Land-surface response to shallow cumulus

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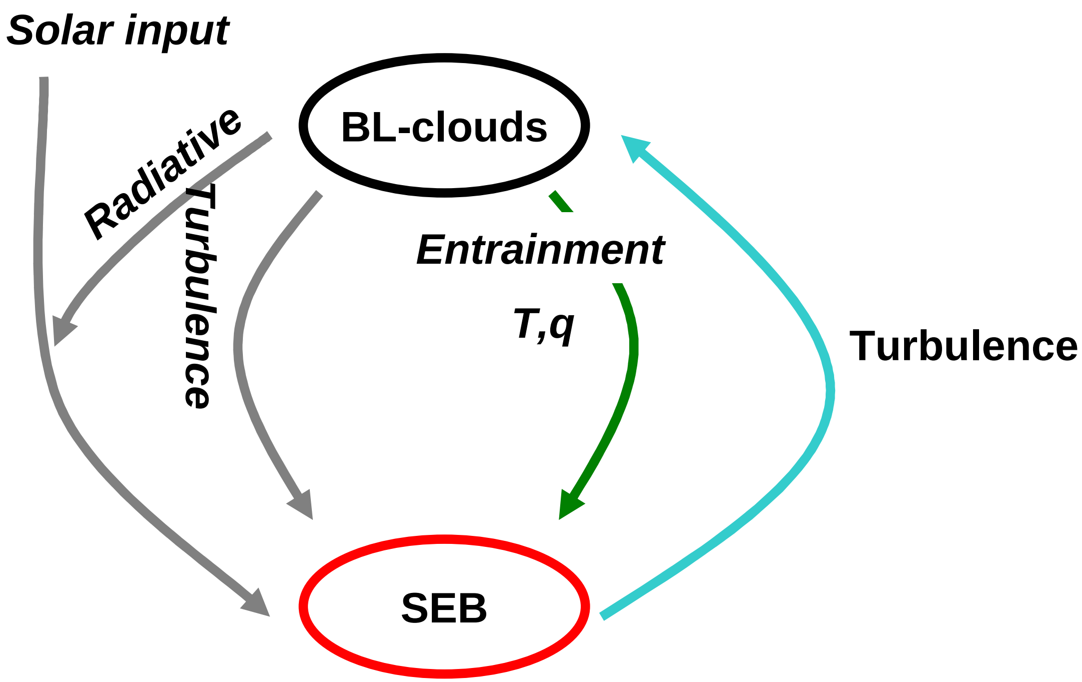
Outline

1/ SEB response on average and locally

(Radiative and turbulent effects (not shown here))



2/ **Boundary layer response to cloud-induced surface flux heterogeneity**

3/ Entrainment associated to BL-clouds

NCAR LES code

Moeng, 1984, 1986 / Sullivan et al., 1996 / Patton et al., 2005

Cloud transmission coefficient (*Joseph et al., 1976*)

Optical depth (*Stephens, 1984*)

Atmos. Forcings
Ch, Cm, θ, q, u, SWdn

NOAH Land surface model

1D set of equations for thermodynamic and hydrologic variables: *Mahrt and Pan, 1984, 1987*

Surface energy balance: *Chang et al, 1999*

Surface Forcings: H, LE, G, Tskin, SMCskin

Simulated case

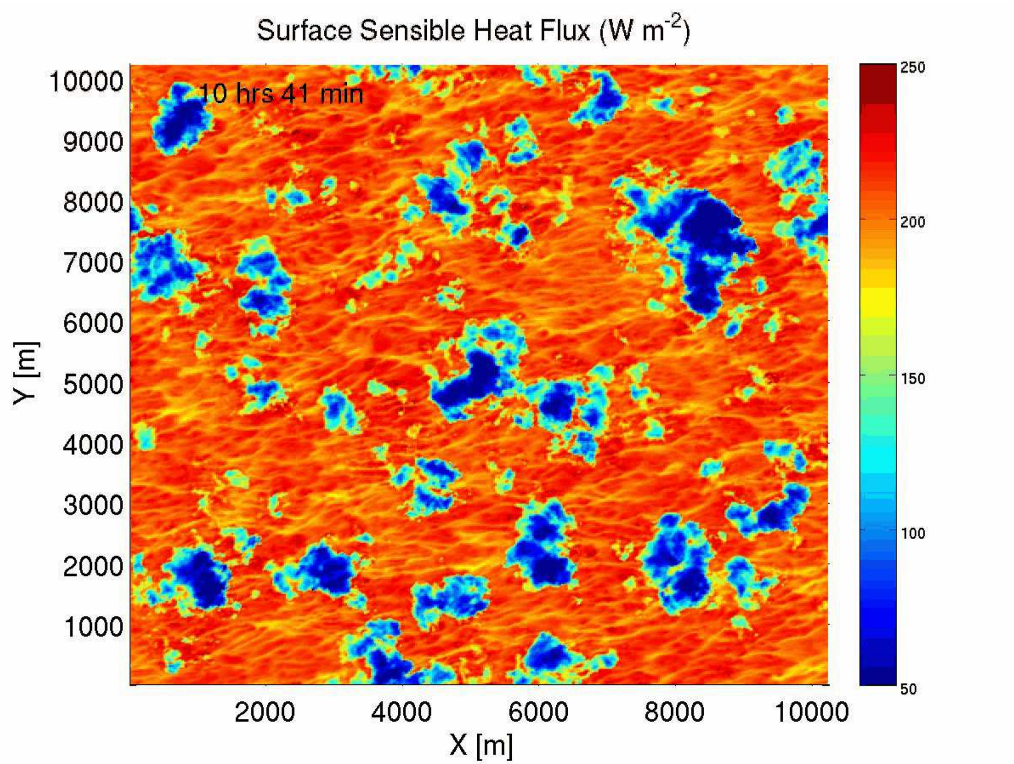
Case: 21 June 1997 ARM SGP: *Golaz et al. 2001, Brown et al. 2002, Vilà-Guereau et al., 2005*

Domain: 10 km^2 x 4 km

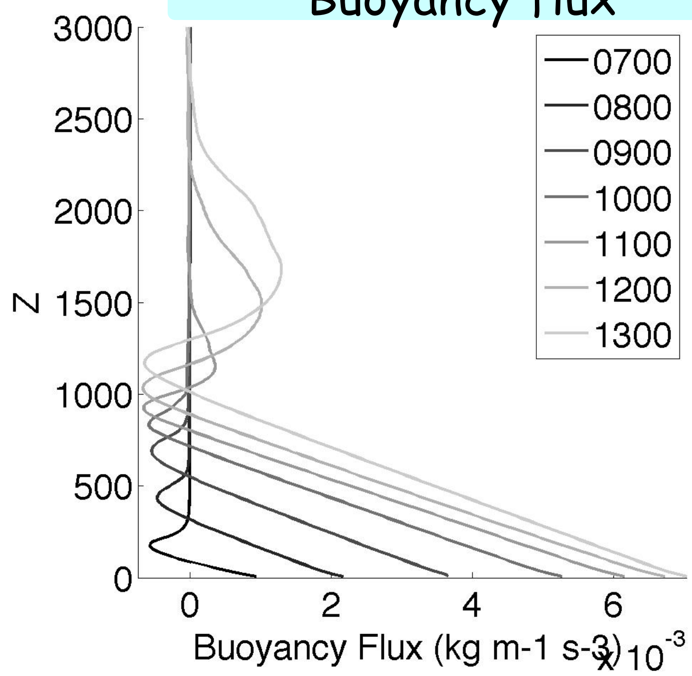
Resolution: $\Delta x = \Delta y = 20$ m and $\Delta z = 8$ m   4 levels in the ground: 5, 20, 60, 100 cm

Soil type: bare / clay-loam *(wilting point = 0.103 m3/m3 // field capacity = 0.465 m3/m3)* soil moisture content: 0.44 m3/m3// soil moisture availability: 0.93

Surface sensible heat flux



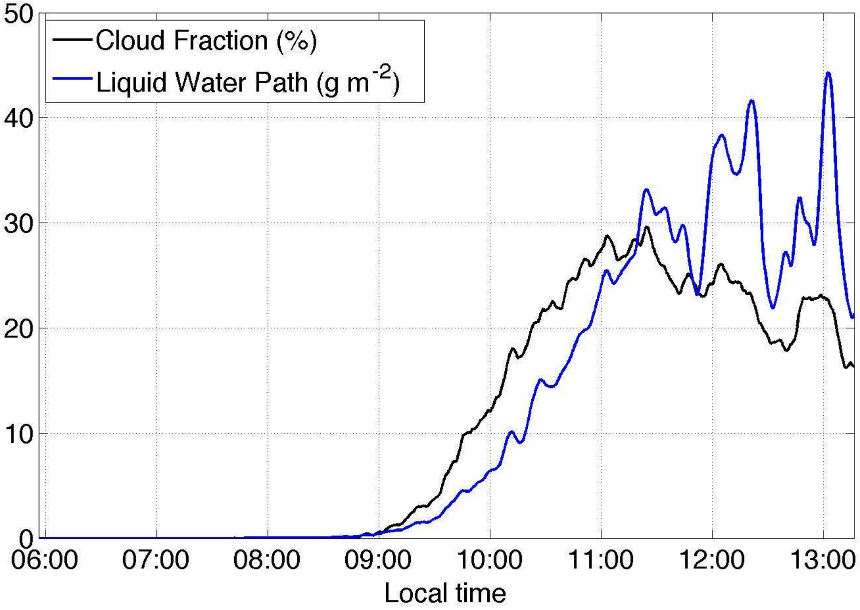
Buoyancy flux

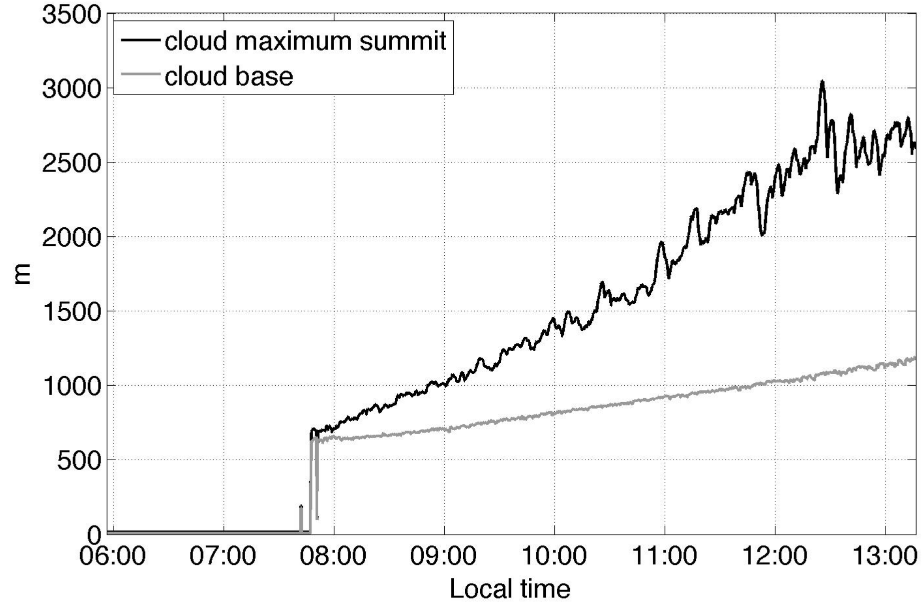


un-shaded area

shaded area

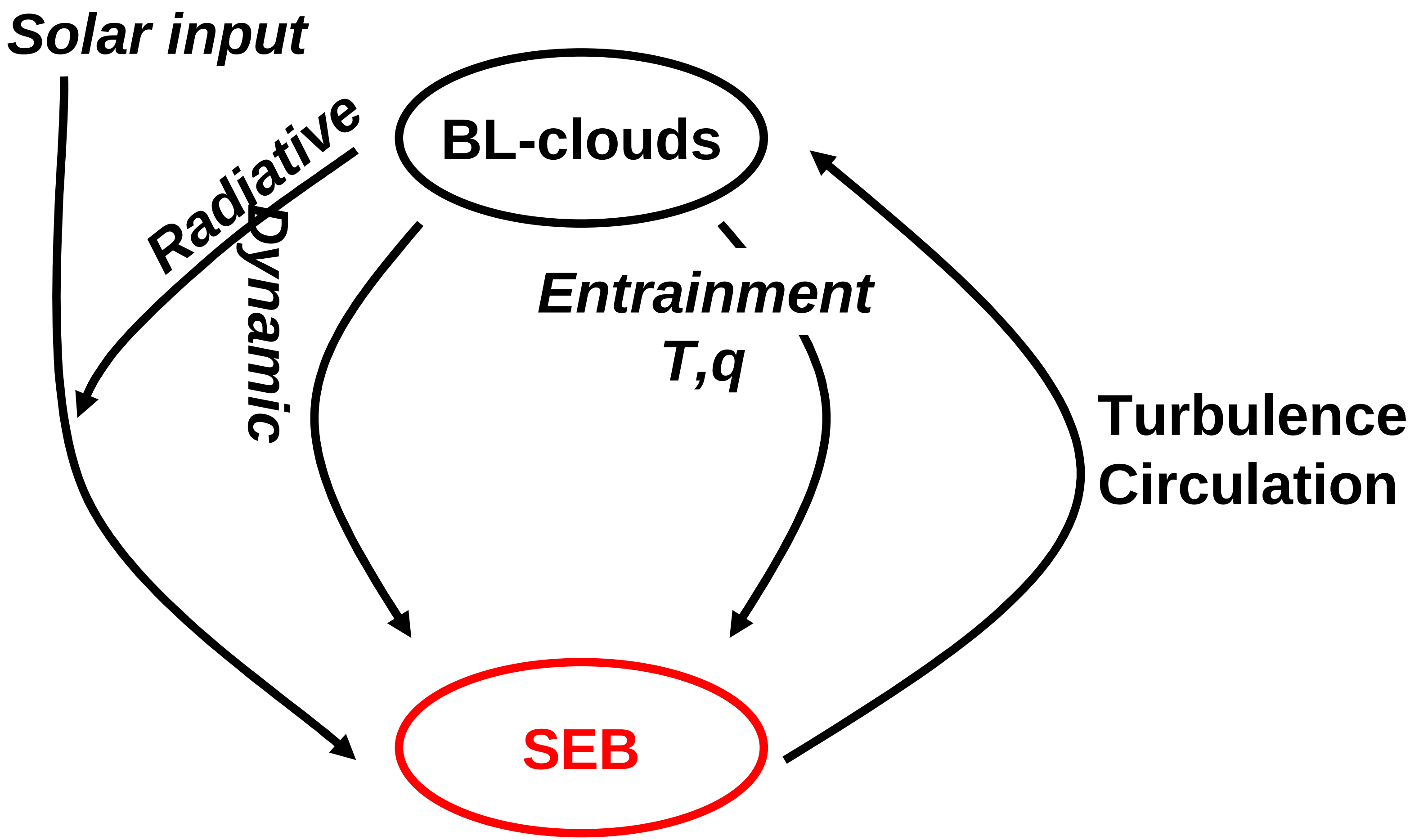
Cloud layer characteristics





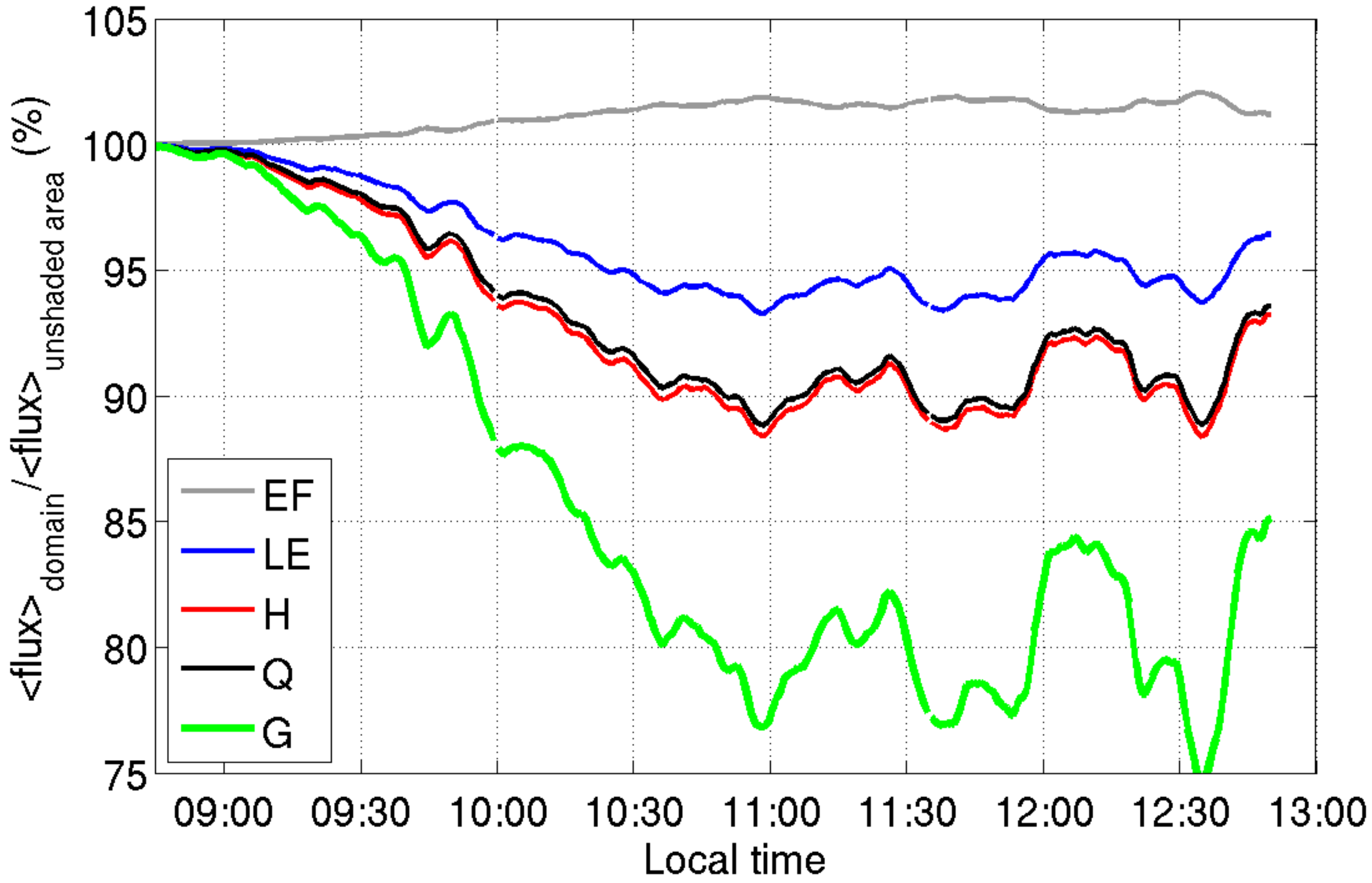
- ✓ Forced Cumuli: cloud top < level of free convection

  (Stull, 1988 ; *Otles and Young, 1996*)
- ✓ Depth up to 1.4 km
- ✓ Diameter up to 1 km
- ✓ Cloud Fraction up to 30%

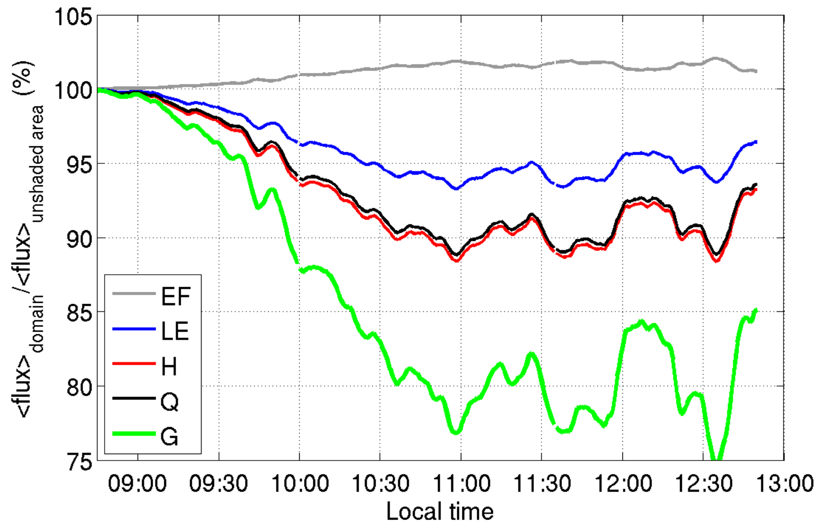


What is the SEB response to BL-Clouds on average and locally?

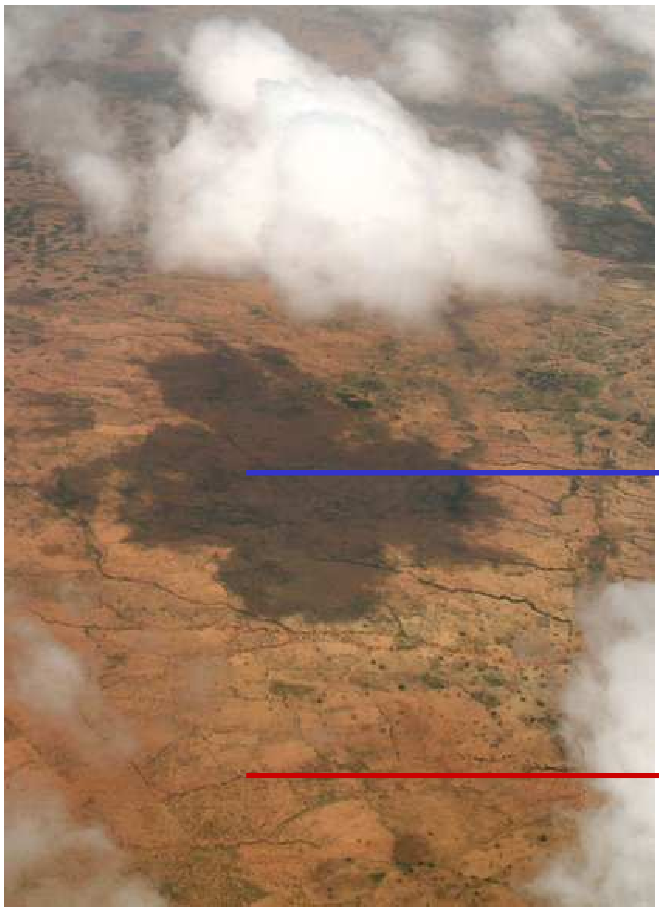
SEB response to BL-clouds on average



SEB response on average



SEB response locally



Shaded area

Q = H + LE + G

Q = 0.3 Q + 1.2 Q + (- 0.5 Q)

EF = 0.8

Un-shaded area

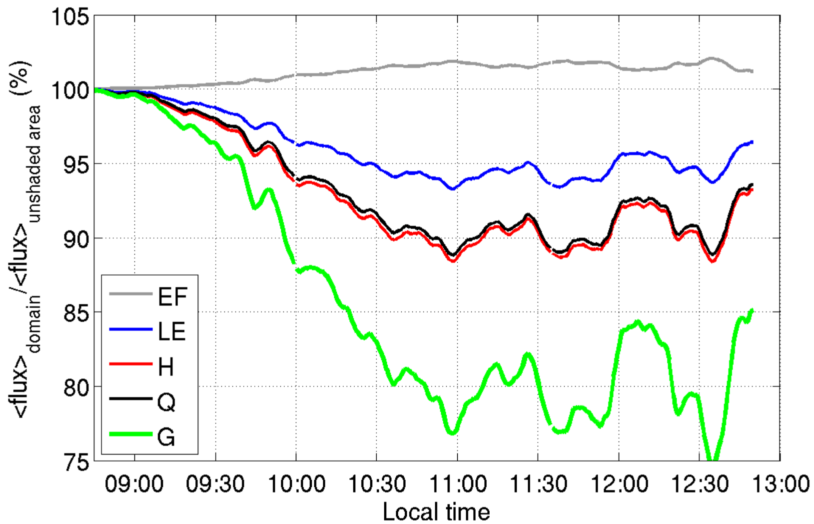
Q = H + LE + G

Q = 0.3 Q + 0.5 Q + 0.2 Q

EF = 0.6

SEB response locally

SEB response on average



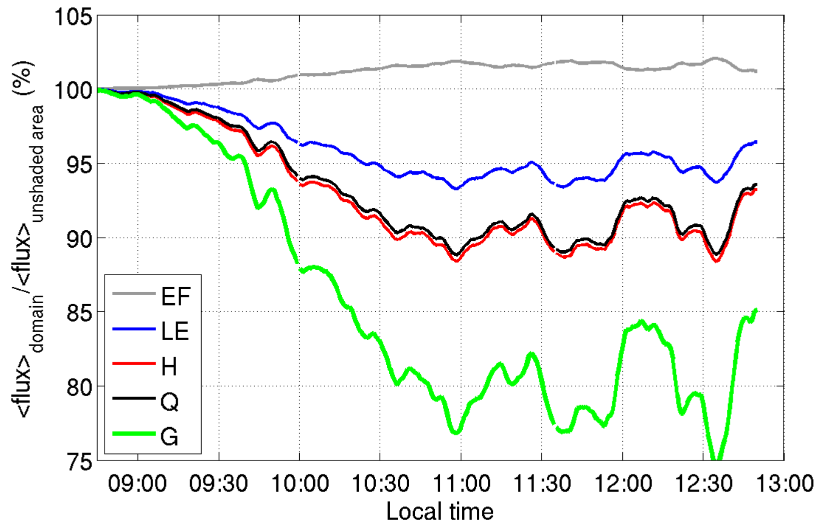
Penman equation

$$\lambda_v E = \frac{\frac{dq_{sat}}{dT_a} Q + \rho_a \, c_p \, \delta_e \, r_a^{-1}}{\frac{dq_{sat}}{dT_a} + \gamma}$$

$$LE = SMI \times \lambda_v E$$

$$H = \frac{\rho_a \, c_p}{r_a} (\theta_s - \theta)$$

SEB response on average

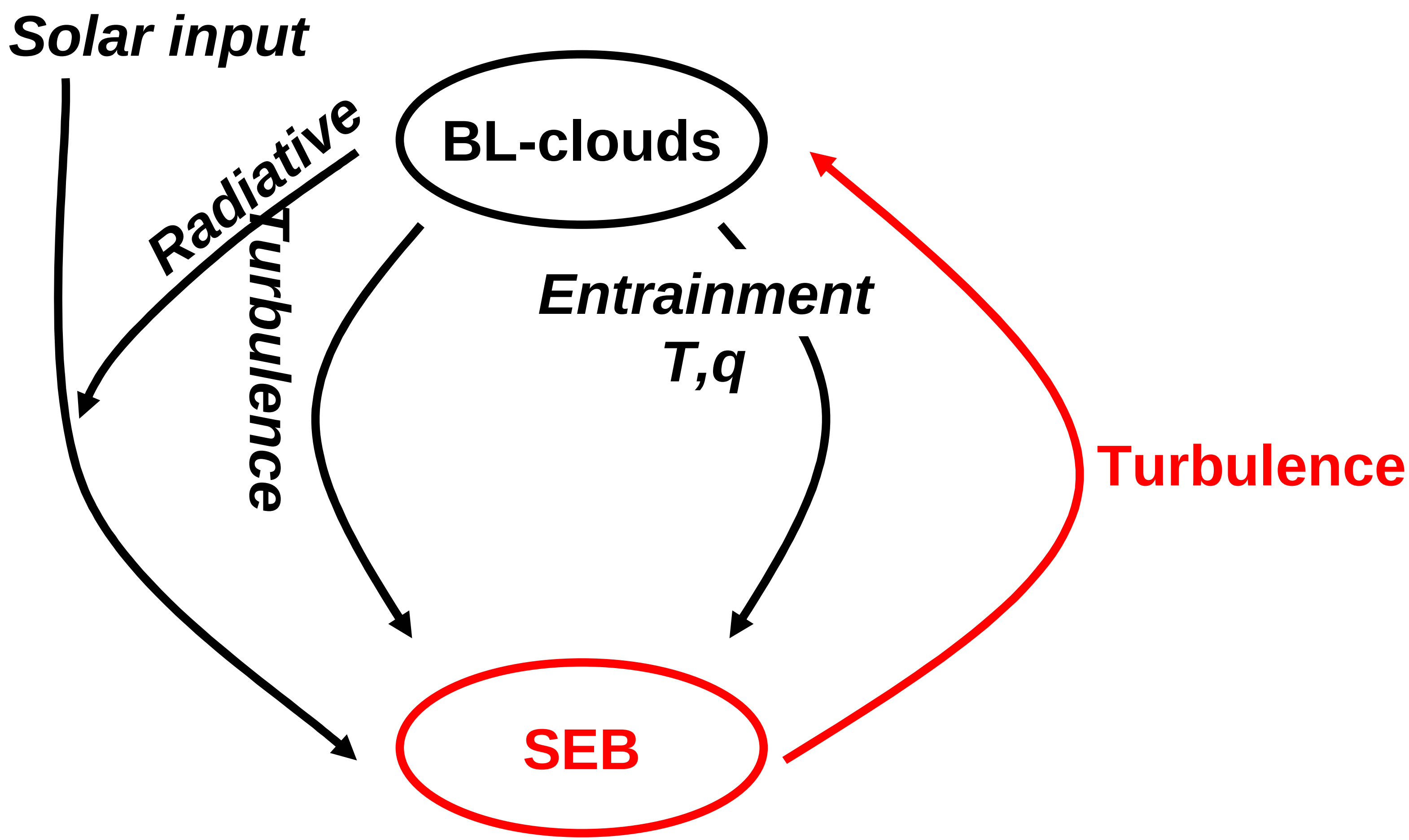


SEB response locally

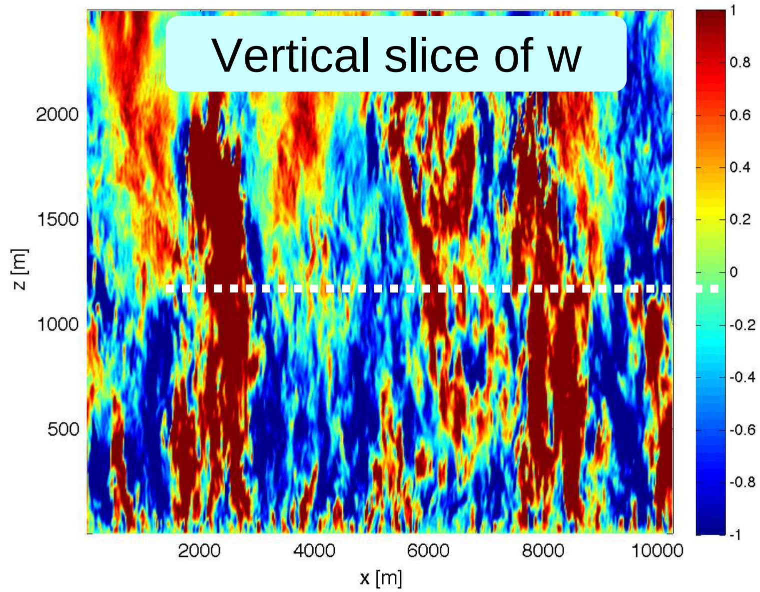
- ✓ Non linear response of the SEB to BL-clouds no matter the soil type and soil moisture. (offline tests with 1D NOAH LSM (not shown))

- ✓ EF increases of 3%

Boundary layer response to cloud-induced surface flux heterogeneity

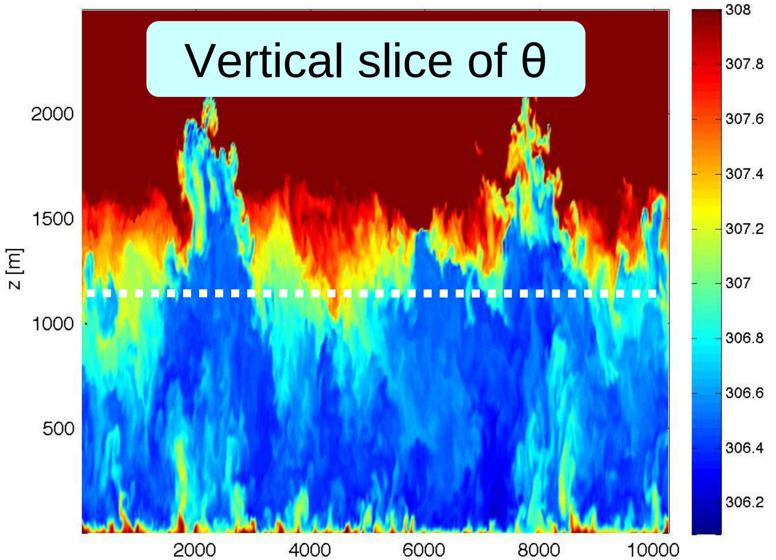


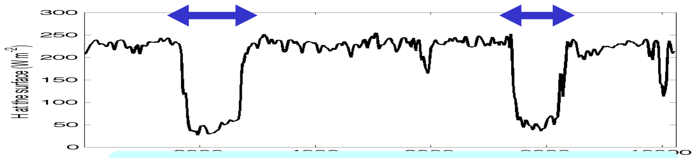
Cloud roots characteristics: mean parameters



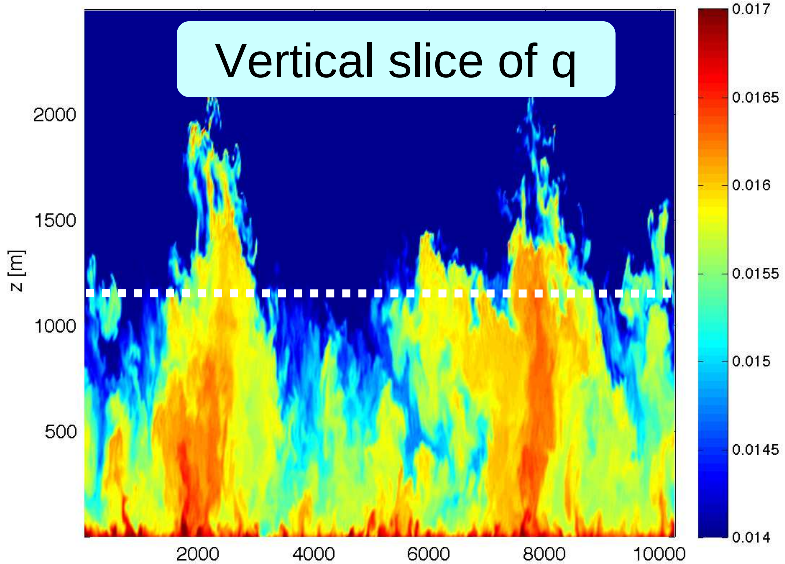
Example at 1300 LST

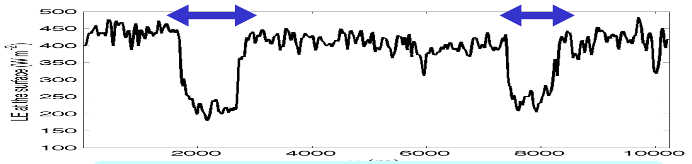
Cloud root ≡ column above shaded area





Surface sensible heat flux

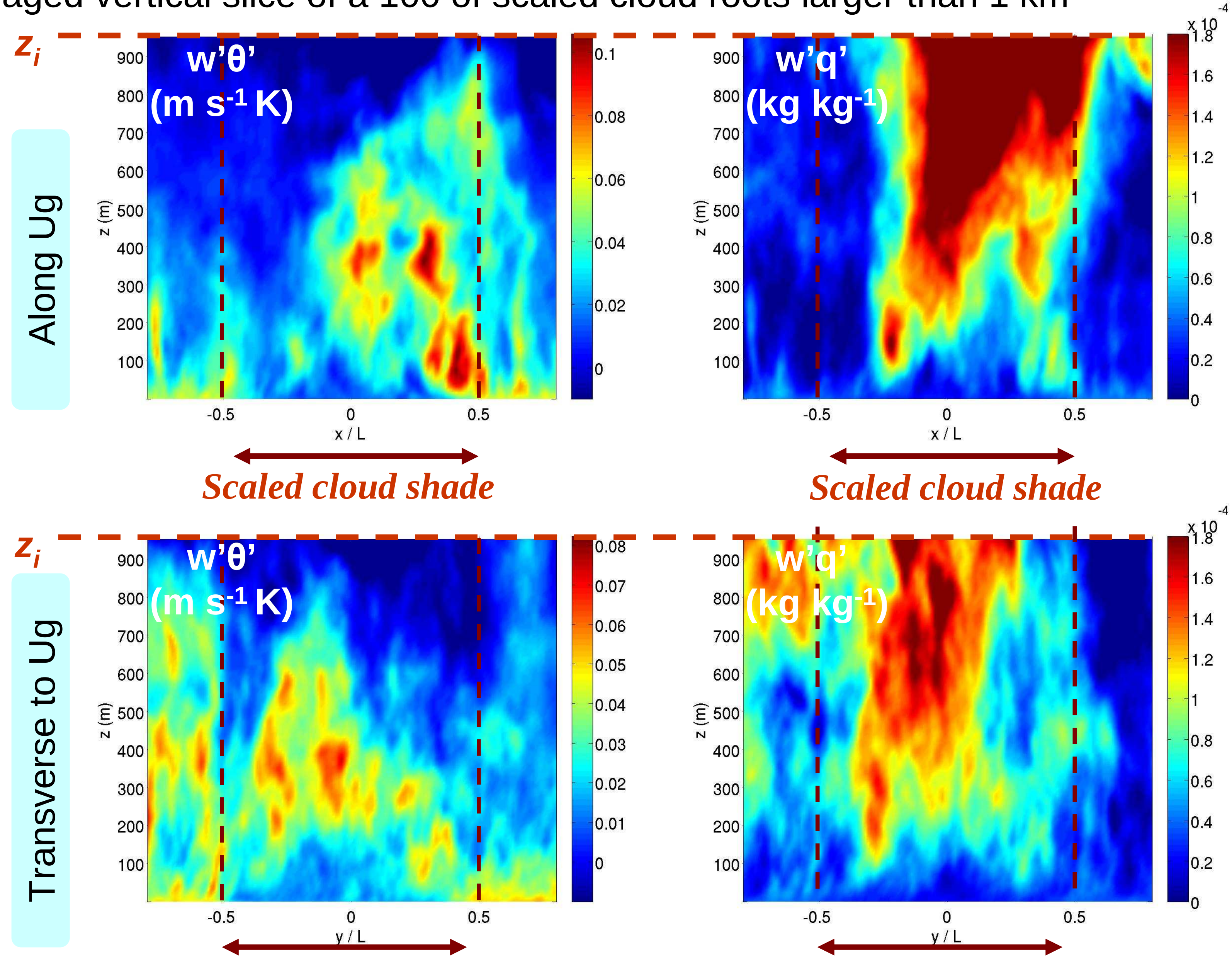




Surface latent heat flux

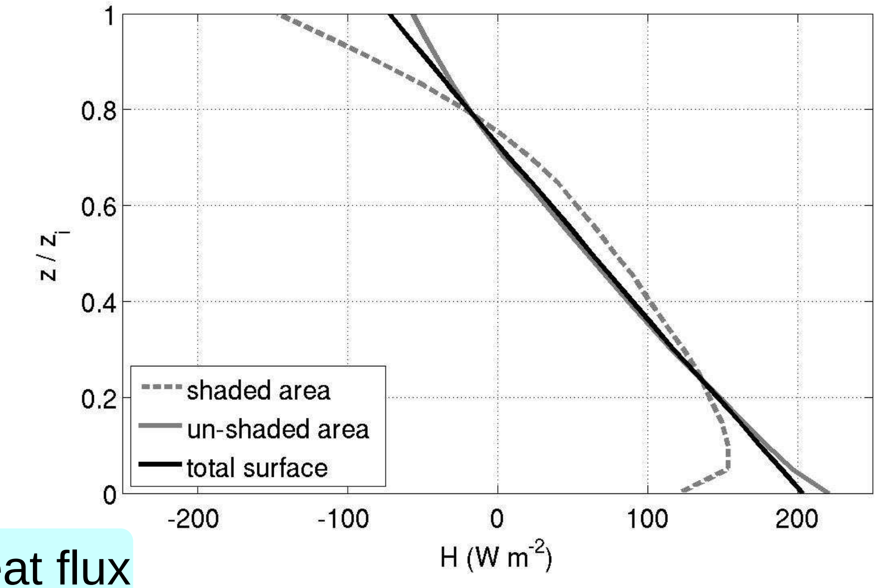
Cloud roots characteristics: vertical fluxes

Averaged vertical slice of a 100 of scaled cloud roots larger than 1 km

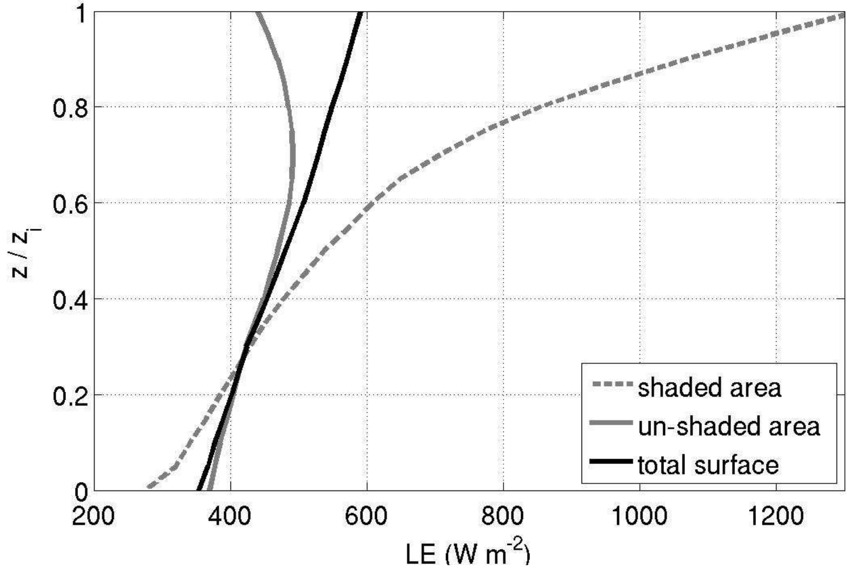


Vertical flux profiles in the shaded and un-shaded areas

Sensible heat flux

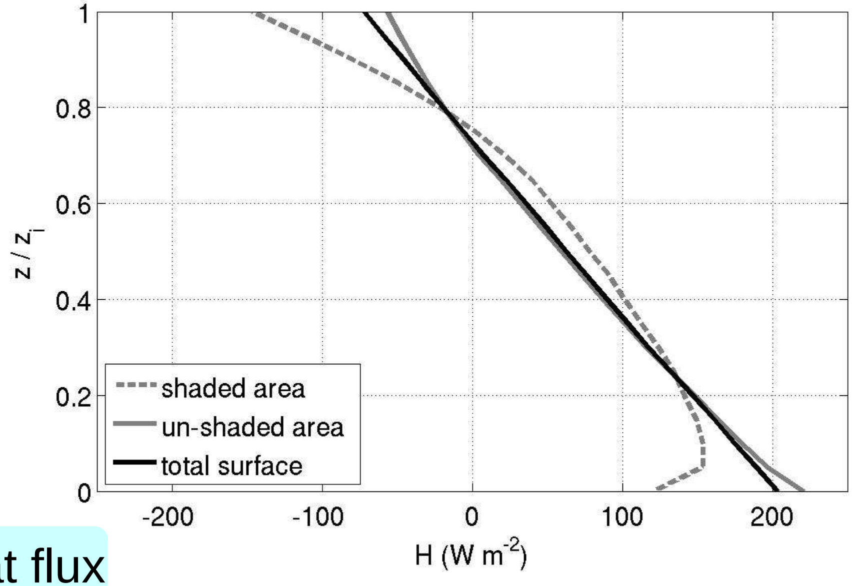


Latent heat flux

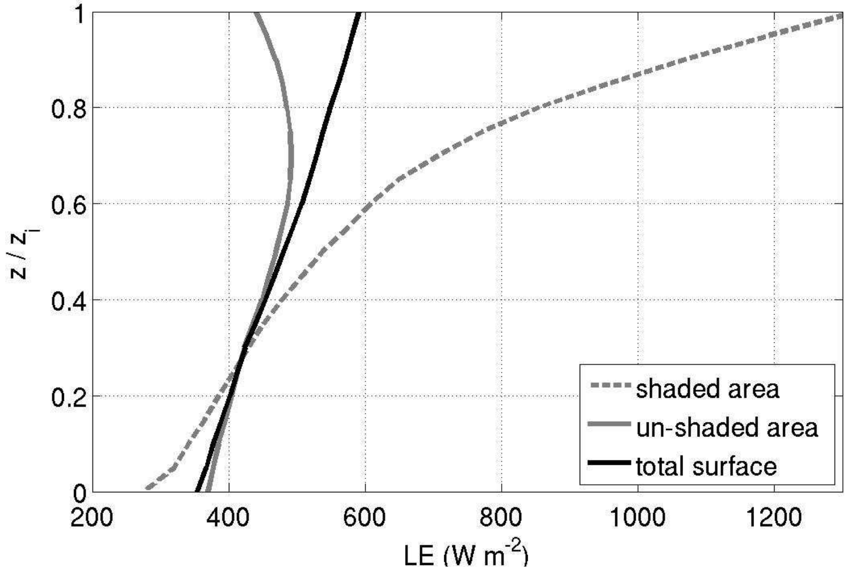


Vertical flux profiles in the shaded and un-shaded areas

Sensible heat flux

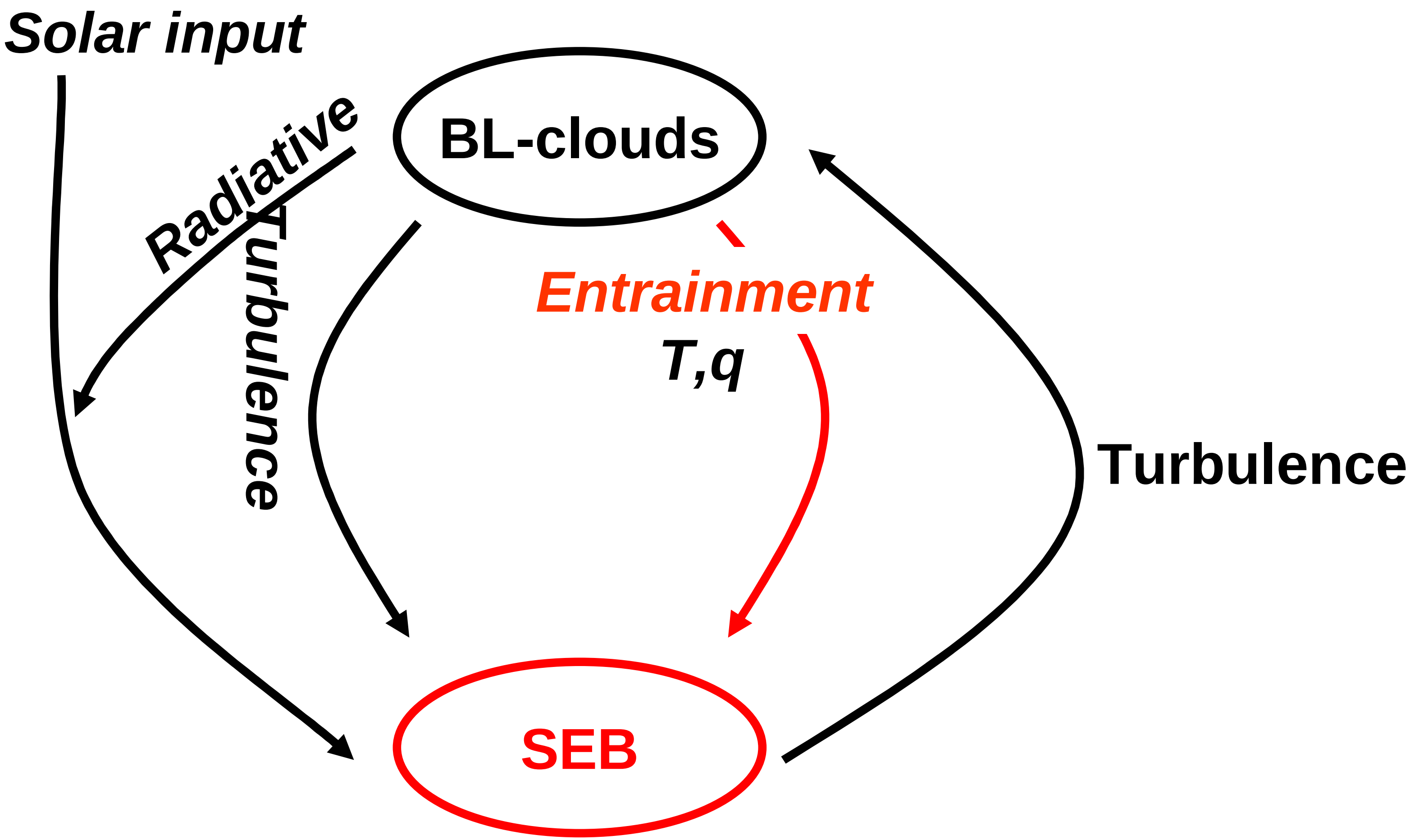


Latent heat flux



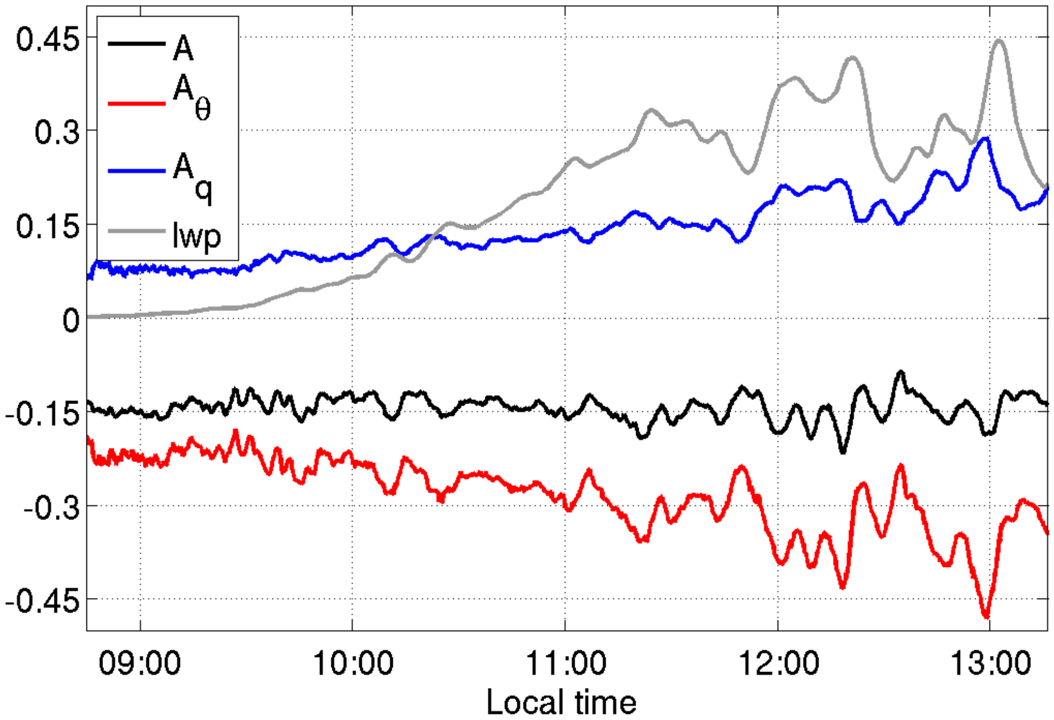
Small and moving surface heterogeneities due to cloud shading and secondary circulation are able to affect the atmospheric flux above the surface layer

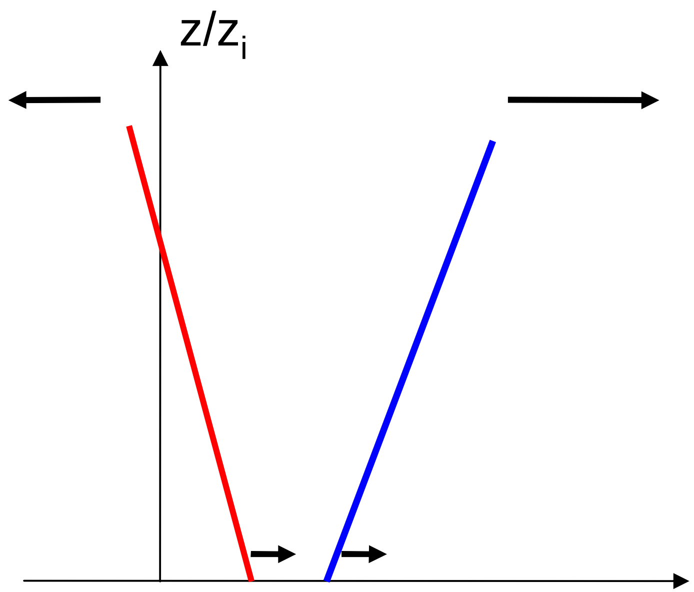
Entrainment associated to cloud BL-clouds



$$A = \frac{\overline{w'\theta_v'}_{zi}}{\overline{w'\theta_v'}_0} \approx \boxed{\frac{\overline{w'\theta'}_{zi}}{\overline{w'\theta_v'}_0}}\left(1+0.61\,\overline{q}\right) + 0.61\,\overline{\theta}\,\boxed{\frac{\overline{w'q'}_{zi}}{\overline{w'\theta_v'}_0}}$$

Sensible contribution A_θ ***Latent contribution A_q***





-0.2 ≤ A ≤ -0.1

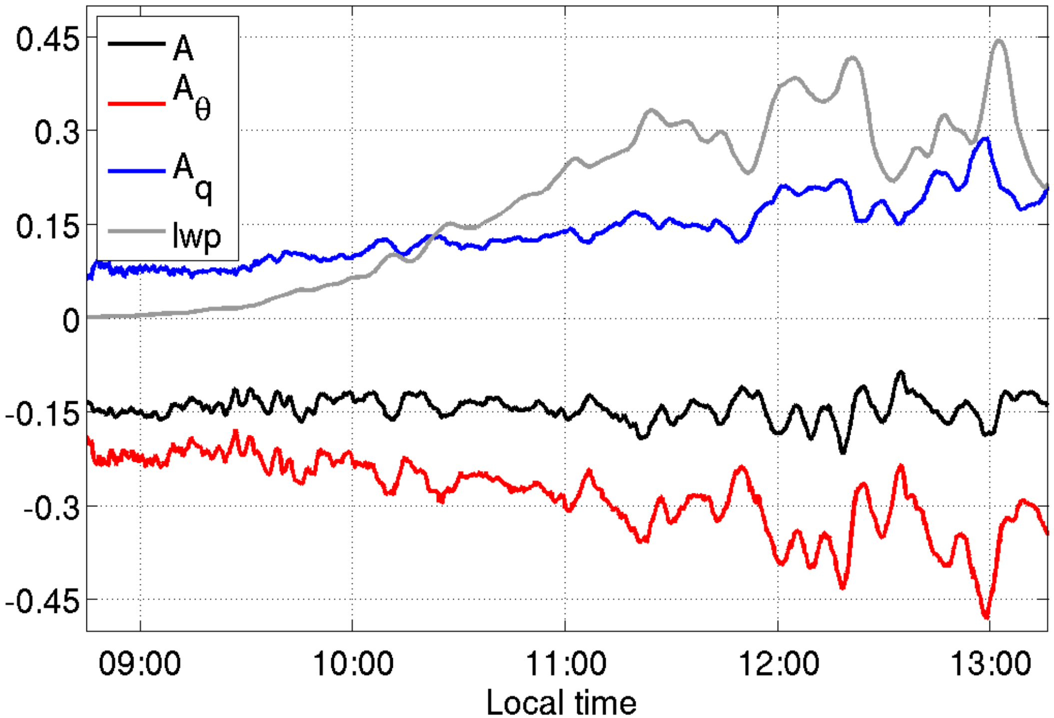
Otles and Young, 1996

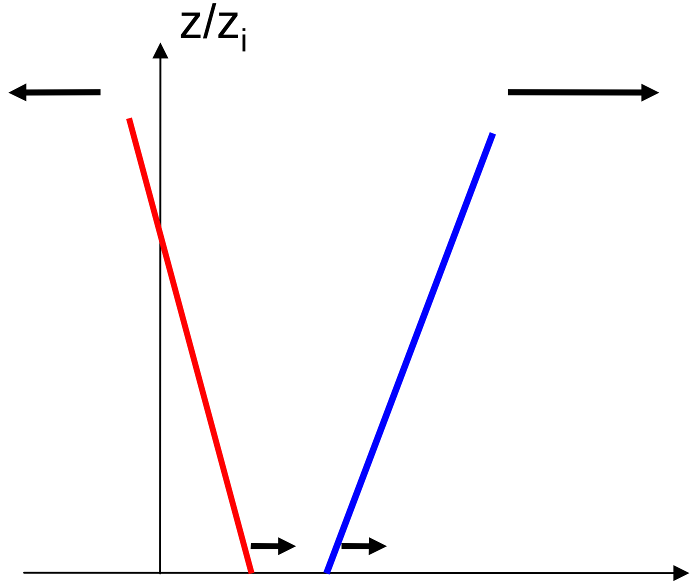
LeMone and Pennel, 1976

Nicholls and LeMone, 1980

$$A = \frac{\overline{w'\theta_v'}_{zi}}{\overline{w'\theta_v'}_{0}} \approx \frac{\overline{w'\theta'}_{zi}}{\overline{w'\theta_v'}_{0}}(1+0.61\,\overline{q}) + 0.61\,\overline{\theta}\,\frac{\overline{w'q'}_{zi}}{\overline{w'\theta_v'}_{0}}$$

Sensible contribution A_θ ***Latent contribution A_q***





Entrainment rate *A* is not changed on average.

But at short time scale, cloud activity tends to slightly increase *A*.

Thank you for your attention

Additional slides

Land-surface / Atmosphere coupling

flux at the surface

$$H = \frac{\rho_a c_p}{r_a}(\theta_s - \theta)$$

$$LE = \frac{\rho_a L}{r_a + r_s}(q_{sat}(T_s) - q)$$

Need of the skin temperature

Pronostic equation for skin temperature

$$C_{skin}\frac{dT_s}{dt} = Q + G - H - LE$$

Cskin : skin layer heat capacity

… hard to define

Penman-Monteith equation

$$Q + G = H + LE$$

No skin heat capacity

Immediate response of the skin layer

NCAR LES code

Moeng, 1984, 1986 / Sullivan et al., 1996 / Patton et al., 2005

Set of Navier-Stokes equation (u,v,w)

- ✓ Subgrid-scale terms are parameterized with the subgrid TKE and a stability-dependent length scale.
- ✓ Condensation scheme is based on all-or-nothing assumption / Non-precipitating clouds.
- ✓ 1D radiation

Cloud transmission coefficient (*Joseph et al., 1976*)

$$t_c = \frac{5 - e^{-\tau}}{(4 + 3\tau(1 - f))}$$

Optical depth (*Stephens, 1984*)

$$\tau = \frac{3}{2}\frac{lwp}{r_e} \quad with \quad r_e = 10\mu m$$

Atmos. Forcings
Ch, Cm, θ, q, u, SWdn

→

NOAH Land surface model

1D set of equations for thermodynamic and hydrologic variables: *Mahrt and Pan, 1984, 1987 // Surface energy balance*: *Chang et al, 1999*

←

Surface Forcings
H, LE, G, T_{skin}, SMC_{skin}

NOAH Land surface model

1D set of equations for thermodynamic and hydrologic variables: *Mahrt and Pan, 1984, 1987 // Surface energy balance*: *Chang et al, 1999*

Atmos. Forcings
Ch, Cm, θ, q, u, SWdn

1/ Penman equation

$$\lambda_v E = \frac{\frac{dq_{sat}}{dT_a} Q + \rho_a c_p \delta_e r_a^{-1}}{\frac{dq_{sat}}{dT_a} + \gamma}$$

$$LE = SMA \times \lambda_v E$$

$$r_a = \frac{1}{uC_h}$$

$$C_h = f(z_0, L, \psi,$$

$$SMA = \frac{SMC - WLTSMC}{SMCMAX - WLTSMC}$$

2/ Soil moisture update

3/ Soil heat flux

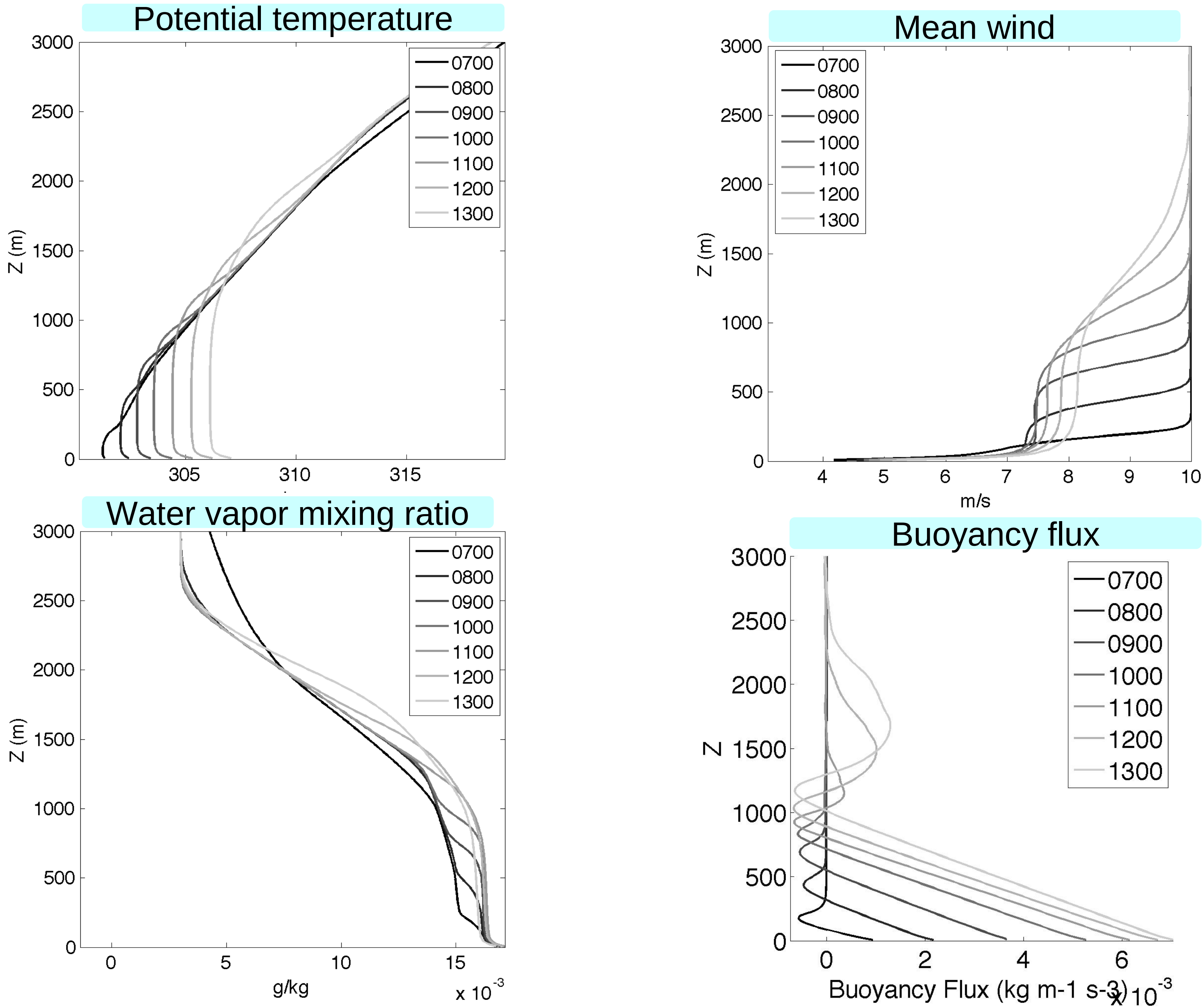
$$G = \gamma \frac{\partial T_g}{\partial z}$$

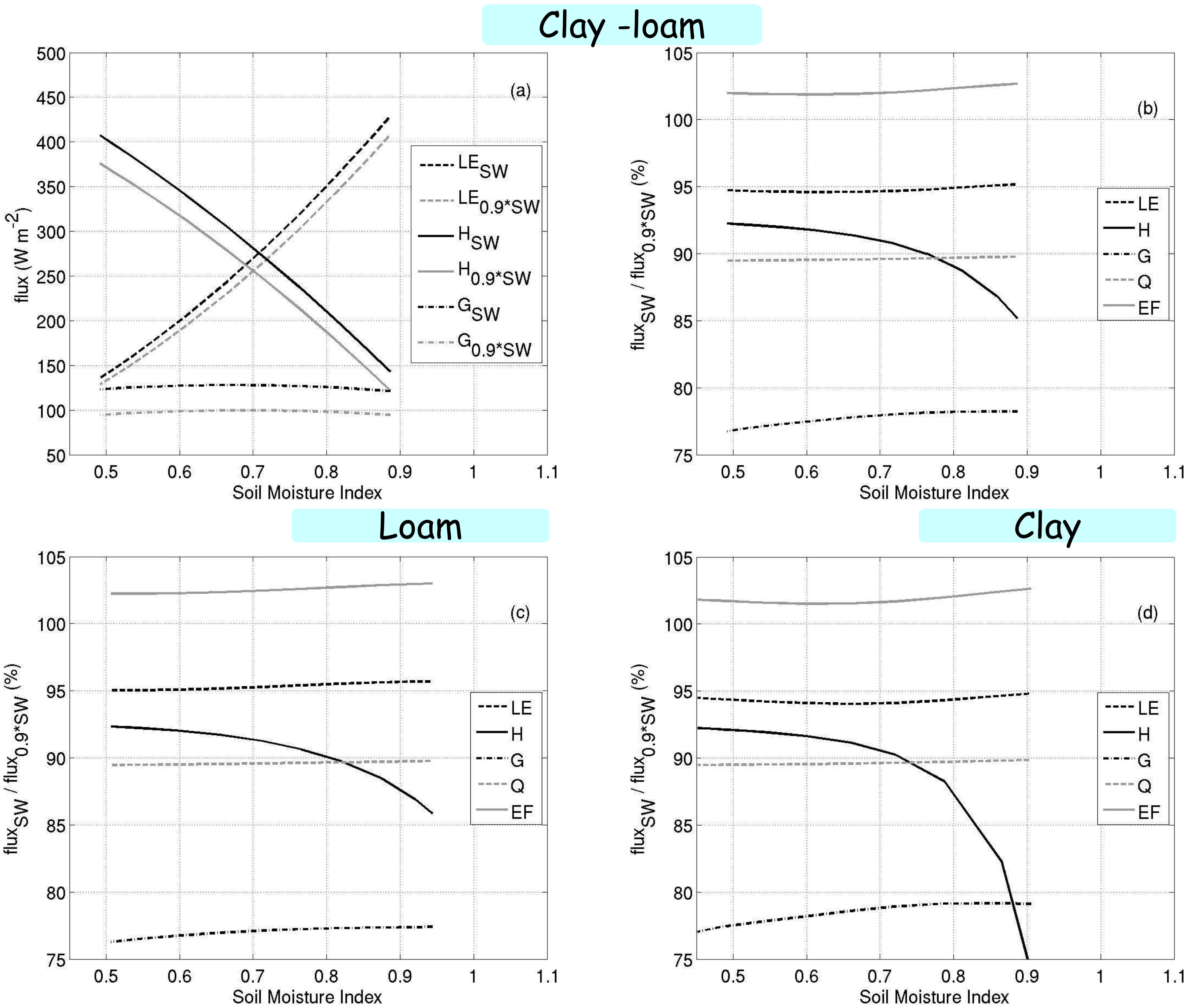
4/ Soil Temperature update

5/ Sensible heat flux

$$H = \frac{\rho_a c_p}{r_a} (\theta_s - \theta)$$

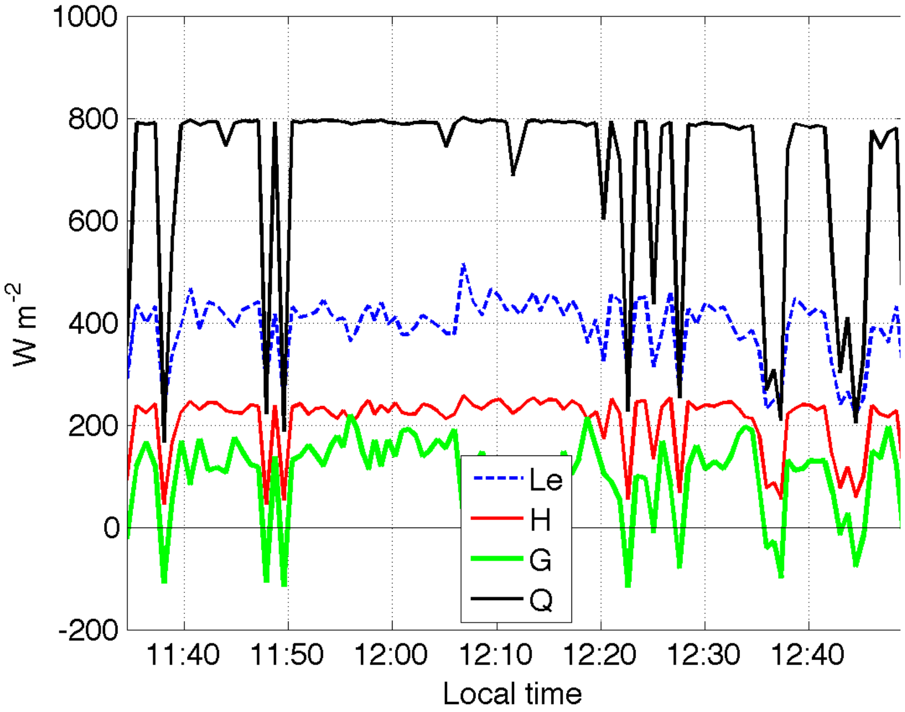
Surface Forcings
H, LE,G, T_{skin}, SMC_{skin}

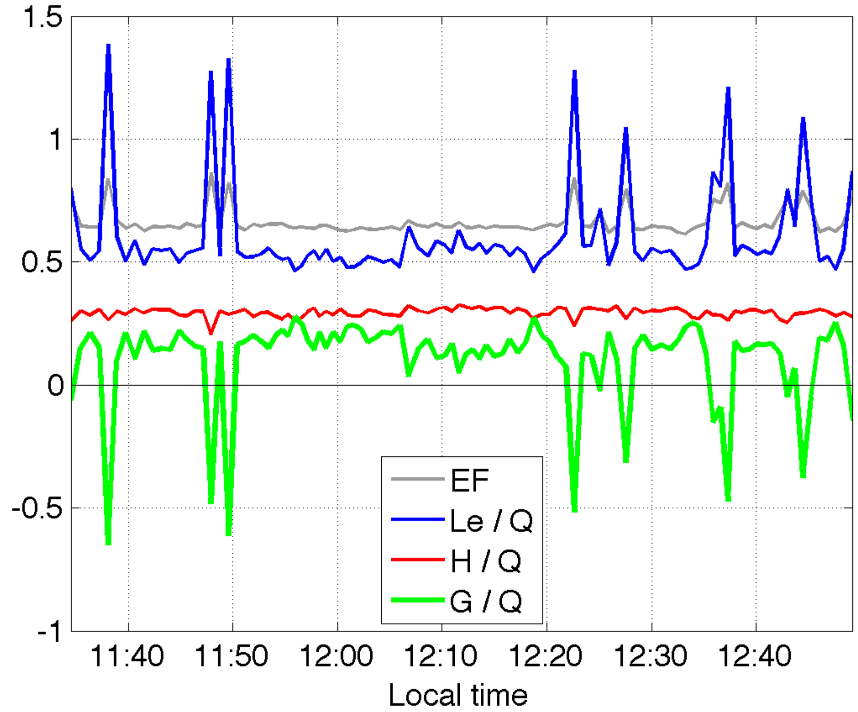

Potential temperature
Z (m)
3000
2500
2000
1500
1000
500
0
305
310
315
0700
0800
0900
1000
1100
1200
1300
Mean wind
Z (m)
3000
2500
2000
1500
1000
500
0
4
5
6
7
8
9
10
m/s
0700
0800
0900
1000
1100
1200
1300
Water vapor mixing ratio
Z (m)
3000
2500
2000
1500
1000
500
0
0
5
10
15
g/kg
x 10^-3
0700
0800
0900
1000
1100
1200
1300
Buoyancy flux
Z
3000
2500
2000
1500
1000
500
0
0
2
4
6
Buoyancy Flux (kg m-1 s-3)
x 10^-3
0700
0800
0900
1000
1100
1200
1300



Clay -loam
(a)
flux (W m-2)
Soil Moisture Index
LE SW
LE 0.9*SW
H SW
H 0.9*SW
G SW
G 0.9*SW
(b)
fluxSW / flux0.9*SW (%)
Soil Moisture Index
LE
H
G
Q
EF
Loam
(c)
fluxSW / flux0.9*SW (%)
Soil Moisture Index
LE
H
G
Q
EF
Clay
(d)
fluxSW / flux0.9*SW (%)
Soil Moisture Index
LE
H
G
Q
EF

Local SEB response to sudden net radiation changes





	un_shaded area	***shaded area***
H	***0.3 Q***	***0.3 Q***
LE	***0.5 Q***	***1.2 Q***
G	***0.2 Q***	***-0.5 Q***

Radiative and turbulence effects on surface flux

In NOAH LSM (Penman, 1948; Monteith, 1981):

$$\lambda_v E = \frac{\frac{dq_{sat}}{dT_a} Q + \rho_a c_p \delta_e r_a^{-1}}{\frac{dq_{sat}}{dT_a} + \gamma}$$

$$r_a = \frac{1}{uC_h}$$

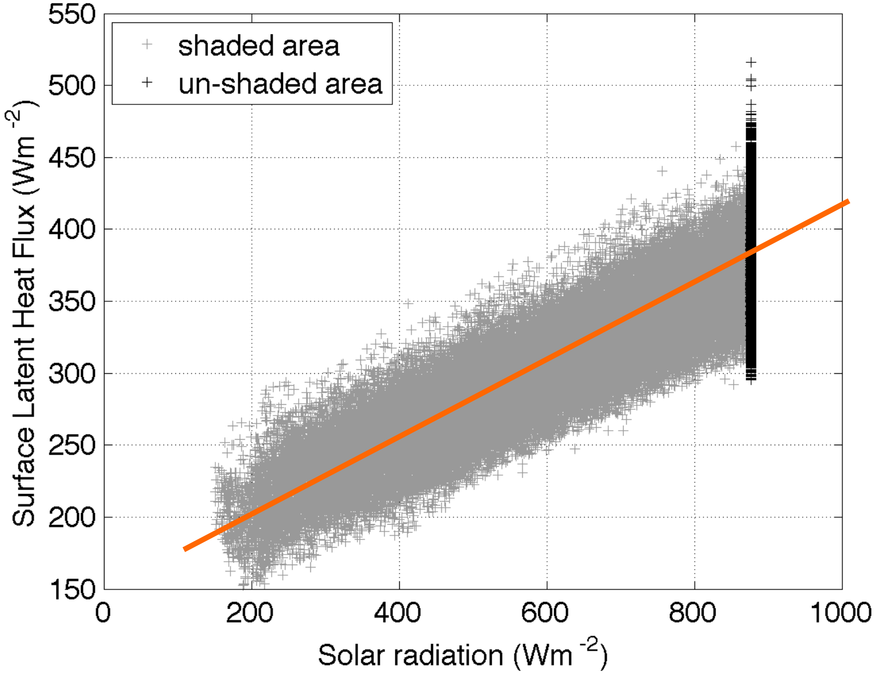
$$C_h = f(z_0, L, \psi)$$

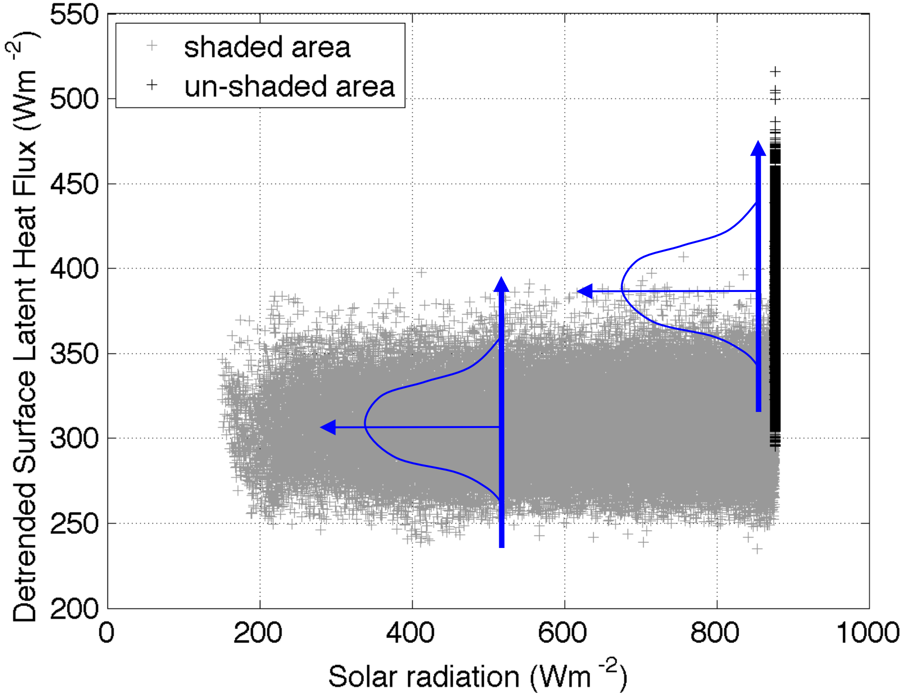
Mean variation of potential evaporation strongly driven by radiative effect.

Cloud-induced turbulence and secondary circulation tend to increase the surface flux variability.

→ Does this variability participate to convection triggering.

At one time step, over the 2D surface





Radiative effect via the

correlation coefficient

SWdn-LE ~ 0.9

SWdn-H ~ 0.98

Turbulent effect via the

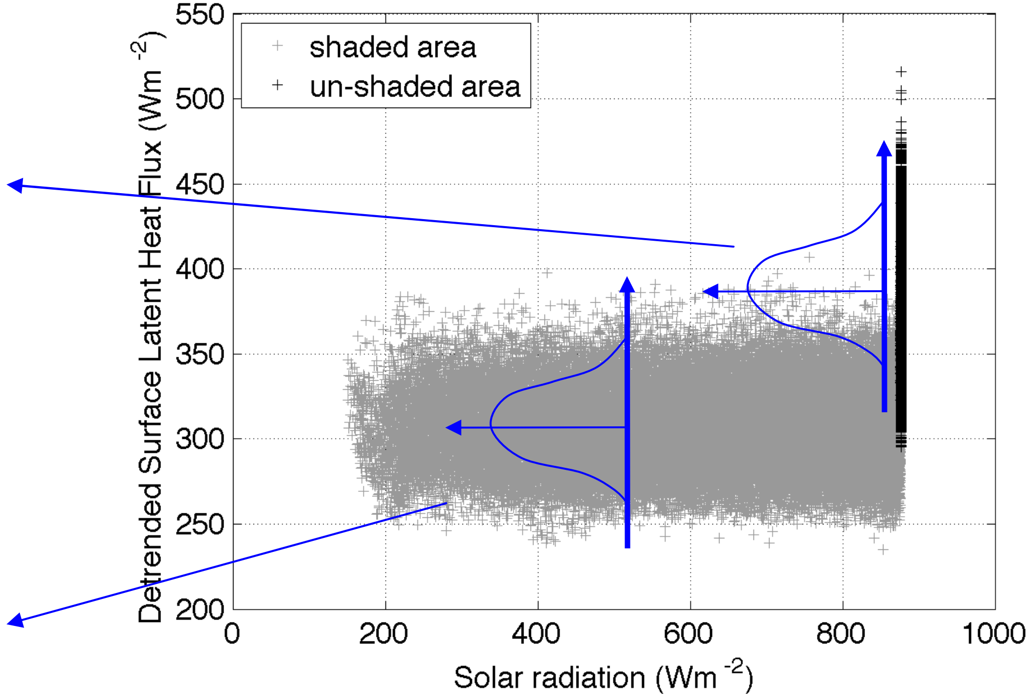
temporal evolution of H and LE distribution

For un-shaded area

$$\frac{\sigma_{F_{US}}}{\langle F \rangle}$$

For shaded area

$$\frac{\sigma_{Fd_S}}{\langle F \rangle}$$



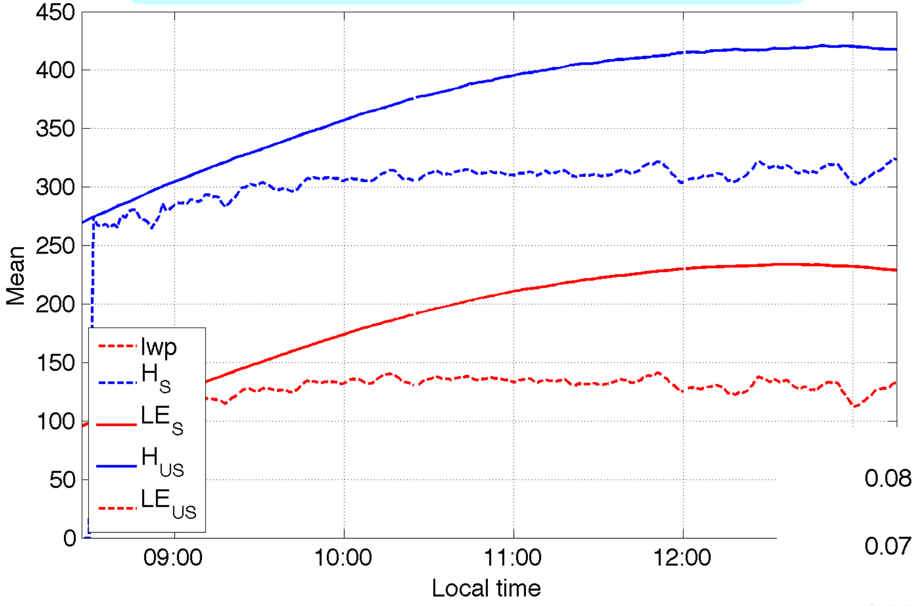
F: H or LE

d: detrended flux

S: shaded area

US: un-shaded area

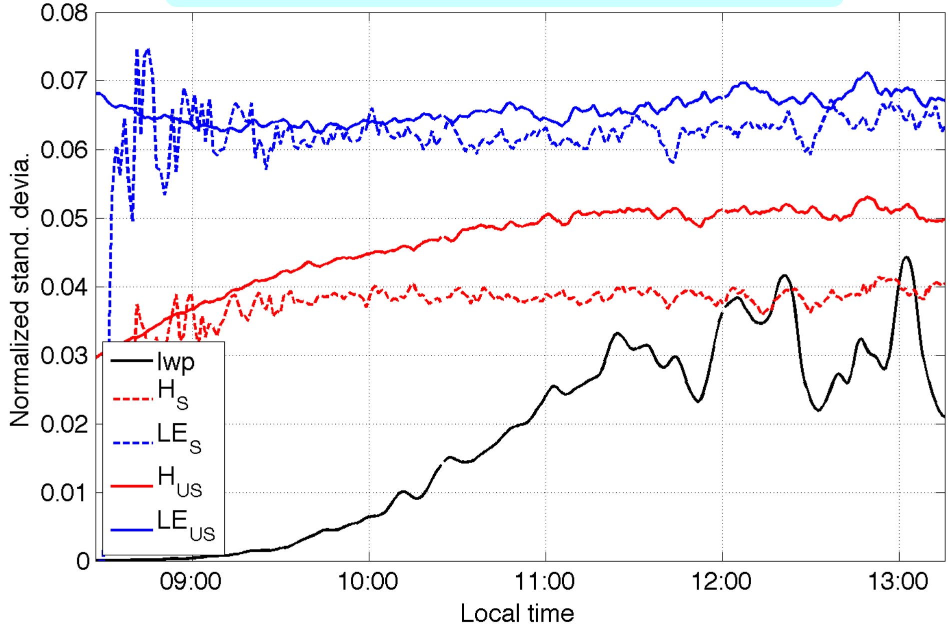
Mean flux



—————— *un-shaded area*

- - - - - - - - *shaded area*

Normalized standard deviation



The secondary circulations and turbulence associated to cloud activity slightly change the surface flux distribution.