Shallow cumulus rooted in photosynthesis

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METEOROLOGY AND AIR QUALITY

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The extend contents of this research have been published recently:

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Geophys. Res. Lett 41, 1796-1802
Doi:10.1002/2014GL059279

Publication can be obtained also by requesting to:

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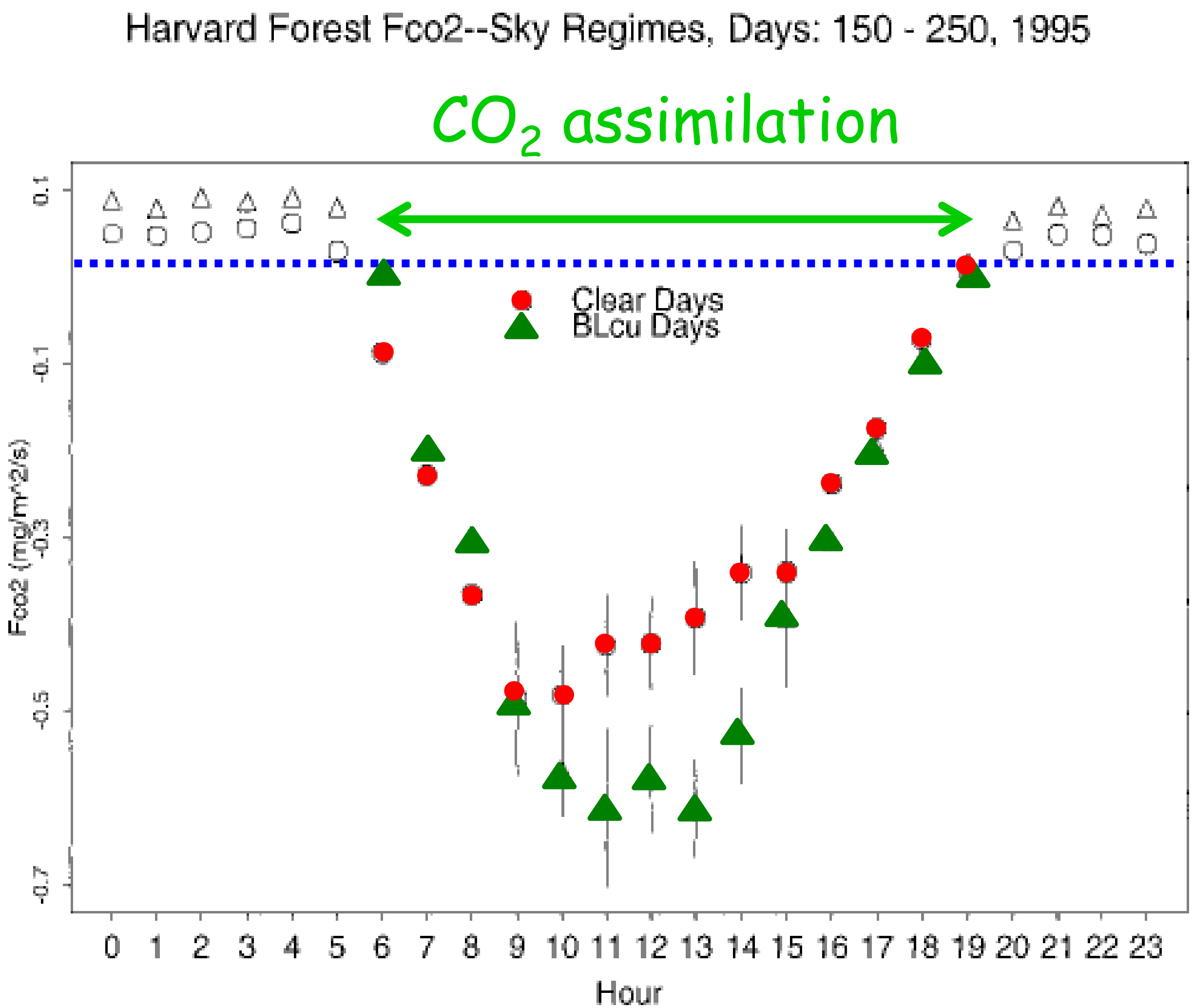
Boundary layer and vegetation feedbacks: Mid-latitudes

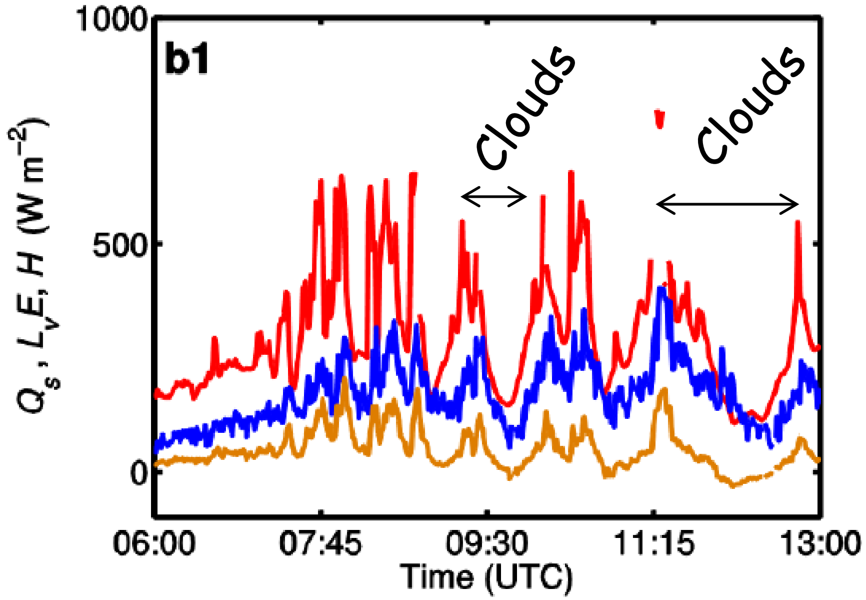


Freedman et al. (2001)

Plants respond to clouds

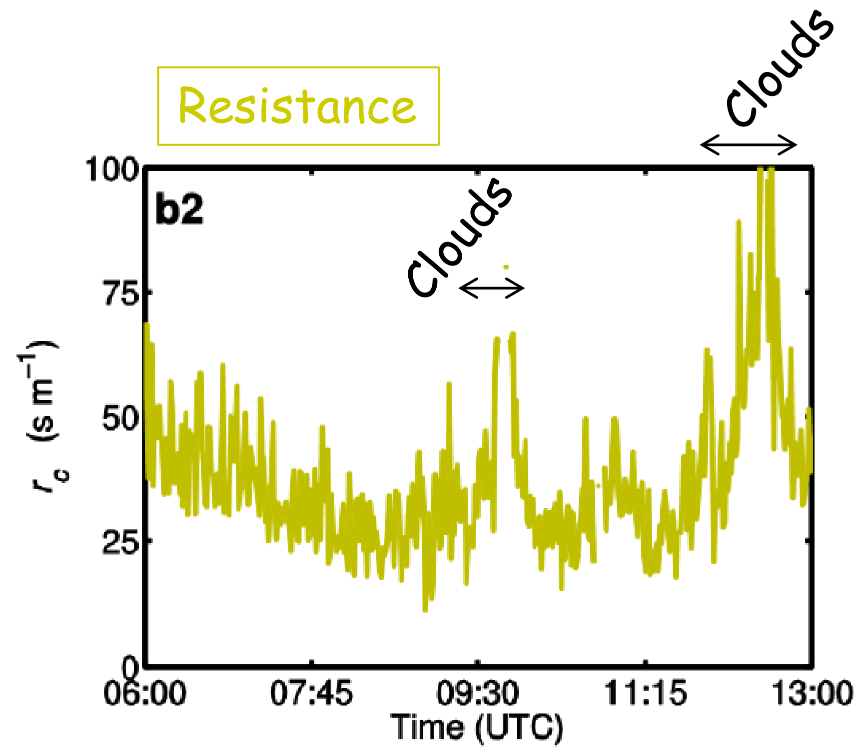
Observational evidence

Incoming short wave radiation
Latent heat flux
Sensible heat flux



Q_s, L_vE, H

Resistance



$$A_n = g_c(C_a - C_i) = \frac{1}{r_c}(C_a - C_i)$$

1-minute turbulent flux
Van Kesteren et al. (2013)

Research questions:

(1) Is it important to couple evapotranspiration to shallow cumulus clouds?

(2) Does the short timescale related to stomatal adaptation via opening and closing influence surface energy balance and clouds?

(3) Do more optimal C4 plants (maximum assimilation CO_2 whilst minimal water loss) enhance shallow convection?

Vegetation-atmosphere system understudy
(focus on diurnal scales)

The approach:

Explicit coupling of atmospheric-land process interactions (including boundary-layer clouds) to a plant physiology model

Atmosphere:

Large-eddy simulation technique (DALES, Heus et al., 2010)

Land:

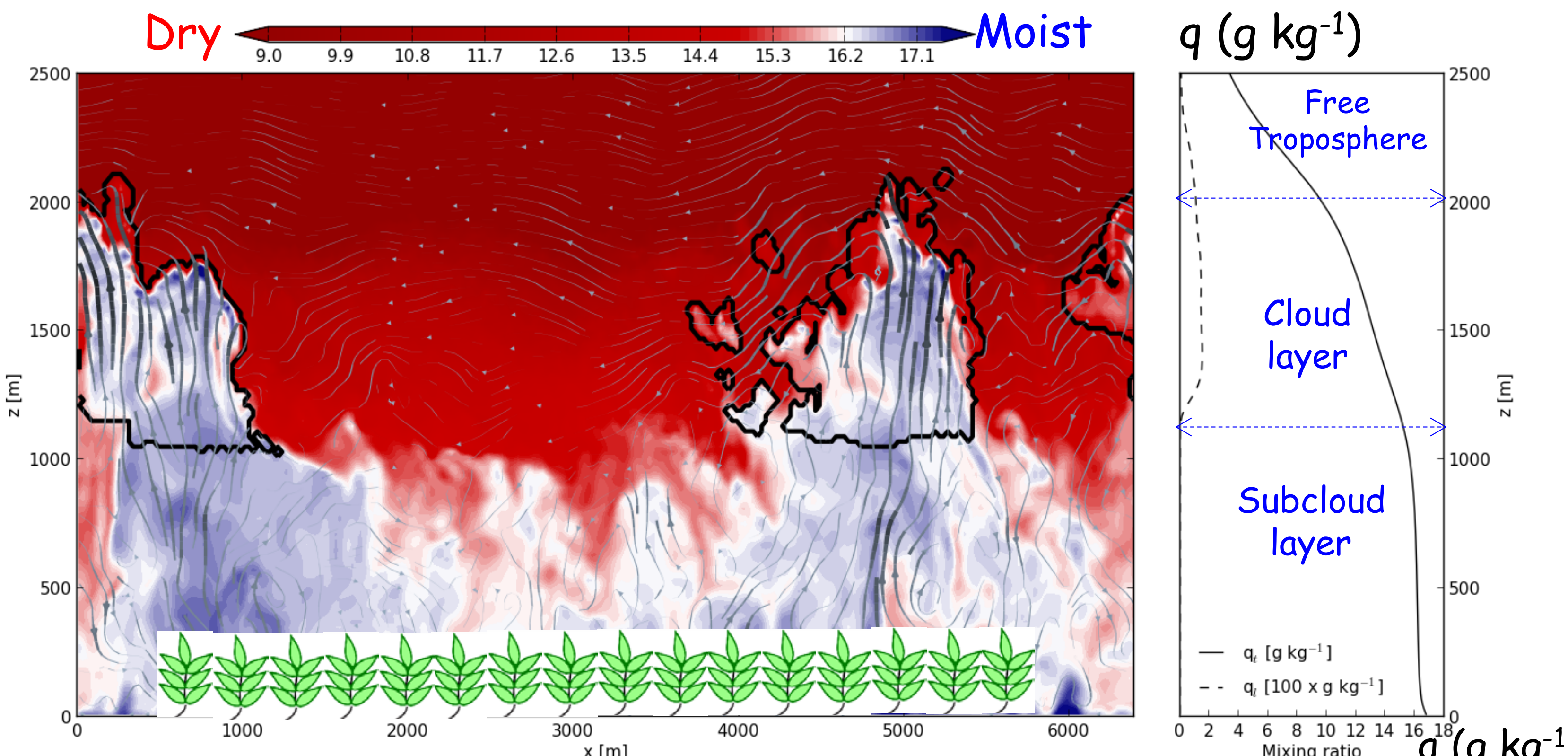
Surface energy balance.

Soil model (two-layers) to diffuse heat and moisture (van Heerwaarden et al., 2009)

Plant physiology:

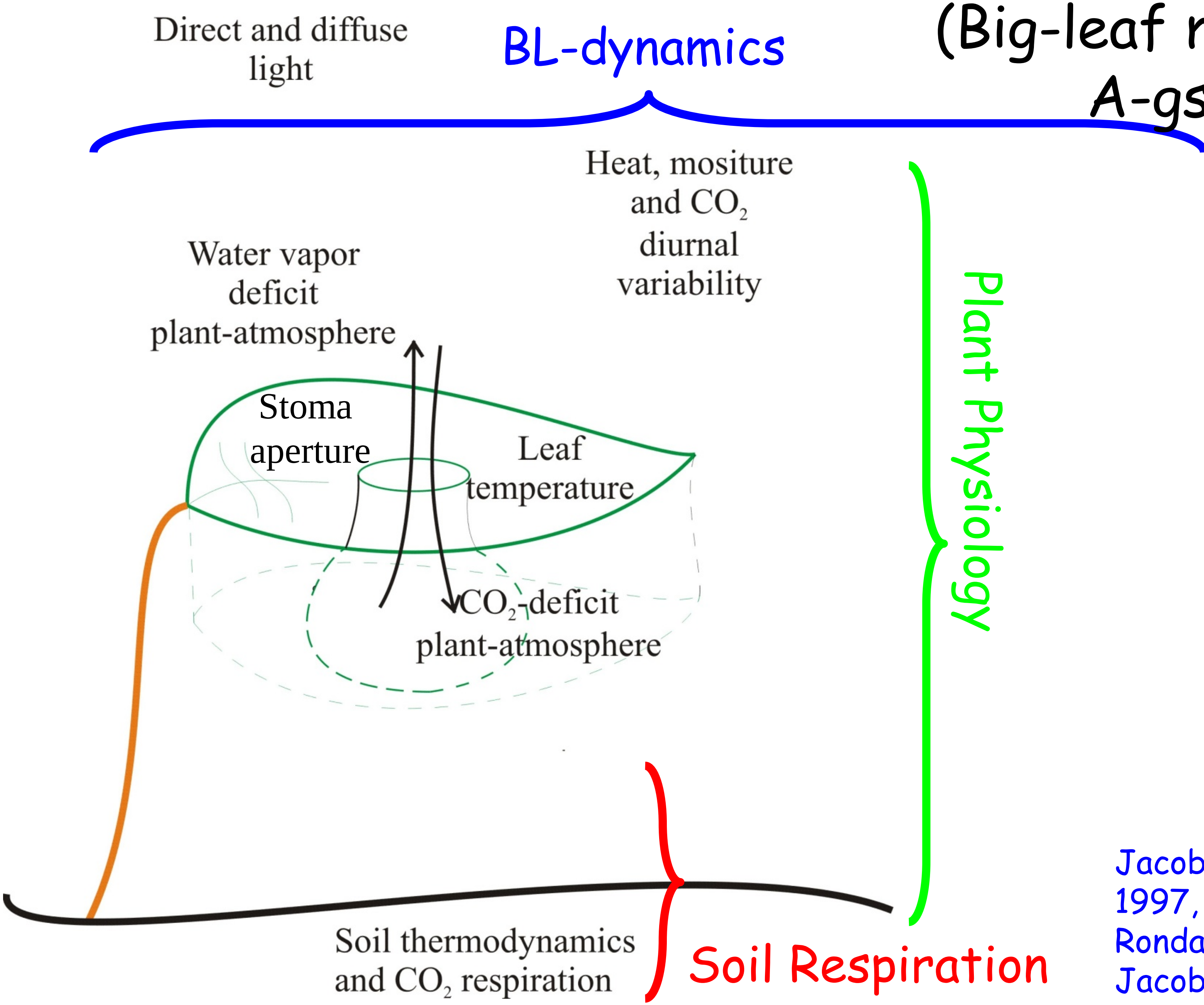
Stomata aperture: controls the exchange water and carbon dioxide

Intercellular CO_2 concentration



Dry
Moist
9.0 9.9 10.8 11.7 12.6 13.5 14.4 15.3 16.2 17.1
z [m]
x [m]
q (g kg-1)
Free Troposphere
Cloud layer
Subcloud layer
q_t [g kg-1]
q_l [100 x g kg-1]
Mixing ratio
q (g kg-1)

Plant physiology model (Big-leaf model) A-gs

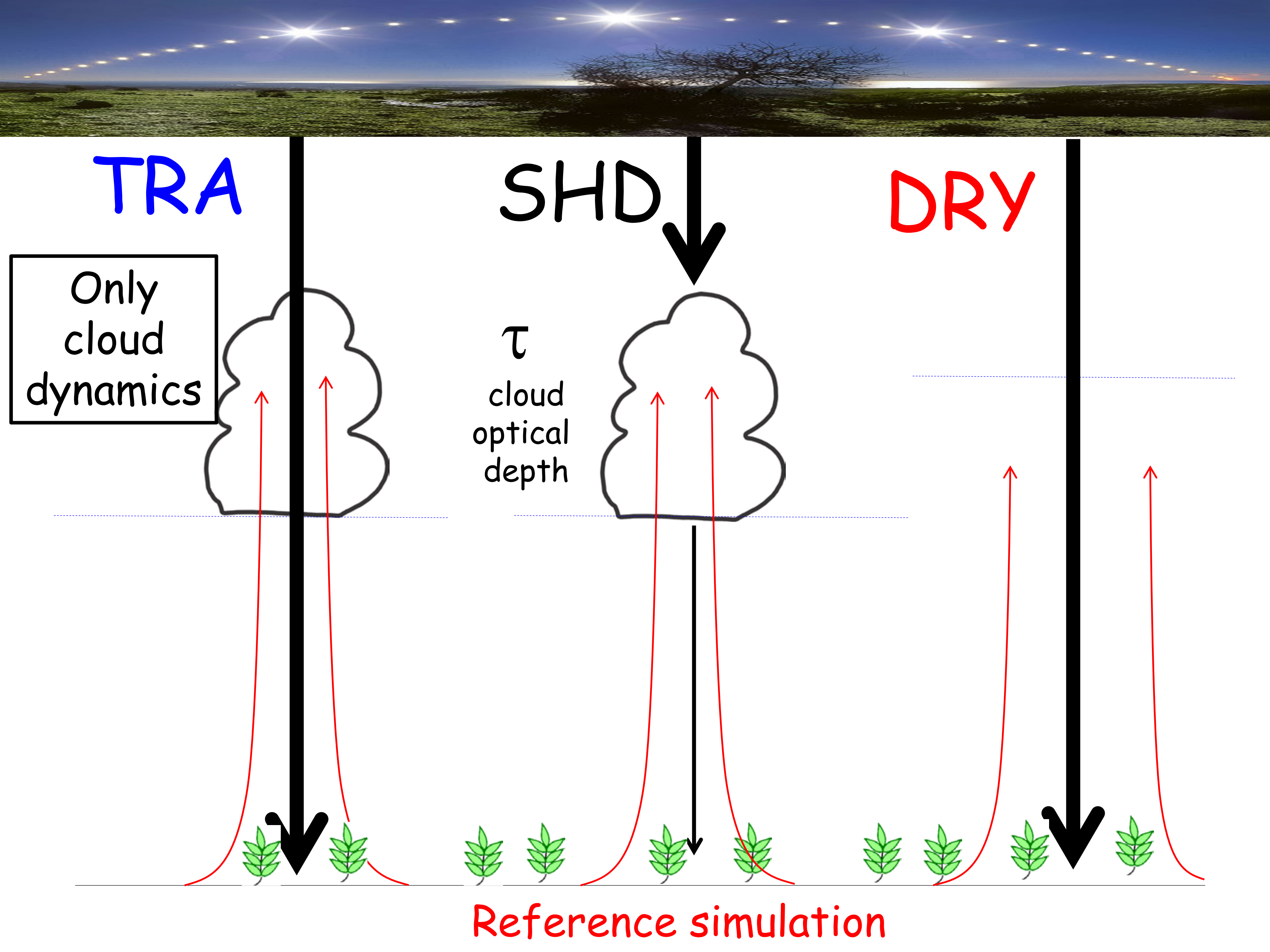


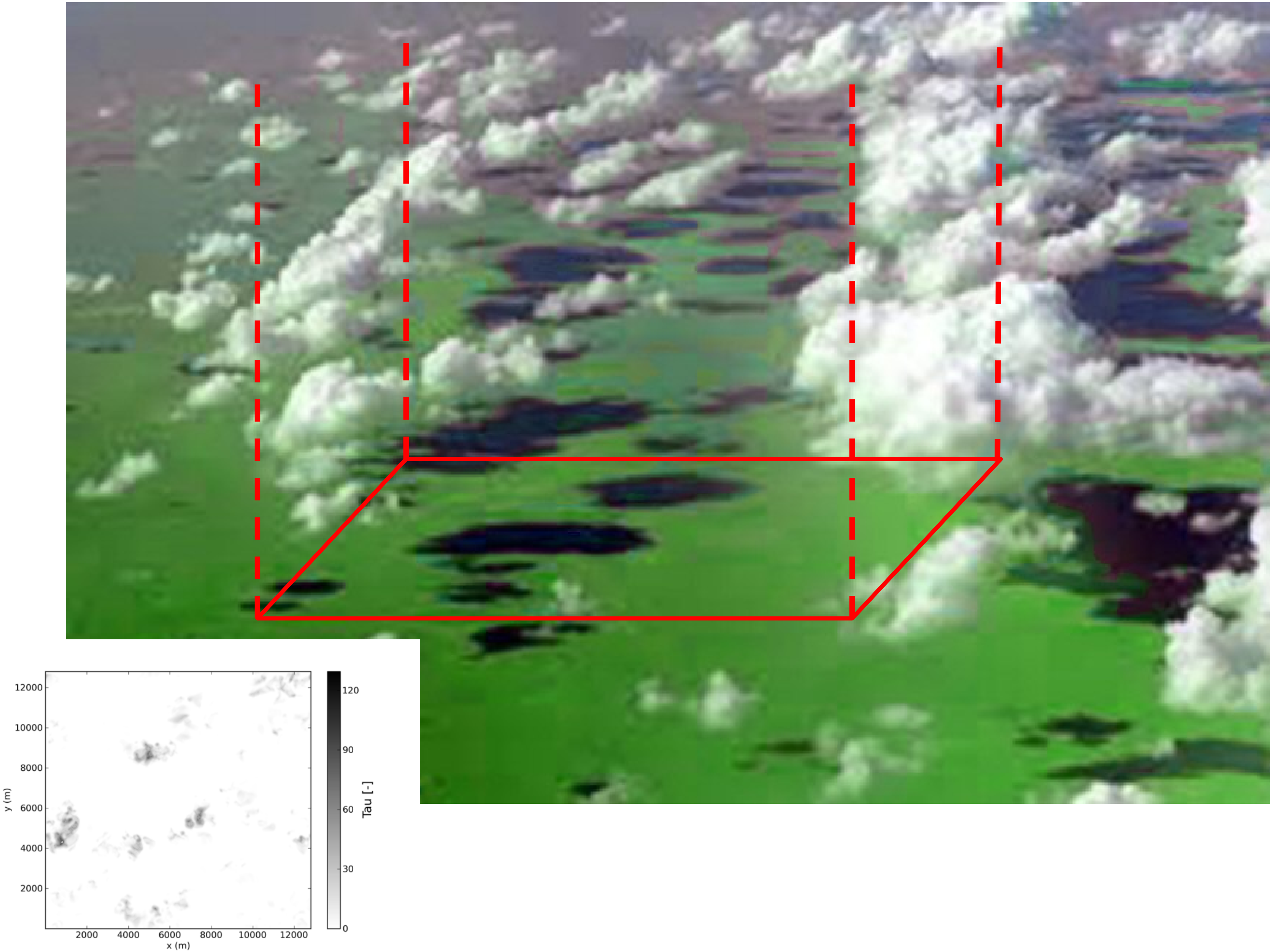
Jacobs & de Bruin 1997,
Ronda et al., 2001
Jacobs et al., 2007

(1)Is it important to couple evapotranspiration to shallow cumulus clouds?

Three(3) 14-hour day-light grass-LES simulations:
Prototype CBL with wind

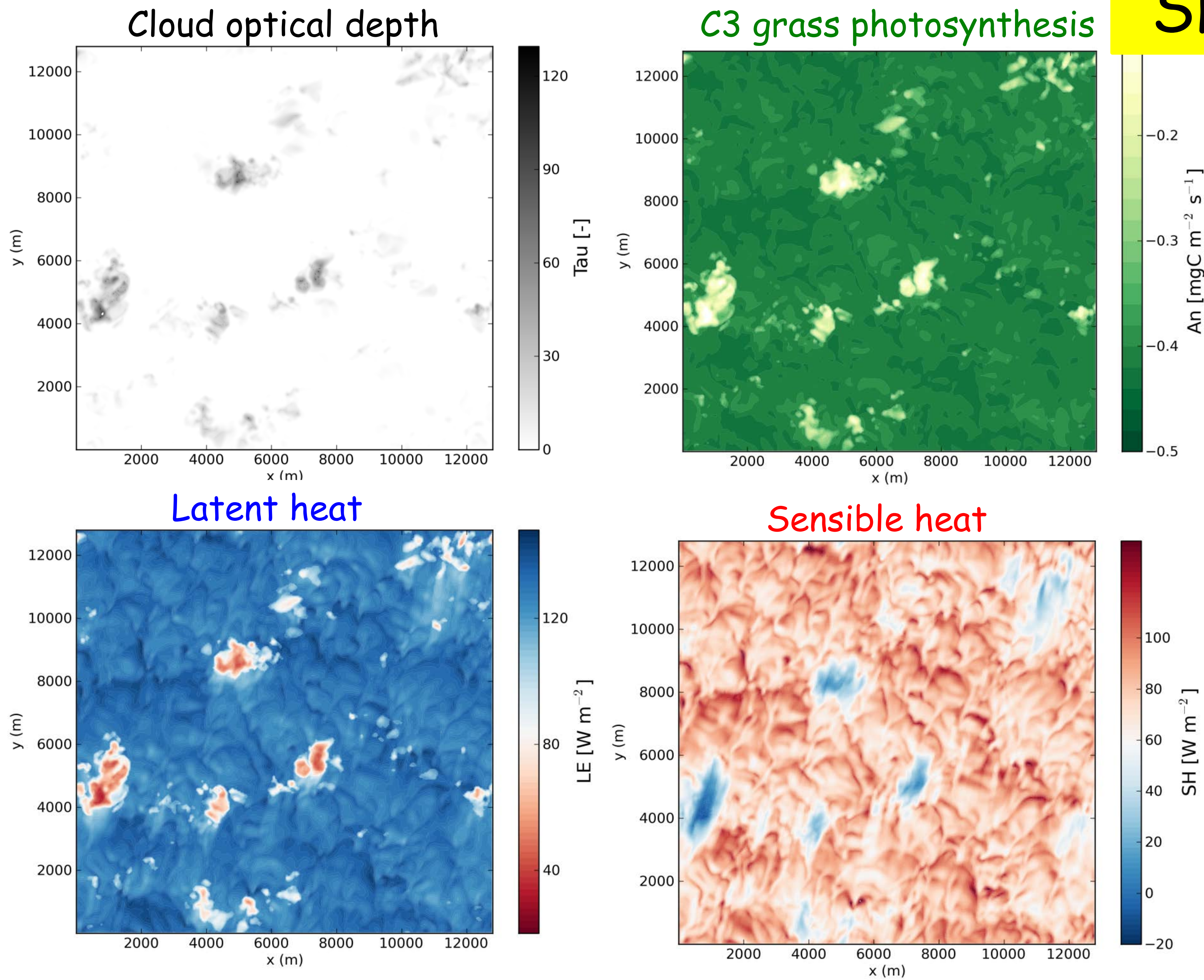
TRA: Transparent clouds
SHD: Shading clouds
DRY: no clouds


TRA
SHD
DRY
Only cloud dynamics
τ
cloud optical depth
Reference simulation

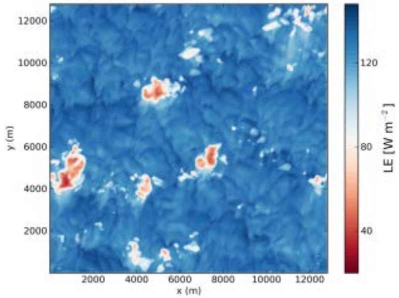


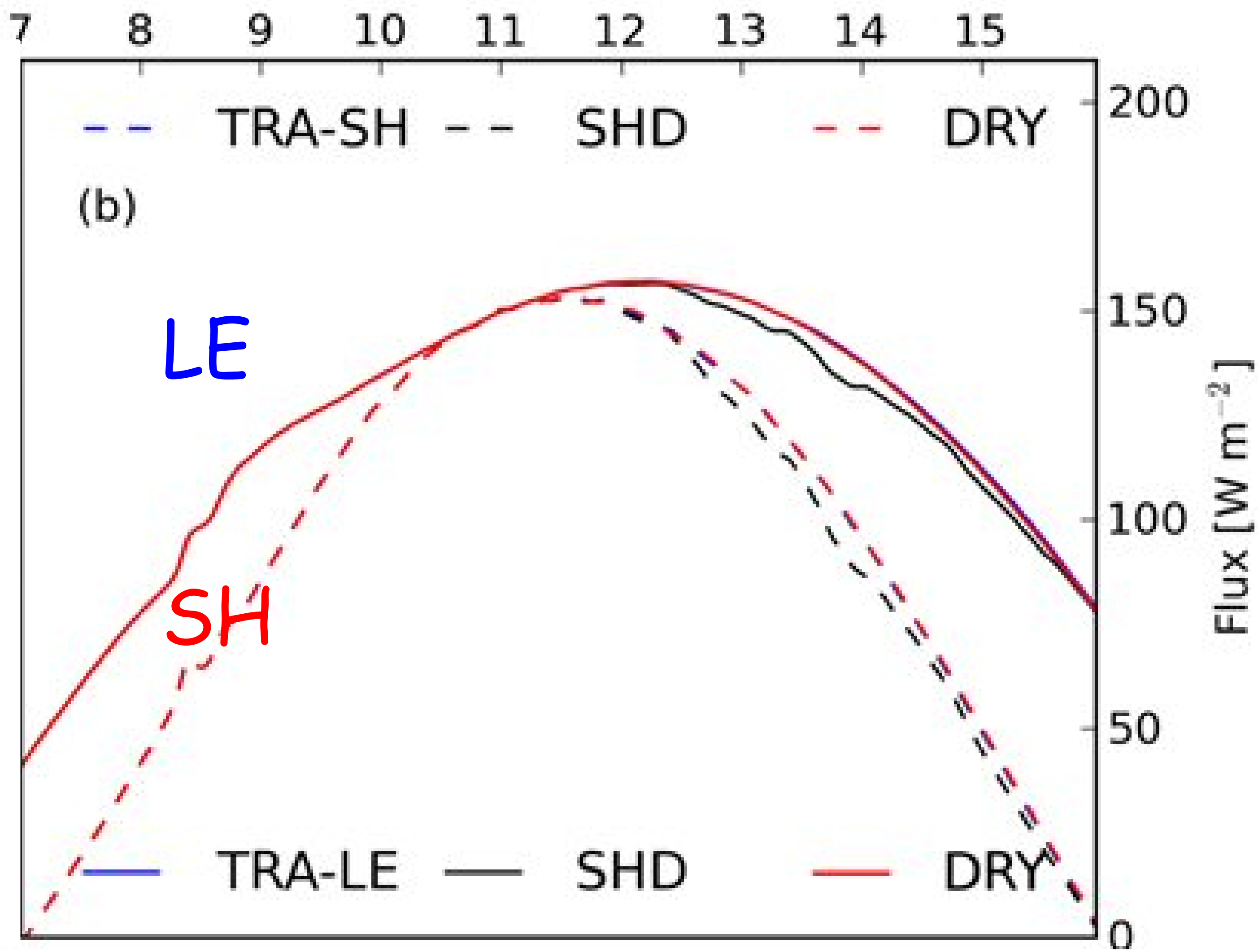
12000
10000
8000
6000
4000
2000
y (m)
2000 4000 6000 8000 10000 12000
x (m)
120
90
60
30
0
Tau [-]

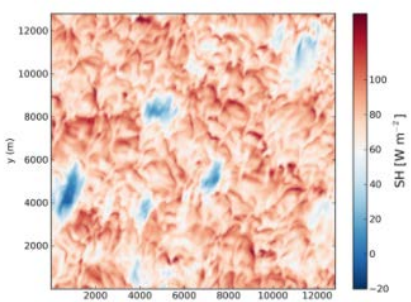
SHD

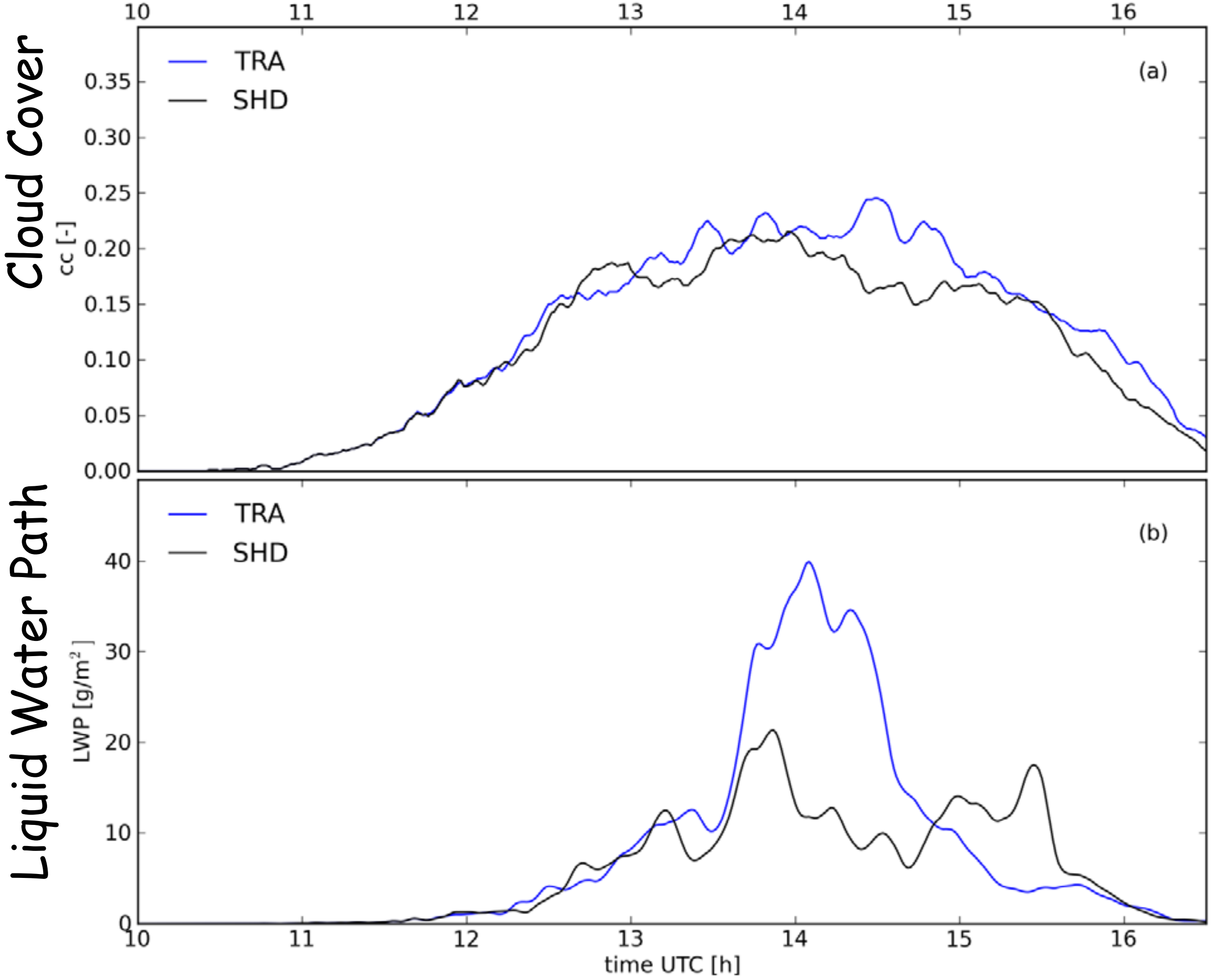

Cloud optical depth
y (m)
x (m)
Tau [-]
0
30
60
90
120
C3 grass photosynthesis
y (m)
x (m)
An [mgC m^{-2} s^{-1}]
−0.5
−0.4
−0.3
−0.2
Latent heat
y (m)
x (m)
LE [W m^{-2}]
40
80
120
Sensible heat
y (m)
x (m)
SH [W m^{-2}]
−20
0
20
40
60
80
100
2000
4000
6000
8000
10000
12000

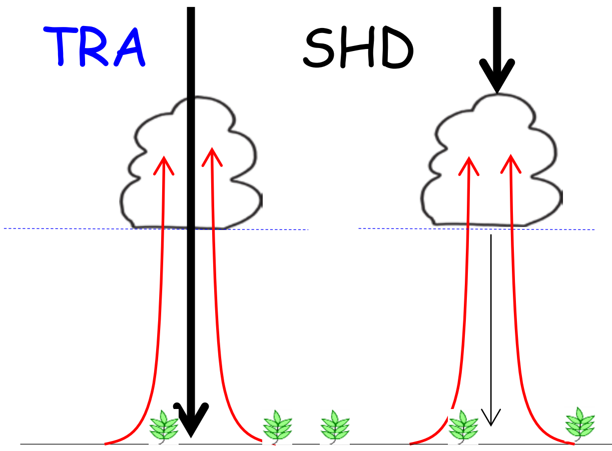
Surface fluxes: evaporation and sensible









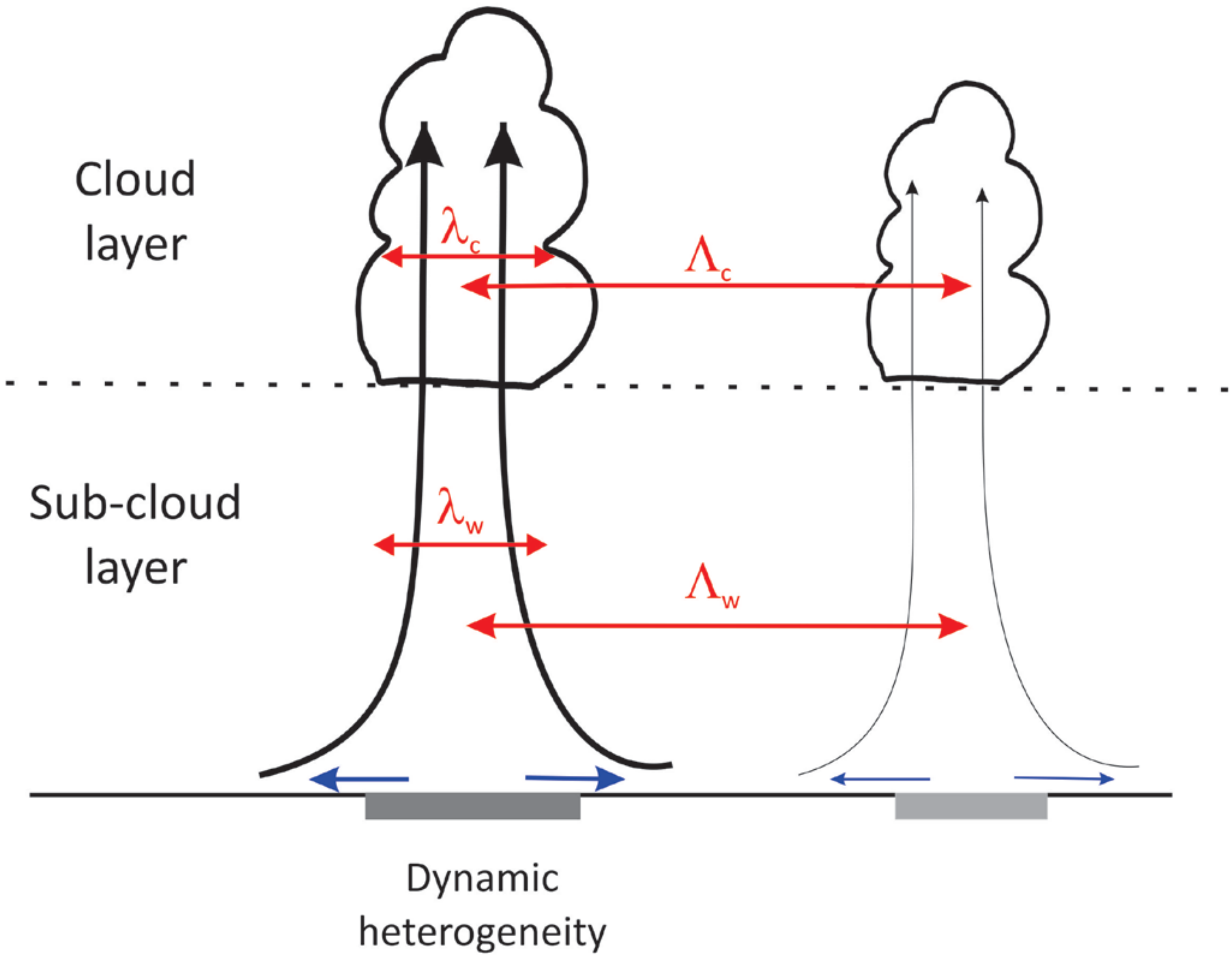


More extreme values TRA

=> Larger <u>skewness</u> in LWP for TRA

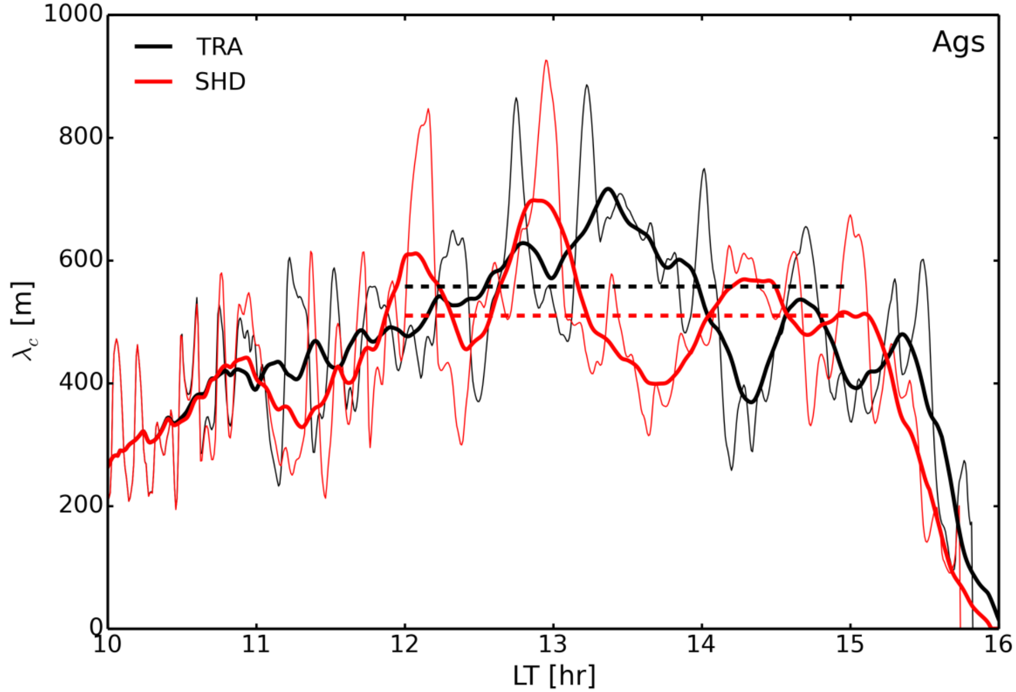
Could we quantify it further?

Analysis of length scales



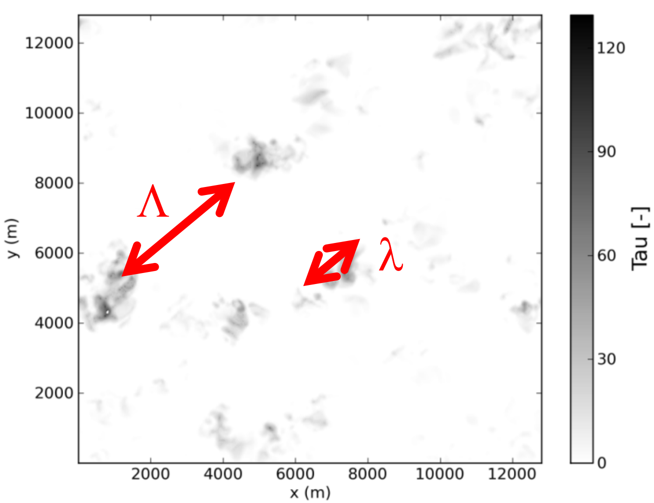
λ: calculated using autocorrelation (zero-crossing)

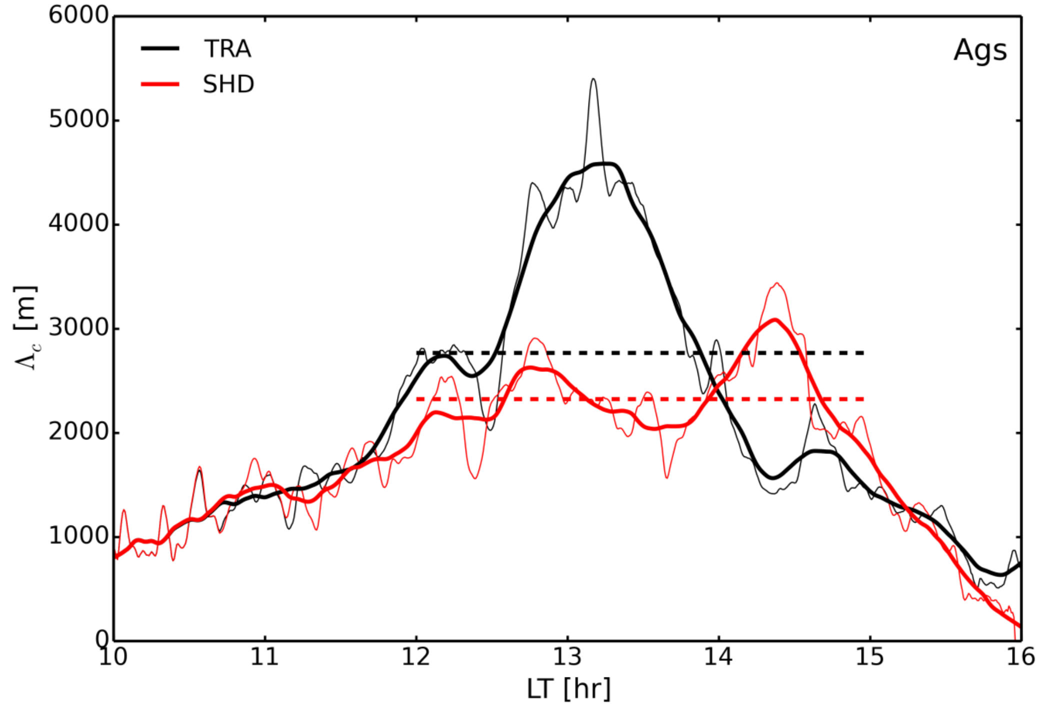
Λ: calculated using 2D-spectra (maximum energy peak)



Working hypothesis:

With cloud shading:
Smaller but more clouds
=> Similar cloud cover





(1) Is it important to couple evapotranspiration to shallow cumulus clouds?

- Small effects in energy and carbon budgets at the surface (averaged over the whole domain)

- The coupling (SHADING) modulates the extreme fluctuations of cloud =>

It is less energy, but this less energy is localized at the roots of the clouds

- Difference in the cloud characteristics and population

(3) Do C4 plants enhance or decrease shallow convection?

C4 plants are more efficient in assimilating CO_2 and loosing less water
=> (for us) different plant response to VPD, T and radiation

C4P: C4 plants (grass)
SHD: C3 plants (grass)

C4 plants more water use efficient

Negative effect on clouds

Less evaporation

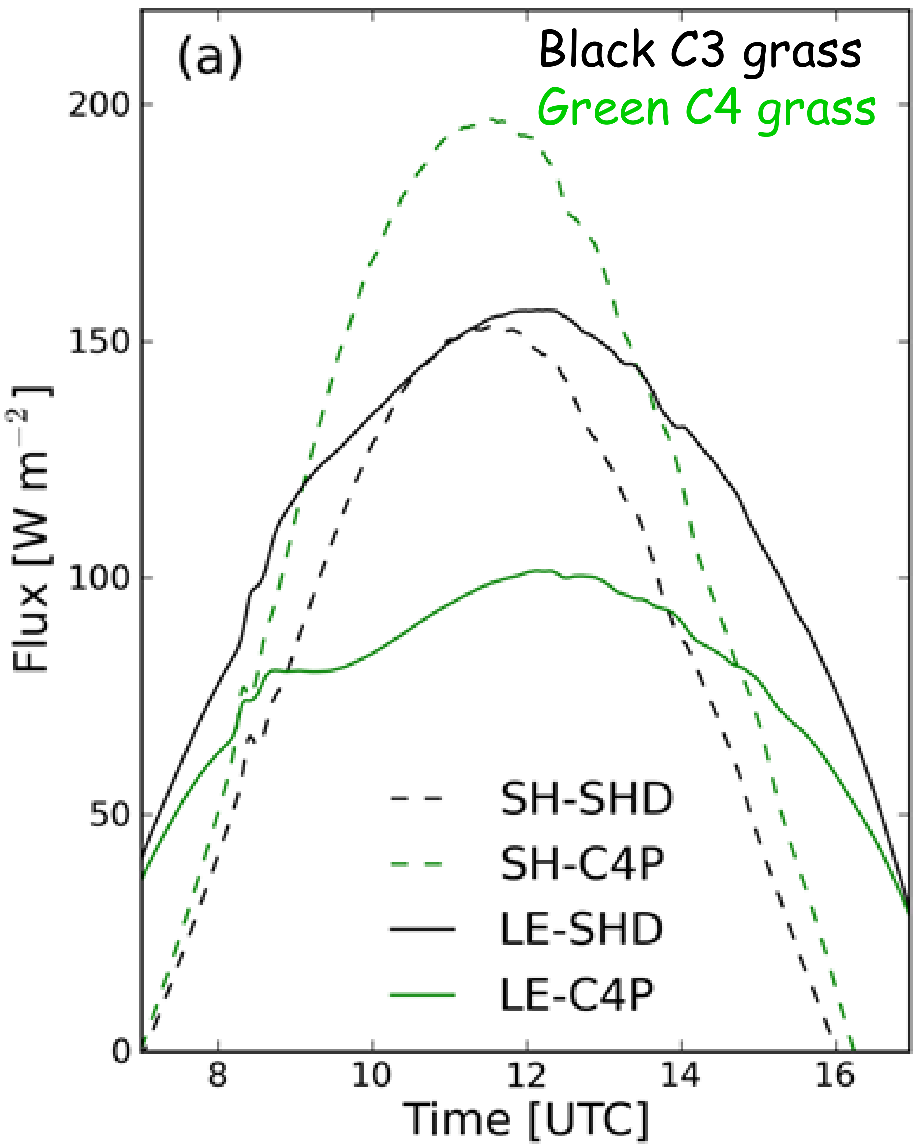
Turbulent motions transport <u>less moisture</u>
$\Rightarrow$ Less optimal conditions for saturation

Positive effect on clouds

Shift of the surface energy balance towards sensible heat flux

Large-eddies reach higher altitudes where absolute <u>T are colder</u>
$\Rightarrow$ More optimal conditions for saturation

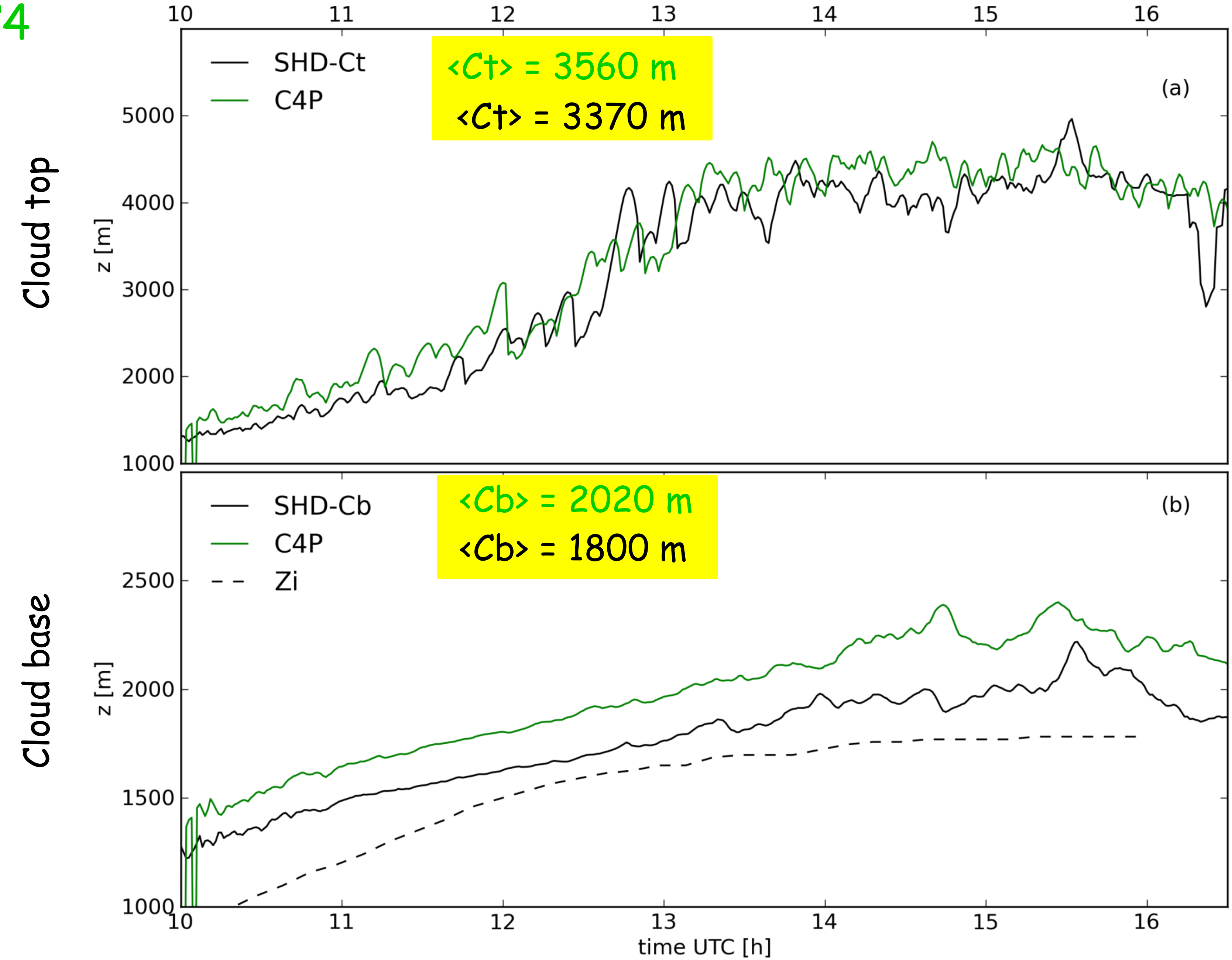
Surface fluxes: LE and SH



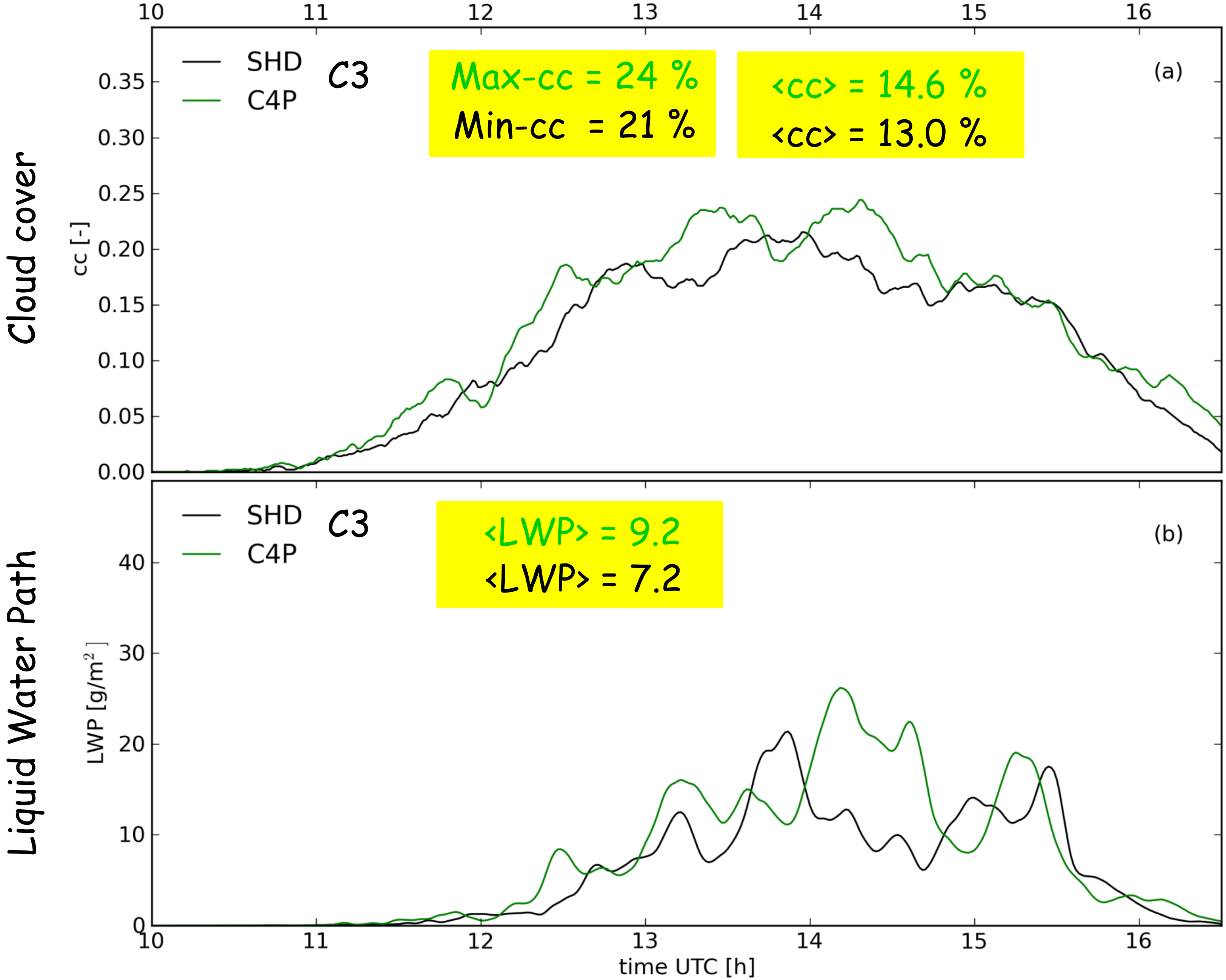
C4 evaporates less => more available energy used for sensible heat flux

C3=SHD

C4

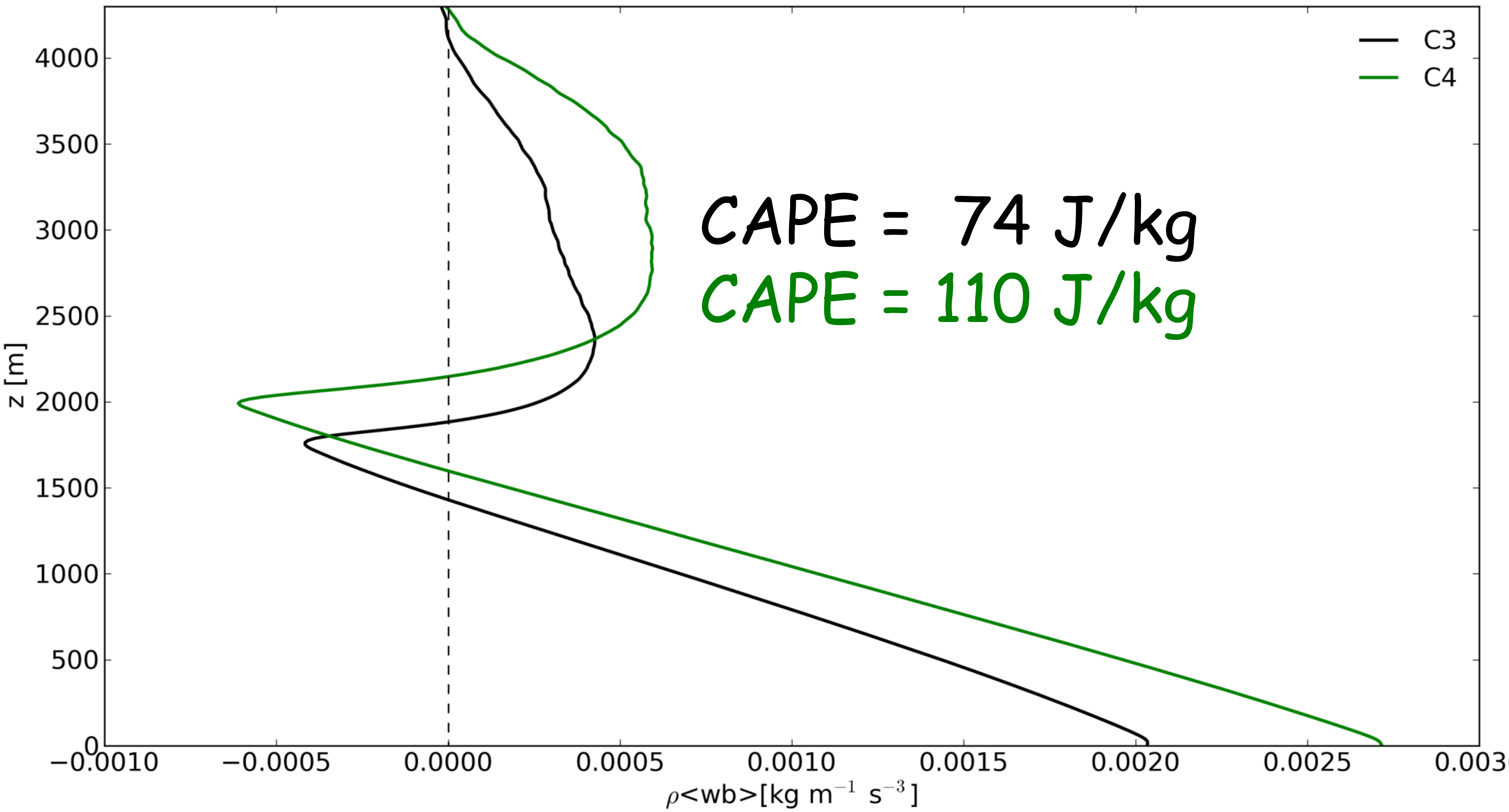


Cloud top
<Ct> = 3560 m
<Ct> = 3370 m
SHD-Ct
C4P
(a)
z [m]
Cloud base
<Cb> = 2020 m
<Cb> = 1800 m
SHD-Cb
C4P
Zi
(b)
z [m]
time UTC [h]



Cloud cover
cc [-]
SHD
C4P
C3
Max-cc = 24 %
Min-cc = 21 %
<cc> = 14.6 %
<cc> = 13.0 %
(a)
Liquid Water Path
LWP [g/m2]
SHD
C4P
C3
<LWP> = 9.2
<LWP> = 7.2
(b)
time UTC [h]

Vertical profiles buoyancy flux



(3) Do C4 plants enhance or decrease shallow convection?

- C4 plants enhance the cloud cover, liquid water path and cloud base

- Thermals intensity and larger length scales (C4) offsets the decrease in the latent heat flux and the lesser content moisture at sub-cloud layer

Conclusions

Relevant to study the coupling between vegetation and atmosphere at diurnal scales:

=> impact atmospheric phenomena at larger scales (transition shallow to deep convection)

=> plant response memory in setting cloud patterns

LES + plant physiology model is an appropriate platform to study the feedbacks between vegetation and clouds:

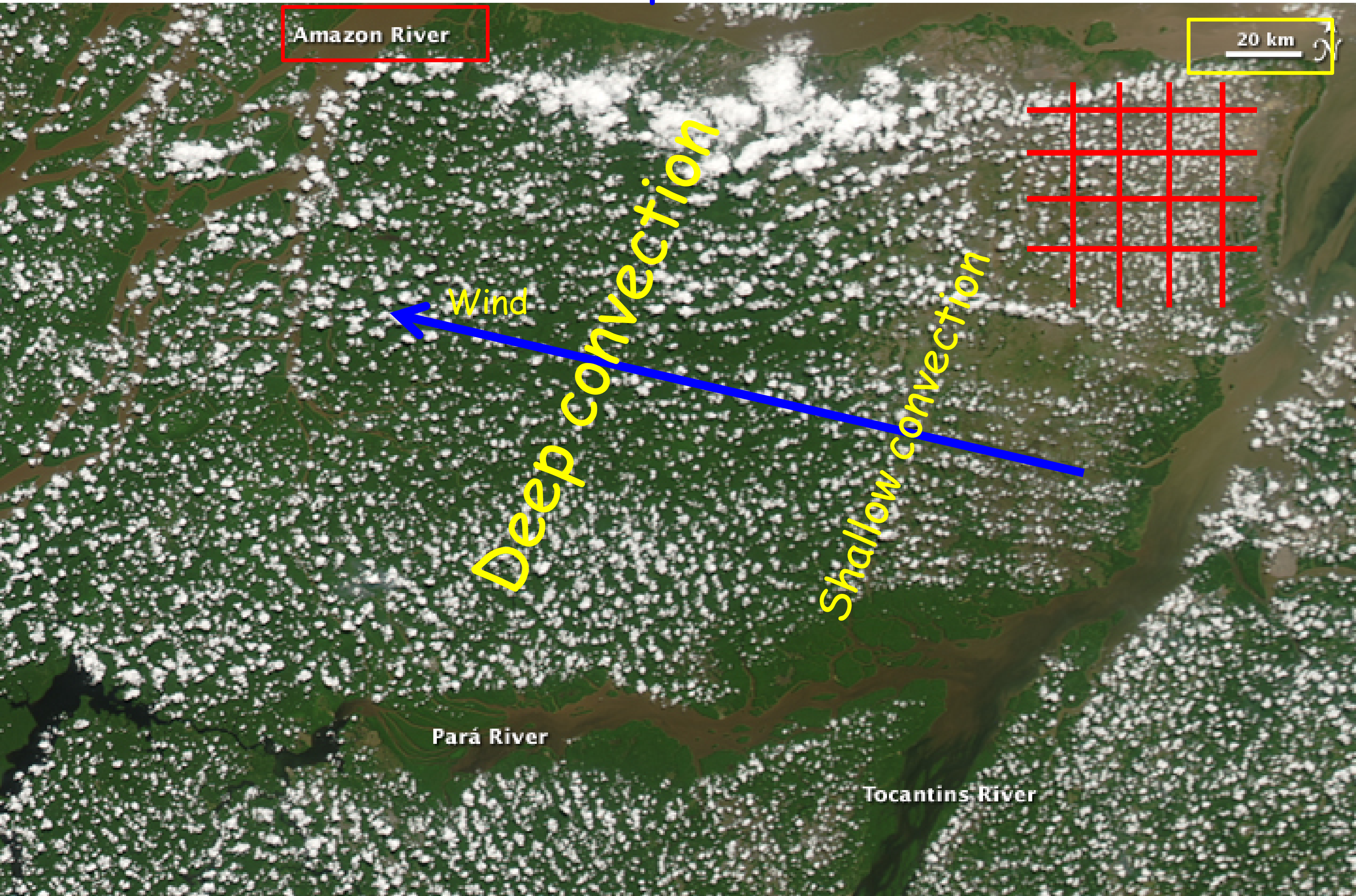
=> different contributions direct and diffuse radiation

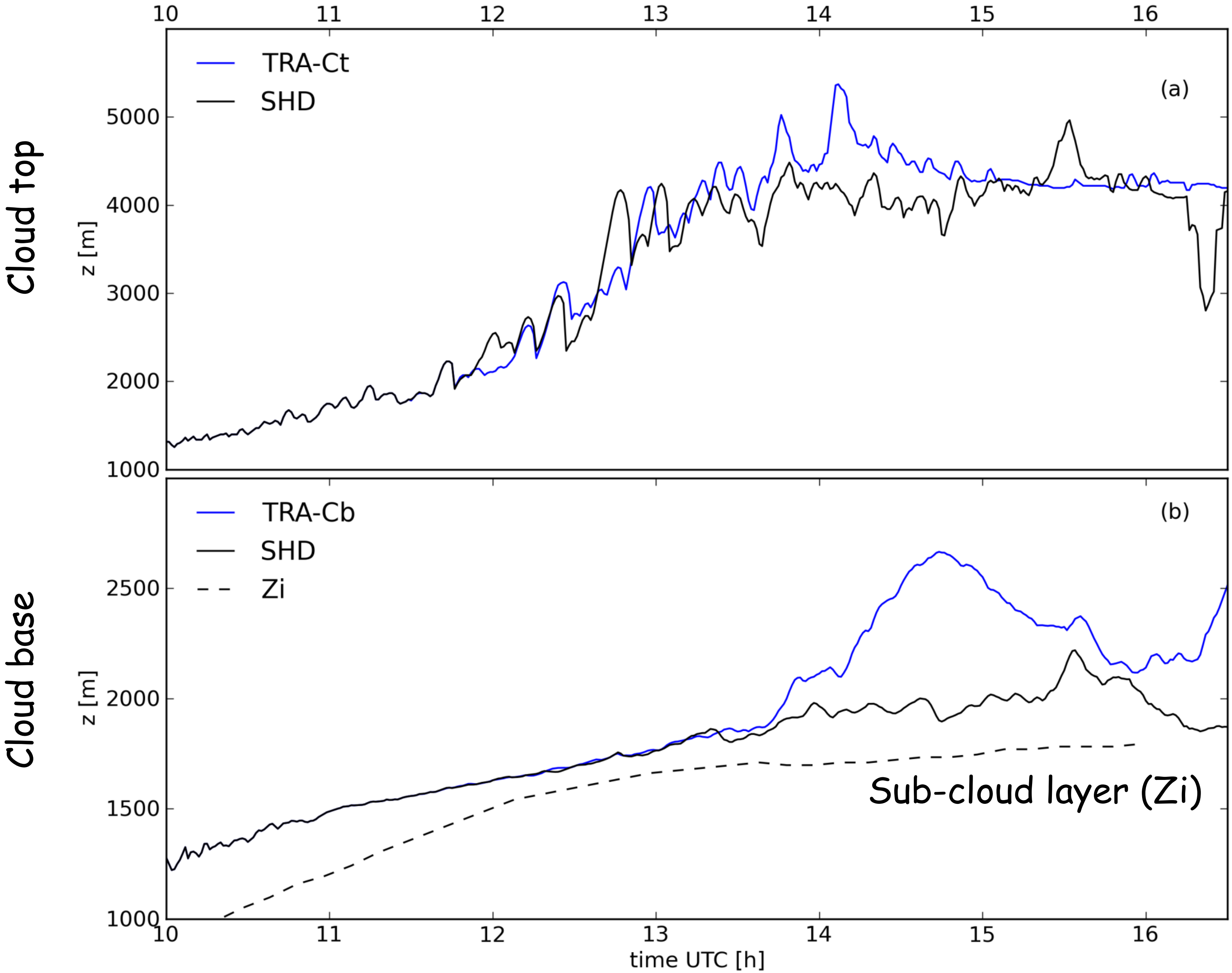
=> different plant response to VPD and T

Outlook:

Clouds and terrestrial CO_2 uptake still 2 of the largest sources of uncertainty/understanding in the Earth System

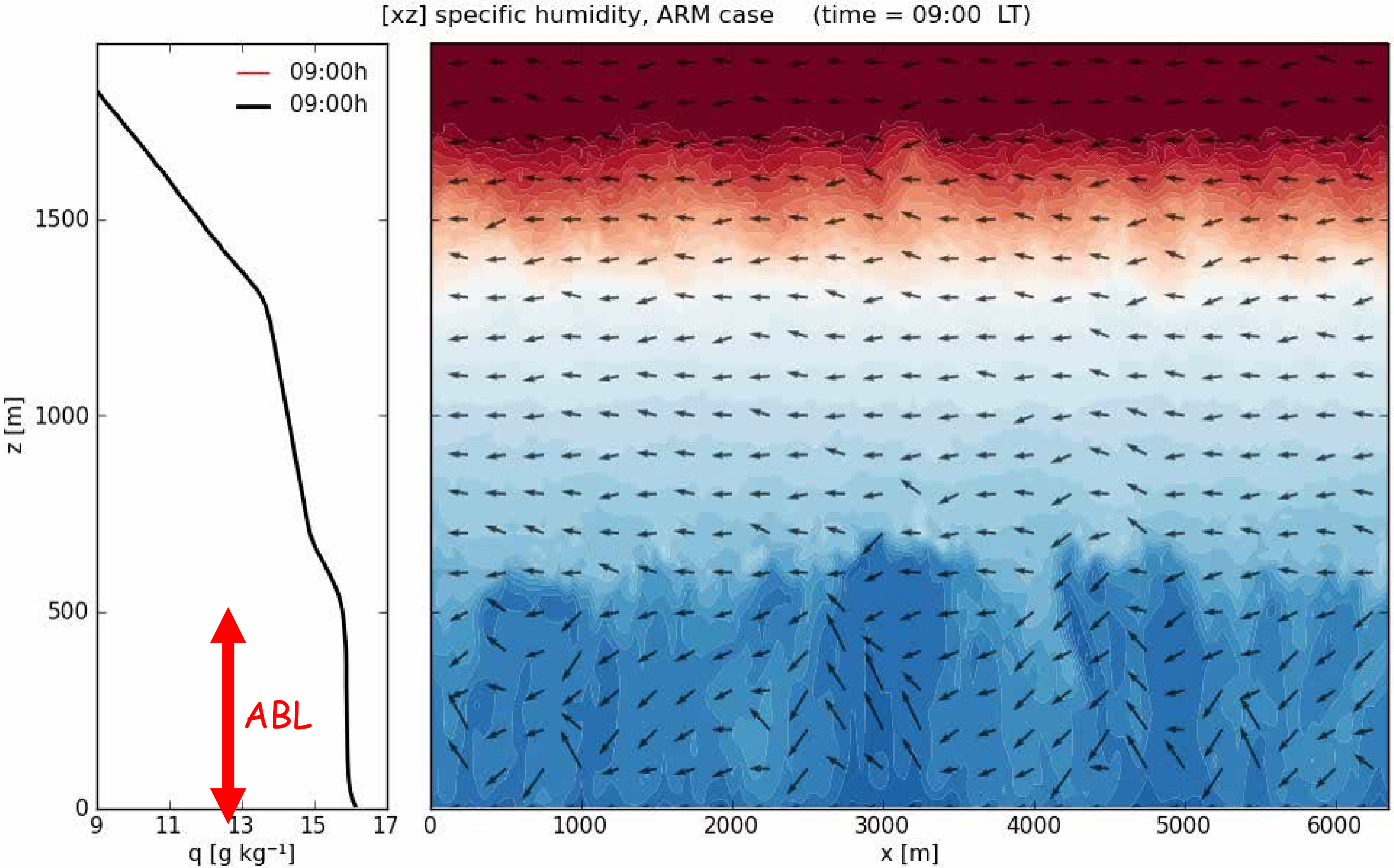
Boundary layer and vegetation feedbacks: Tropical





Cloud top
Cloud base
TRA-Ct
SHD
(a)
TRA-Cb
SHD
Zi
(b)
Sub-cloud layer (Zi)
z [m]
z [m]
time UTC [h]
10
11
12
13
14
15
16
1000
2000
3000
4000
5000
1000
1500
2000
2500

Atmospheric large-eddy simulation



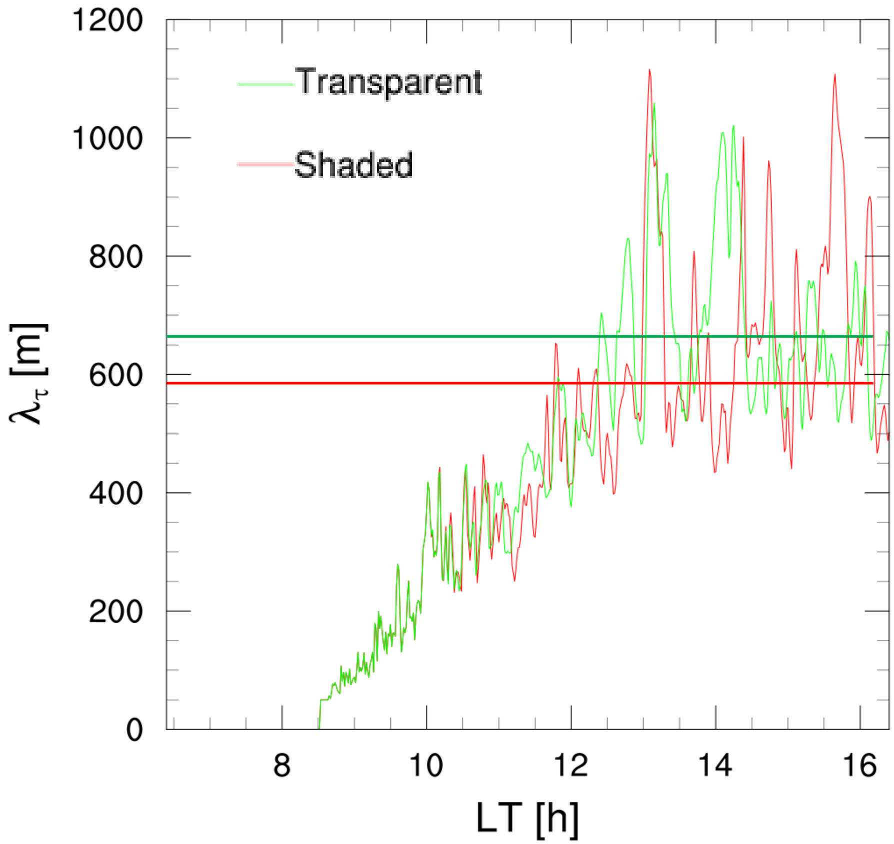
(van Stratum et al., 2014)

(1) Is it important to couple evapotranspiration to shallow cumulus clouds?

- Small effects in energy and carbon budgets at the surface (averaged over the whole domain)

- The coupling (SHADING) modulates the extreme fluctuations of cloud =>
It is less energy, but less energy localized at the roots of the clouds

⇒ Relevance for deep convection
⇒ Relevance of timing in the interaction between radiation, vegetation response, moist thermal intensity and clouds



Larger clouds in TRA case

Less separation SHD case

=> Similar cloud cover