}$

with  $t_{growth}$  the monthly temperature (°C)

# Temperature acclimation

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–  $T_{opt}$

–  $\Delta S_{Jmax}$  and  $\Delta S_{Vcmax}$

–  $J_{max,25} / Vc_{max,25}$

$$p = a + b \times t_{growth}$$

with  $t_{growth}$  the monthly temperature (°C)

# Code management

- The new scheme has been merged in the trunk
  - Revision 2031 – April 2014
- No explicit documentation but the references used are cited both in the `diffuco_trans_co2` routine and in the parameter module

```
REAL(r_std), PARAMETER, DIMENSION(nvmc) :: E_KmC_mtc = &           !! Energy of activation for KmC (J mol-1)
& (/undef, 79430., 79430., 79430., 79430., 79430., 79430., &     !! See Medlyn et al. (2002)
& 79430., 79430., 79430., 79430., 79430., 79430. /)           !! from Bernacchi al. (2001)

REAL(r_std), PARAMETER, DIMENSION(nvmc) :: E_KmO_mtc = &           !! Energy of activation for KmO (J mol-1)
& (/undef, 36380., 36380., 36380., 36380., 36380., 36380., &     !! See Medlyn et al. (2002)
& 36380., 36380., 36380., 36380., 36380., 36380. /)           !! from Bernacchi al. (2001)

REAL(r_std), PARAMETER, DIMENSION(nvmc) :: E_gamma_star_mtc = &   !! Energy of activation for gamma_star (J mol-1)
& (/undef, 37830., 37830., 37830., 37830., 37830., 37830., &     !! See Medlyn et al. (2002) from Bernacchi al. (2001)
& 37830., 37830., 37830., 37830., 37830., 37830. /)           !! for C3 plants - We use the same values for C4 plants

REAL(r_std), PARAMETER, DIMENSION(nvmc) :: E_Vcmax_mtc = &       !! Energy of activation for Vcmax (J mol-1)
& (/undef, 71513., 71513., 71513., 71513., 71513., 71513., &     !! See Table 2 of Yin et al. (2009) for C4 plants
& 71513., 71513., 71513., 67300., 71513., 67300. /)           !! and Kattge & Knorr (2007) for C3 plants (table 3)

REAL(r_std), PARAMETER, DIMENSION(nvmc) :: E_Jmax_mtc = &         !! Energy of activation for Jmax (J mol-1)
& (/undef, 49884., 49884., 49884., 49884., 49884., 49884., &     !! See Table 2 of Yin et al. (2009) for C4 plants
& 49884., 49884., 49884., 77900., 49884., 77900. /)           !! and Kattge & Knorr (2007) for C3 plants (table 3)

REAL(r_std), PARAMETER, DIMENSION(nvmc) :: aSV_mtc = &           !! a coefficient of the linear regression (a+bT) defining the Entropy
erm for Vcmax (J K-1 mol-1)
& (/undef, 668.39, 668.39, 668.39, 668.39, 668.39, 668.39, &     !! See Table 3 of Kattge & Knorr (2007)
& 668.39, 668.39, 668.39, 641.64, 668.39, 641.64 /)           !! For C4 plants, we assume that there is no
                                                                !! acclimation and that at for a temperature of 25Â°C, aSV is the same
for both C4 and C3 plants (no strong justification - need further parametrization)
```

# Downregulation of photosynthesis

- Done by Shushi Peng (2014)
- Photosynthesis could down-regulate the response to double CO<sub>2</sub> because of
  - acclimatation to increasing atmospheric CO<sub>2</sub> (Sellers et al., 1996, Science; Bounoua et al., 1999, J. Clim.)
  - or limitation by other nutrients (Kattge et al., 2009, GCB; Levis et al., 2010, New Phytol.)

$$v_{\text{cmax\_downr}}(jv) = v_{\text{cmax}}(jv) * (\text{un-downregulation\_co2\_coeff}(jv) * \log(\text{Ca}(:) / \text{downregulation\_co2\_baselevel}))$$

⇒  $V_{\text{cmax}} \sim 15\%$  lower at 400ppm

(compared to 280ppm)



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ORCHIDEE-DEV meeting, 2017 December 5<sup>th</sup>

