THE DIURNAL CYCLE OF CONVECTION
CURRENT KNOWLEDGE

Françoise Guichard (CNRM, Toulouse in France)

diurnal cycle

known by every living entity on the earth

a fundamental mode of climatic variability a wide range of manifestations

solar radiation (!)
surface temperature
land-sea breeze
summer thunderstorms...
(river discharge...)

around Toulouse, May 2004

convection

atmospheric vertical motions

dry : daytime boundary layer

moist : cumulus convection

organization

well known spatial patterns: cloud streets, squall lines...

diurnal cycle : mode of temporal organization

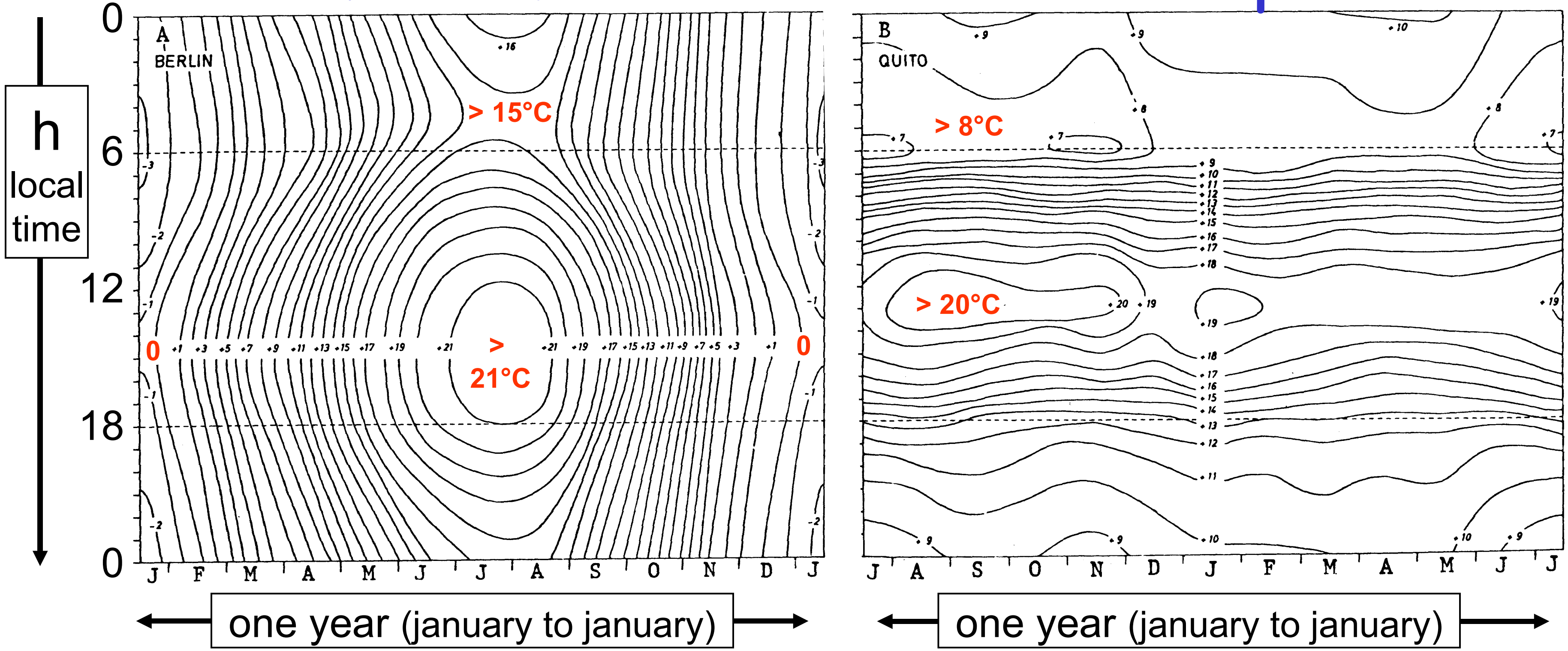
DIURNAL TEMPERATURE RANGE (DTR)

over land *: can be quite large , seasonal & regional variations*

Hastenrath (1985)

Midlatitudes

Tropics



in summer, DTR ~ same range as ATR*
in winter, DTR much weaker
*ATR : annual temperature range

DTR dominates over STR
note: here, at Quito 2850 m ASL
DTR can be greater at lower elevation

DIURNAL TEMPERATURE RANGE (DTR)

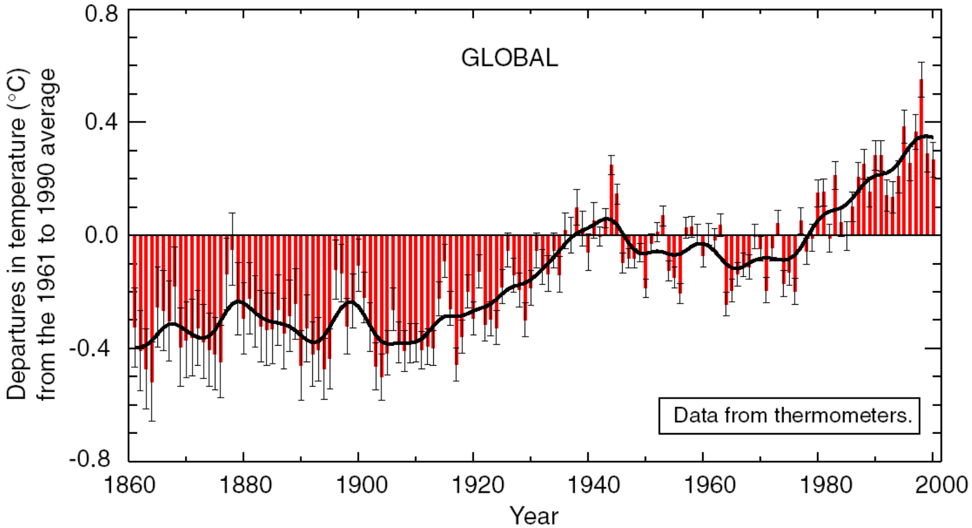
over ocean *: much weaker   (typically less than 1 K)*

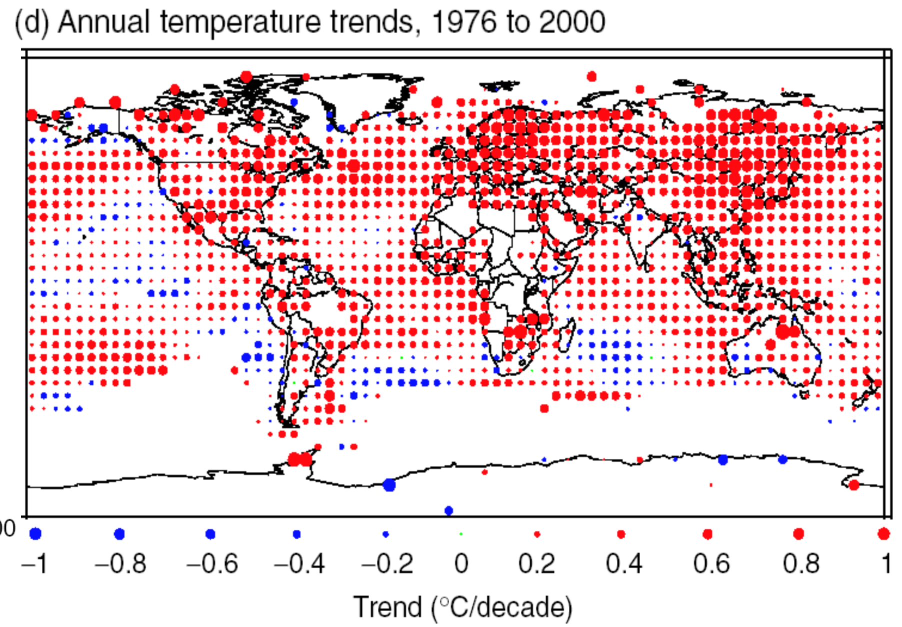
- ✓semi-transparent medium
- ✓strong heat capacity
- ✓vertical mixing

for a 50 m - thick layer : 1 day of solar heating leads to a 0.1 K warming

IPCC 2001

DIURNAL CYCLE AND CLIMATE





« *...daily maximum and minimum land-surface temperatures for 1950 to 1993 ...show that this measure of diurnal temperature range* [DTR] *is decreasing very widely, although not everywhere*. <u>On average, minimum temperatures are increasing at about twice the rate of maximum temperatures (0.2 versus 0.1°C/decade).</u> »

...

« The decrease in the continental diurnal temperature range coincides with increases in cloud amount, precipitation, and increases in total water vapour. »

reasons for/factors involved in/ this DTR change still to be understood

convective processes: role in this change (?) sensitivity to it (?)

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- Introduction
- a brief summary of surface radiative and energy budgets
  diurnal variations
- the growing daytime convective boundary layer over land
- the diurnal cycle of moist convection : mechanisms
  - mechanisms over land
  - mechanisms over ocean

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the diurnal cycle of deep convection

❑ over land

✓strong

in the Tropics year round

in the Midlatitudes in summer

(depending on the sources, variable, several tenths of %)

✓afternoon-evening maximum

modulated by regional effects, orography, regimes (E/W LBA), life cycle of MCSs

some recent papers suggest changes in the last decades over the US

❑ over ocean

✓weaker but still significant *(numbers more ~ 10%)*

✓early morning peak *(variations / regime, life cycle of MCSs)*

but also...

diurnal cycle of stratocumulus (typically thicker deck at night)

(mechanisms involves cloud radiation interactions, + more recently, suggestion of a role of a diurnal cycle of the large-scale subsidence)

diurnal cycle of fair weather cumulus over land (not much)

a few local studies

ISSUES

- **understanding the mechanisms**
  - ✓ situation is worse for deep convection over ocean
  - ✓ still a number of questions over land

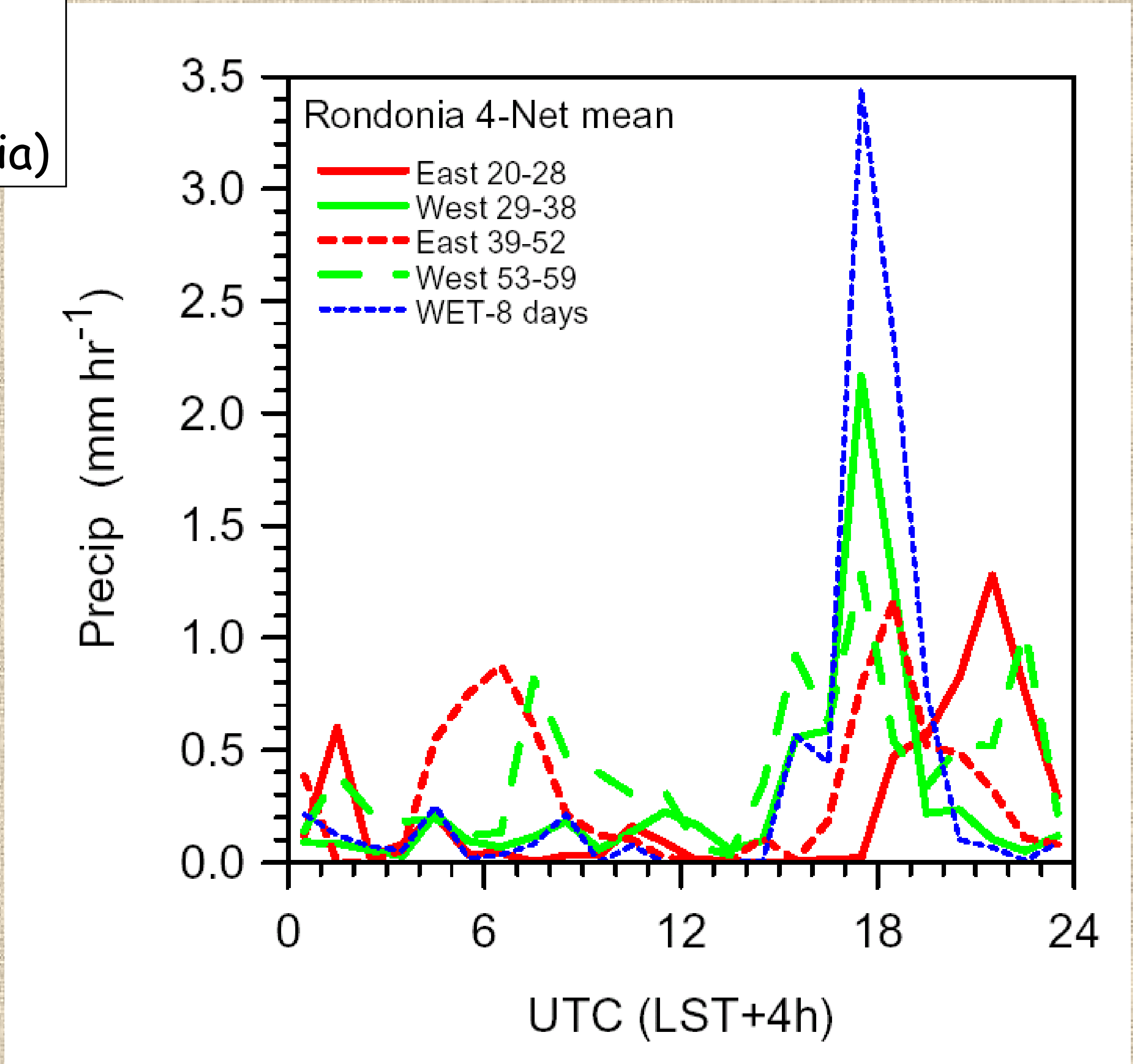
- **quantification (measurement)**
  - ✓ local measurement (rain gauges, lighting, radars ...)
  - ✓ satellite passive sensors (IR)

    very good sampling, but indirect: cloud top temperature
  - ✓ more recently active sensors on board satellite (TRMM*)

    precipitation radar + microwave cloud imager

    not as good sampling, statistics over long periods

**TRMM : tropical rainfall measuring mission (lauched in 1997)* analysis from field campain data (LBA, Amazonia)

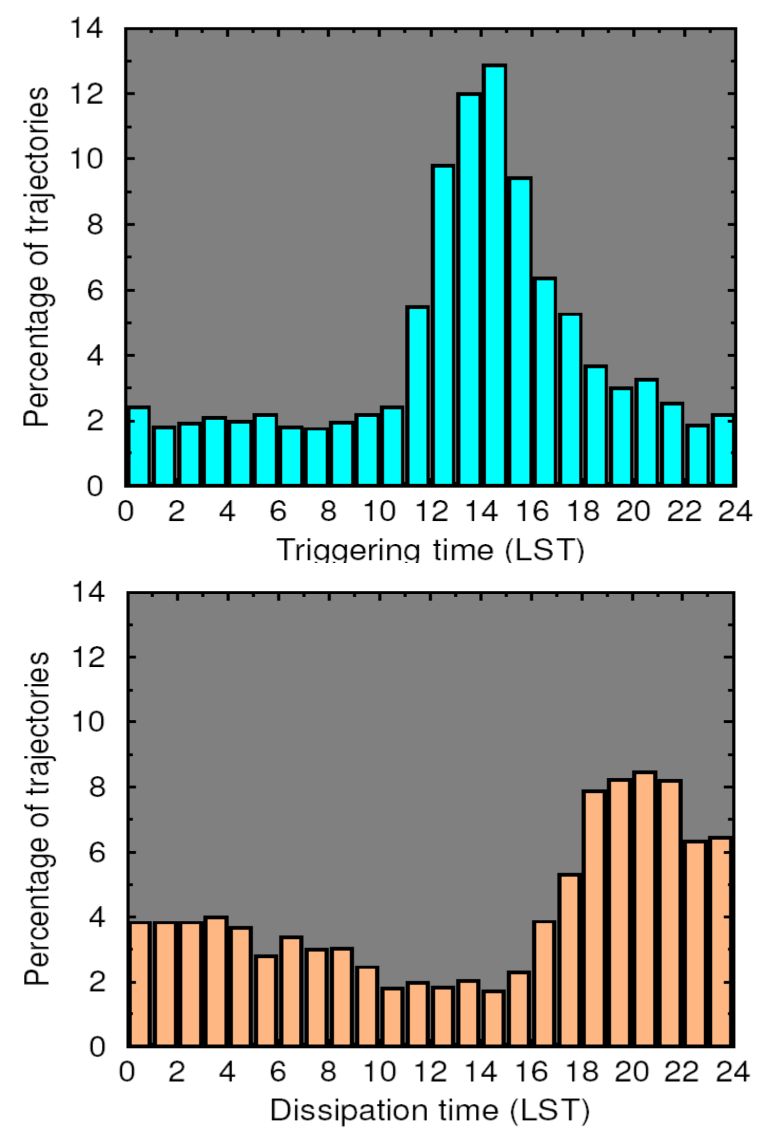


Betts & Jakob (2002)

Morel & Senesi (2002)

for MCS over Europe
in summer
(IR satellite data)

method: tracking systems

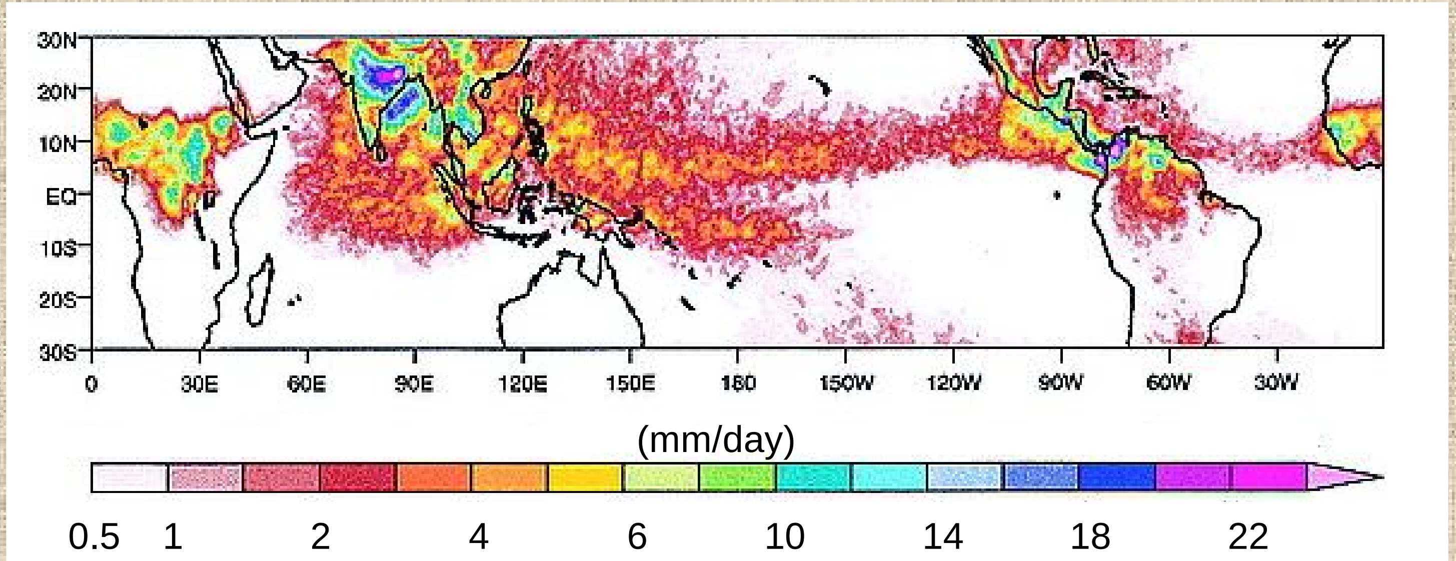


Yang & Slingo (2001)

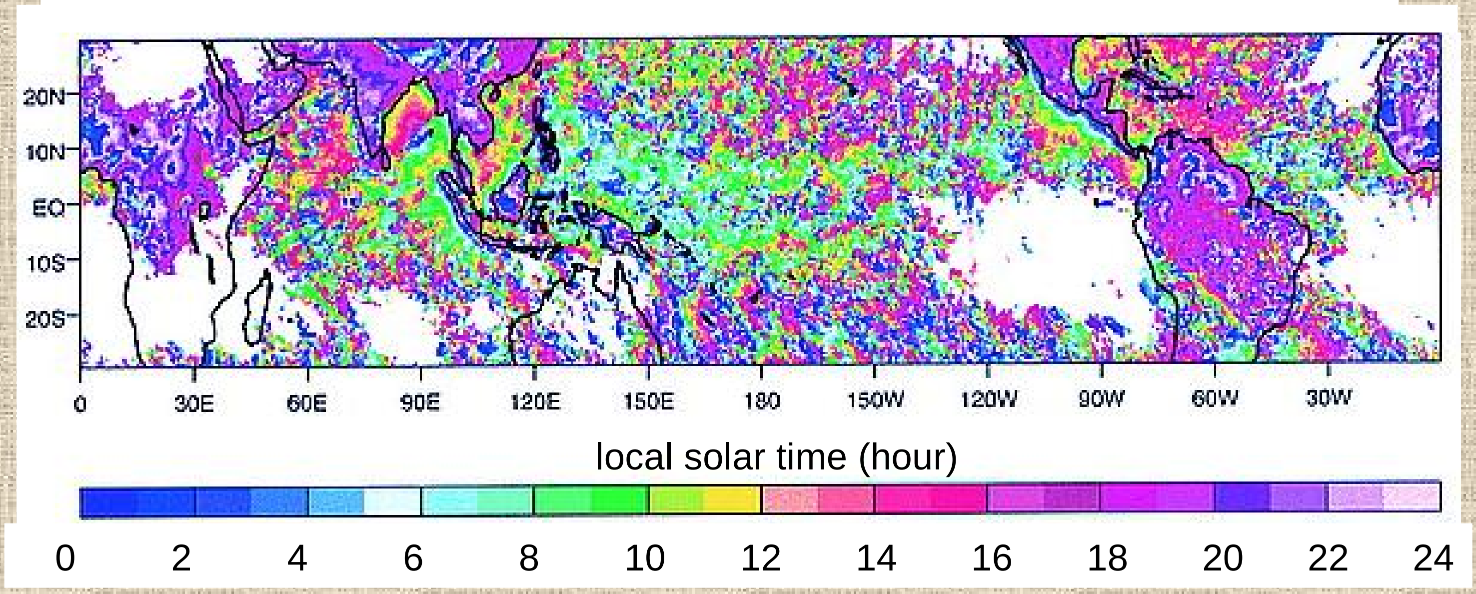
estimated precipitation (from **observations**)

satellite data, CLAUS project, summer 1985,86,87,92

amplitude of the diurnal harmonic



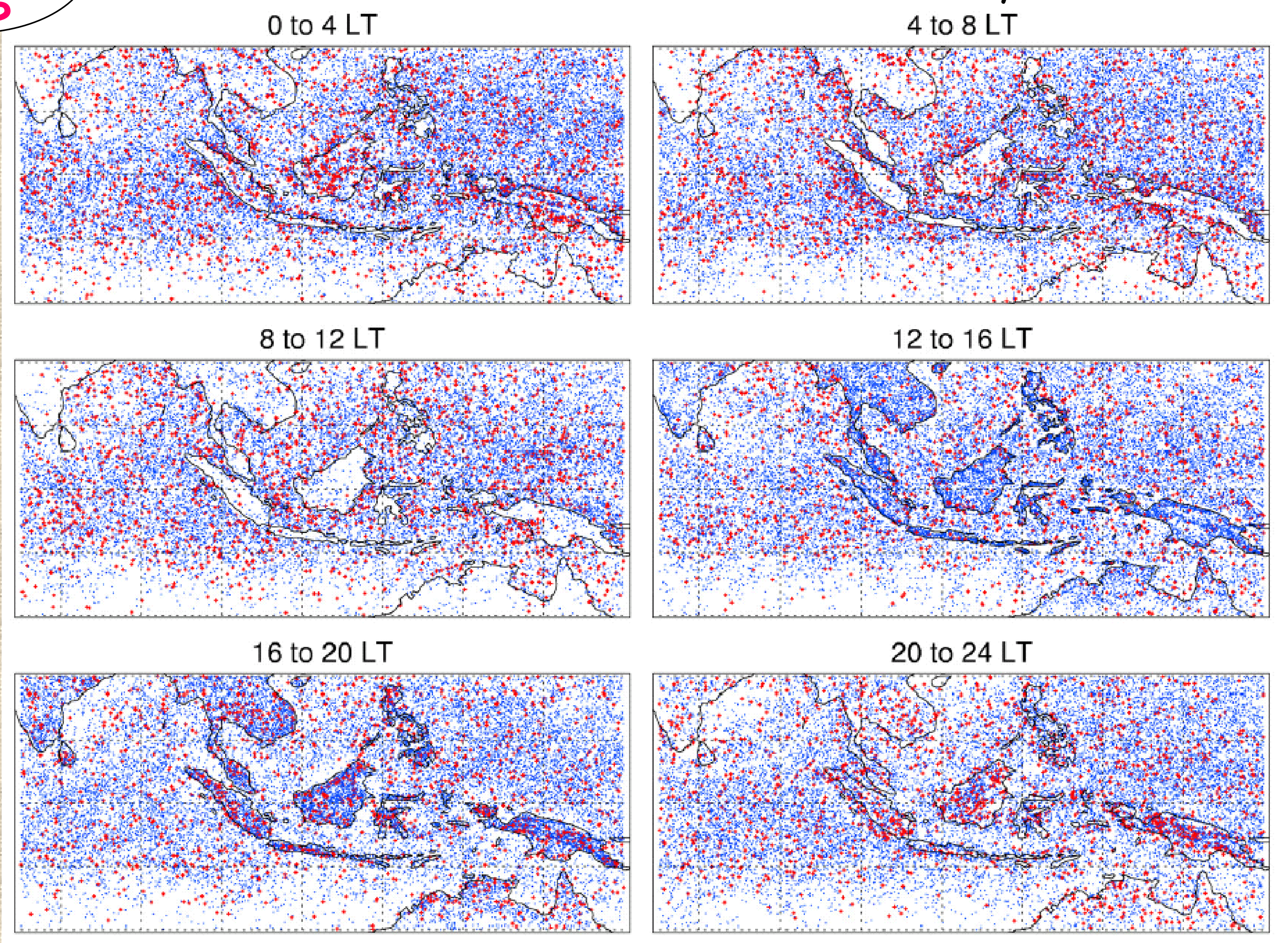
phase of the diurnal harmonic



TRMM data, Nesbitt & Zipser (2003)

deep convection
MCS

from 3 years of data



note the whitening of continental areas in the morning & bluing in the afternoon

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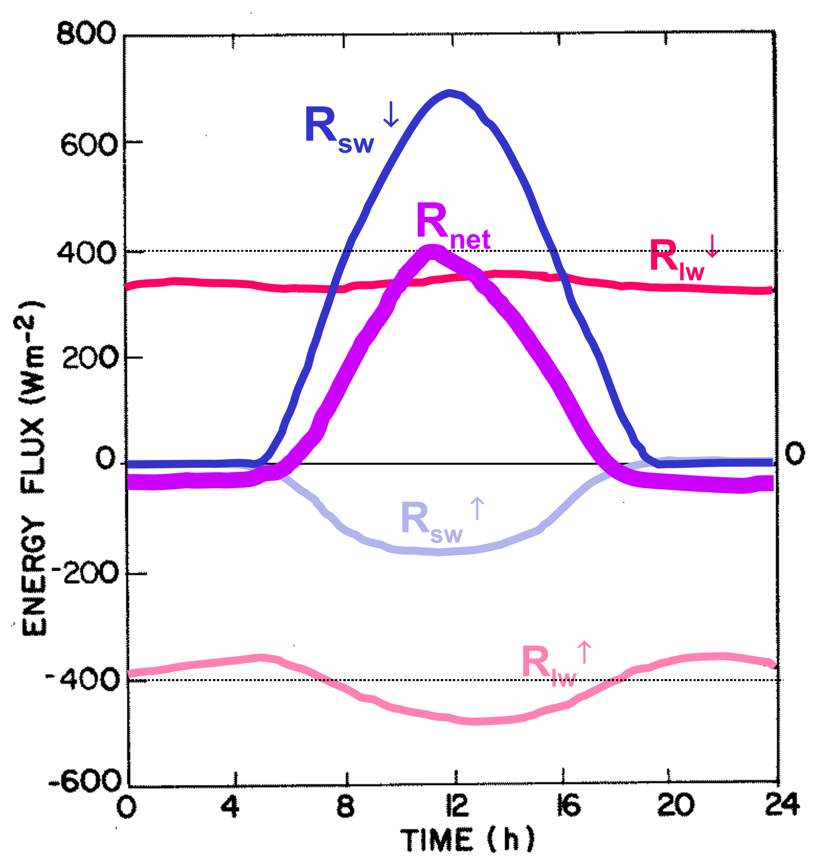
SURFACE RADIATIVE BUDGET

net radiative heat flux : R_{net}
longwave : lw
shortwave : sw
albedo : a

$$R_{net} = R_{lw} + R_{sw}$$

$$= (R_{lw}\uparrow + R_{lw}\downarrow) + (R_{sw}\uparrow + R_{sw}\downarrow)$$

$$R_{net} = (R_{lw}\uparrow + R_{lw}\downarrow) + (1-a)\, R_{sw}\downarrow$$



clear sky day of August
native grass, Matador, Canada (DTR ~2°C)
from Oke (1987)
after Ripley & Redmann (1976)

SURFACE ENERGY BUDGET

$$Rn \approx H + LE + G$$

H: surface sensible heat flux
LE: surface latent heat flux
G: flux under the surface

various space and time scales of variability of this budget

Bowen ratio = H/LE

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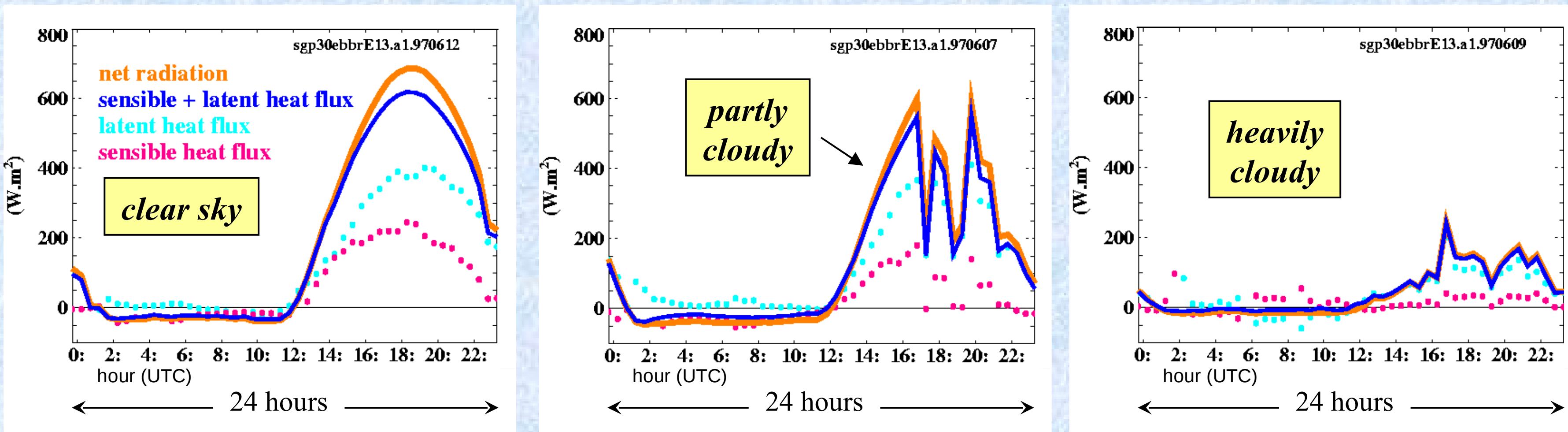
well known (felt) day to day variability associated with clouds



surface fluxes measurements, ARM SGP site (Southern Great Plains USA), 12, 7 & 9 June 1997

contrasted day/night cloud-radiation interactions (lw/sw)
surface: magnitude & partition of sensible/latent heat fluxes (via cloud albedo, rainfall)

SURFACE ENERGY BUDGET

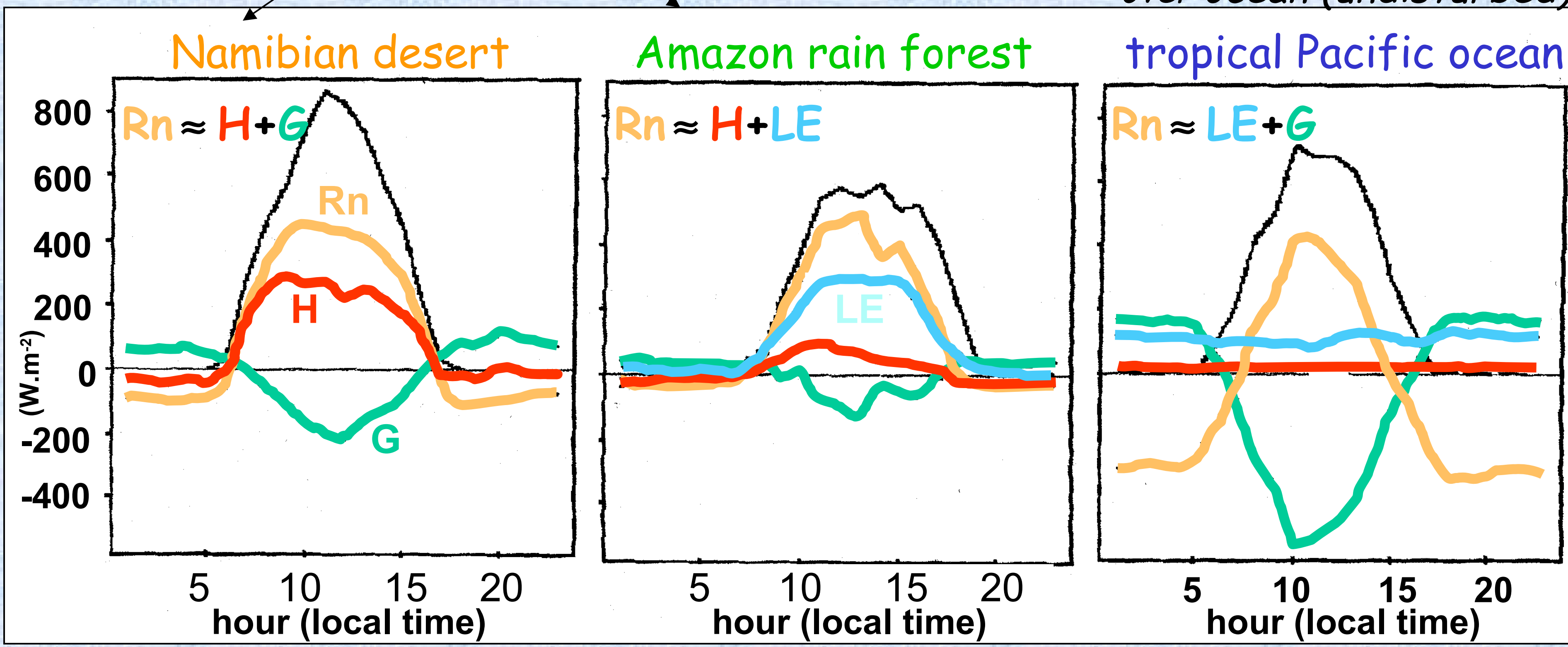
$$Rn \approx H + LE + G$$

H: surface sensible heat flux
LE: surface latent heat flux
G: flux under the surface

3 typical & contrasted examples

over land

over ocean (undisturbed)



adapted from Garstang and Fitzjarrald (1988)

!!! small flux does not mean unimportant flux, e.g., H for stratocumulus regime

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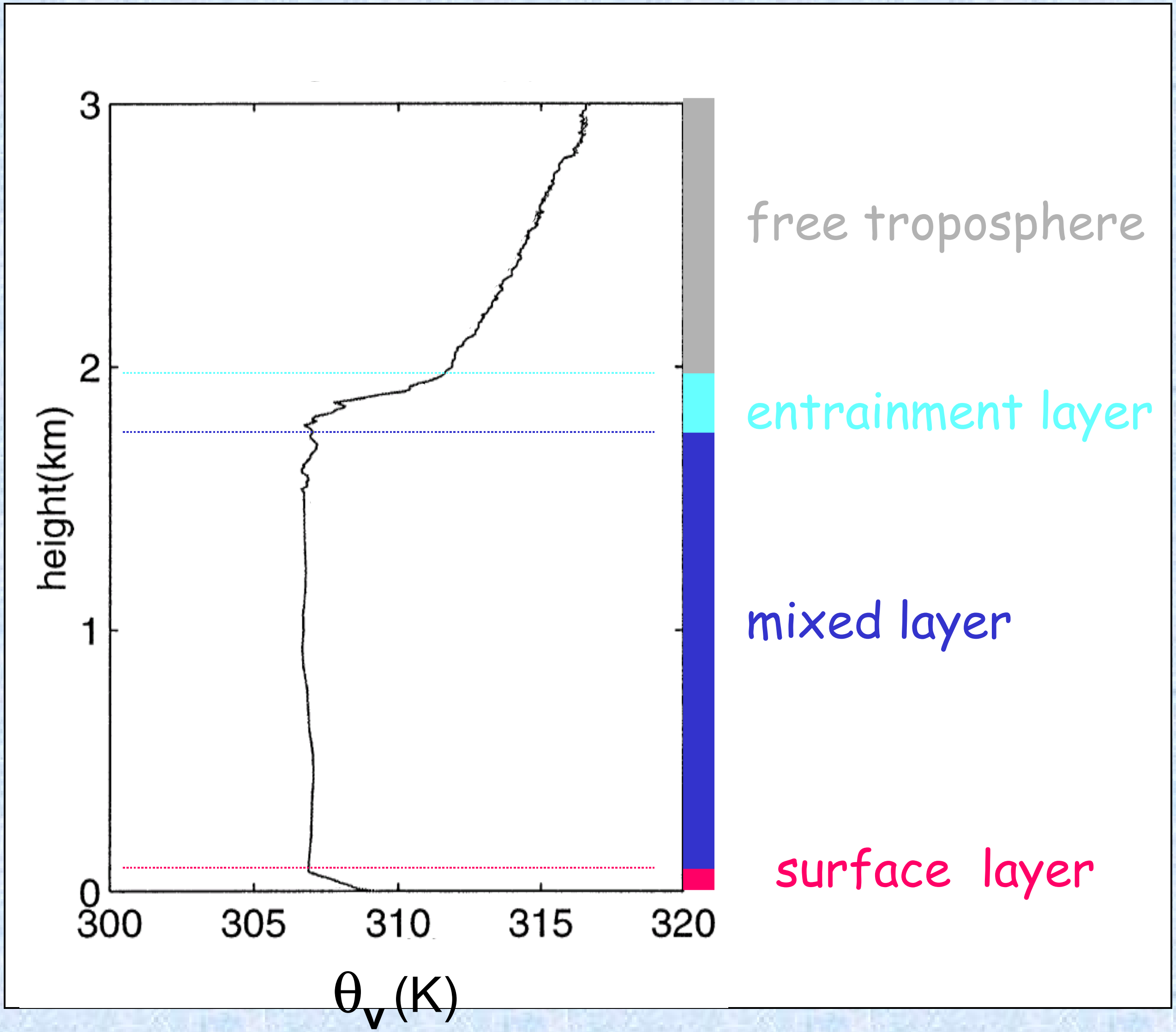
the convective boundary layer

an archetypal example (sounding data)



adapted from Zhu and Albrecht (2002)

convective boundary layer vertical structure as seen from radar

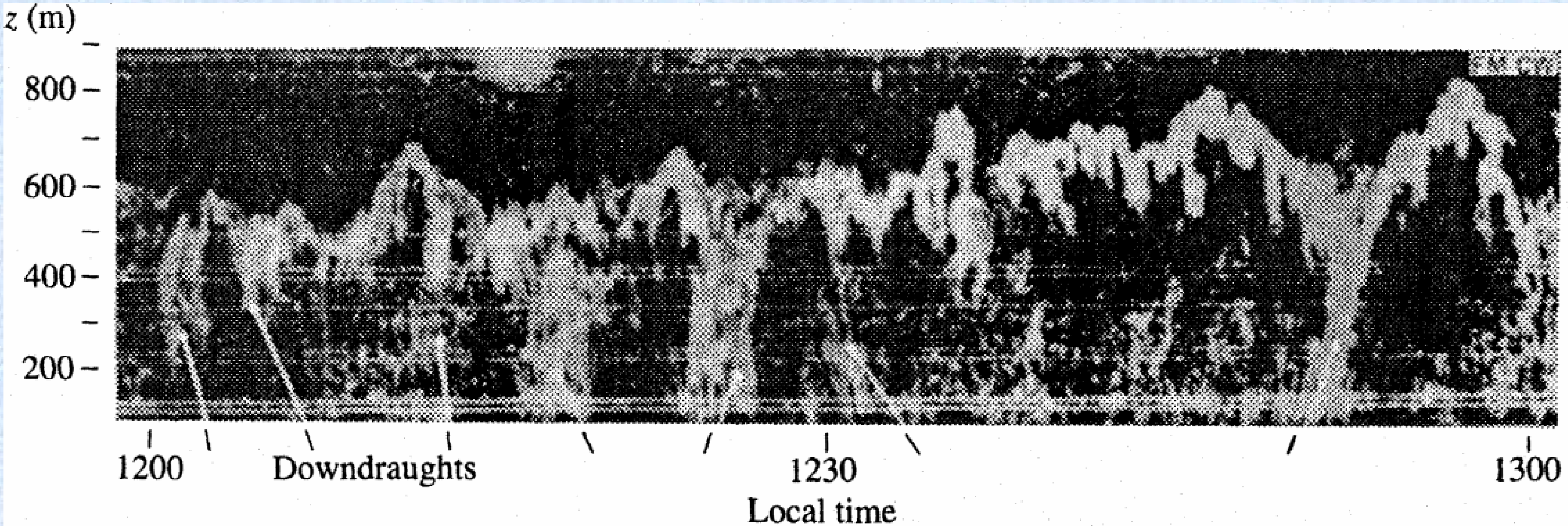
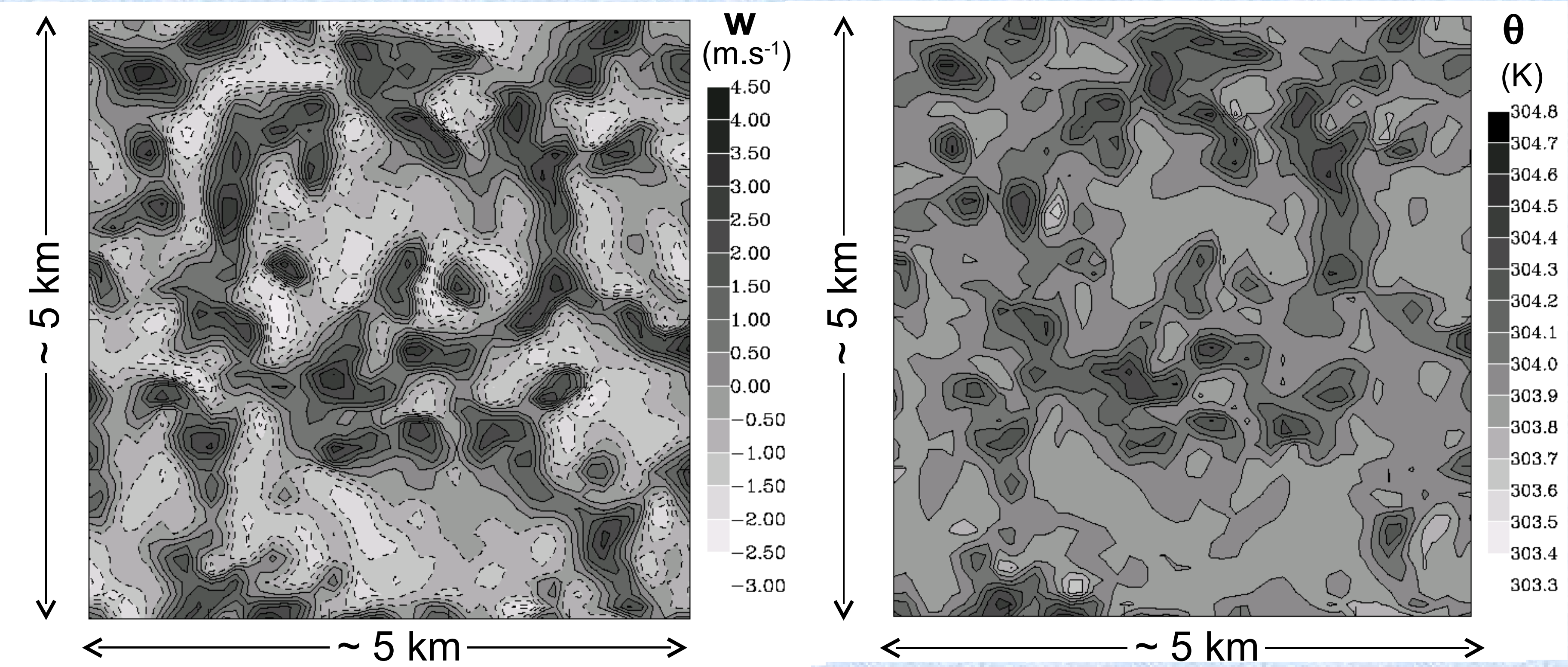


figure from Garrat (1992) book, from Rowland & Arnold (1975)

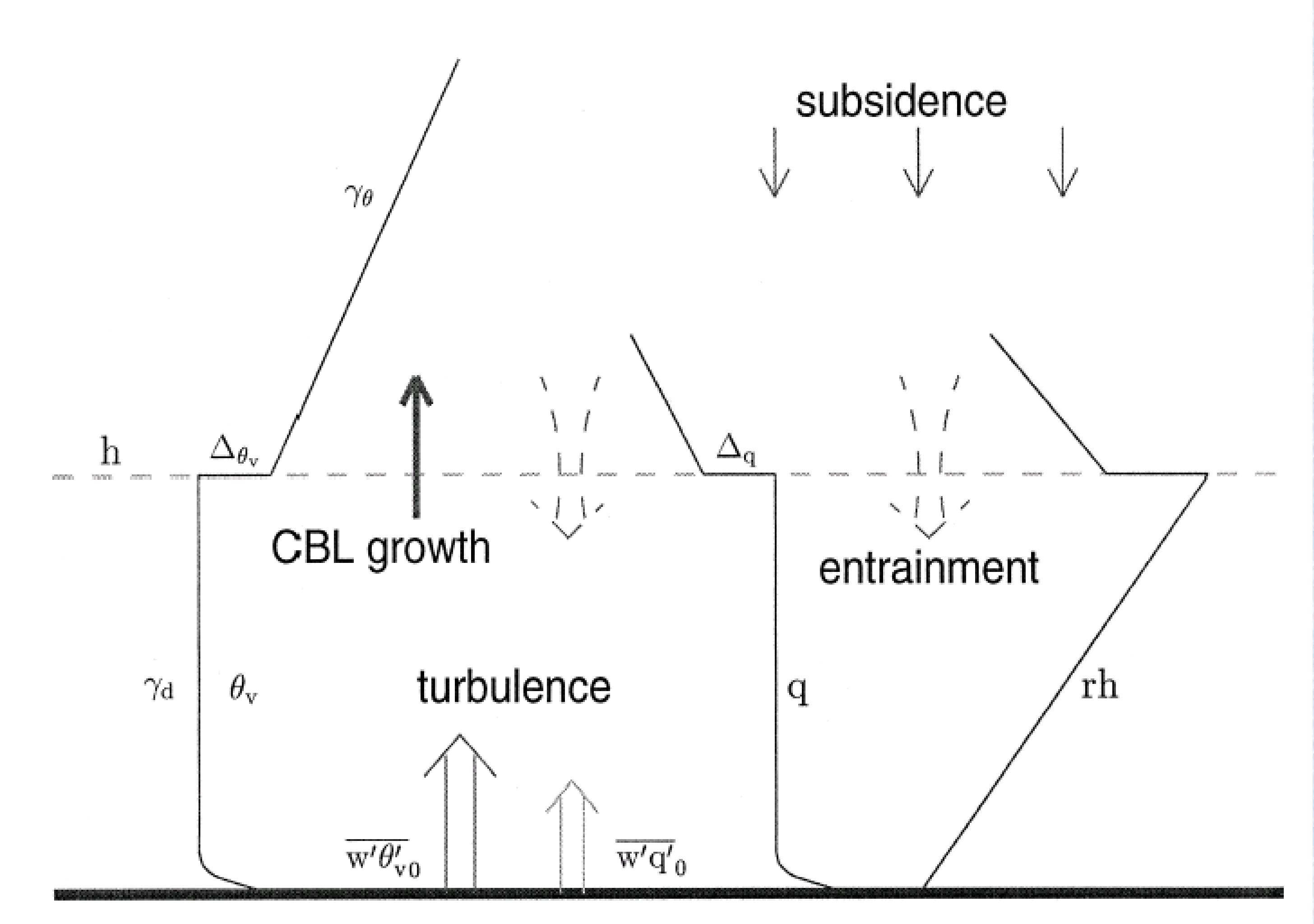
horizontal cross section in the middle of the convective boundary layer

LES results (Couvreux et al. 2004)*
thermals (w > 0, θ' > 0) organized in open cells



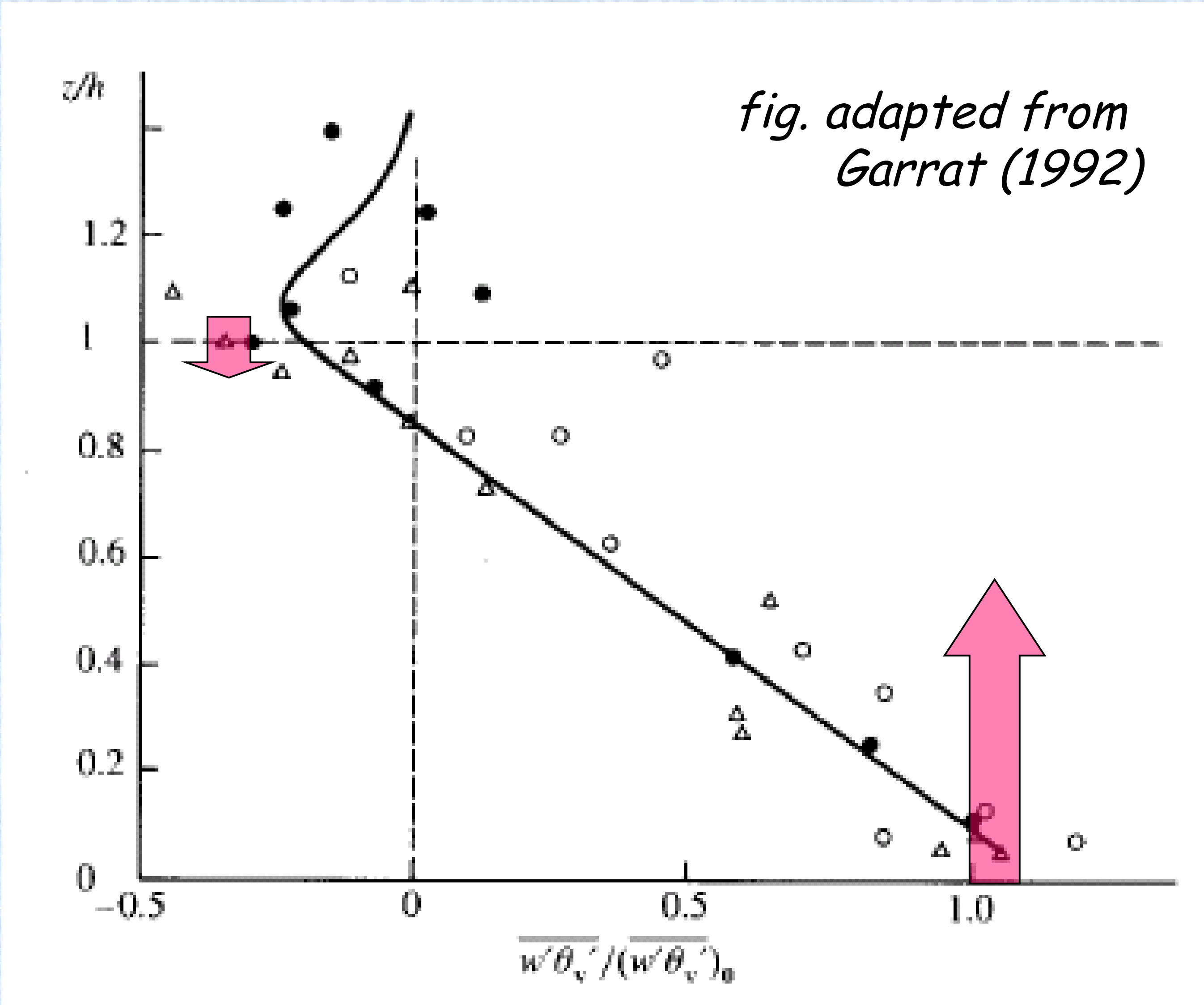
*LES : large eddy simulation
(numerical simulation with resolution: $\Delta x \sim 100$m, $\Delta z \sim 10$ to 50 m

mixed layer model



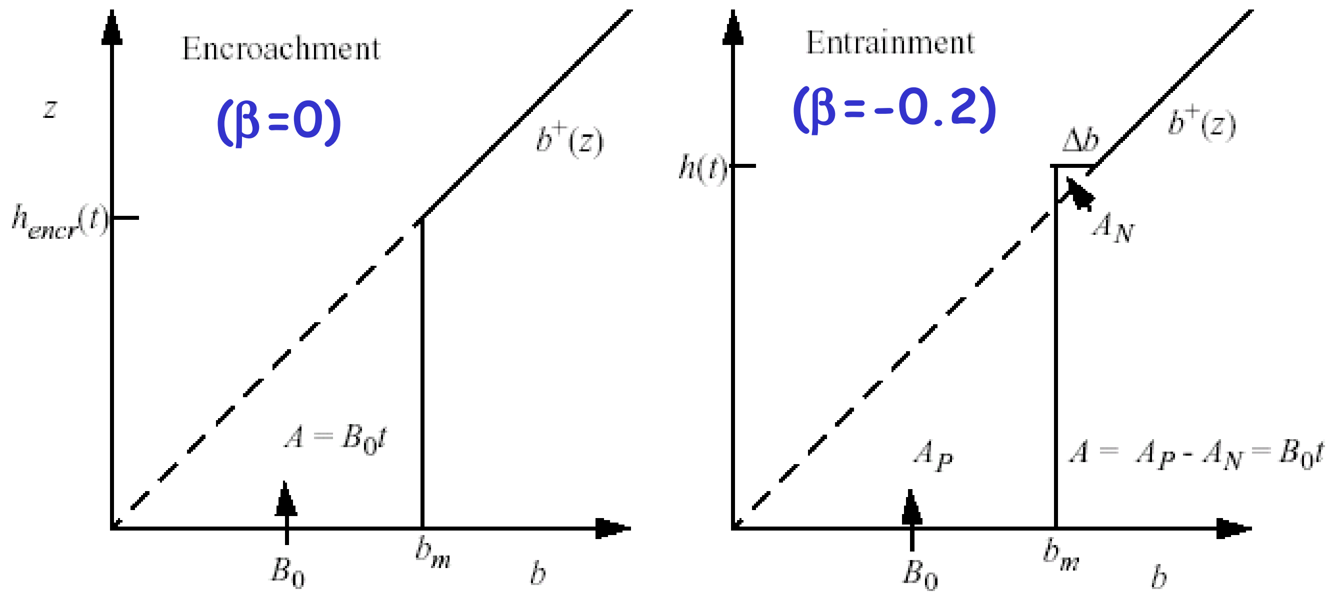
scheme from Zhu and Albrecht (2002)

normalized buoyancy flux in a convective boundary layer



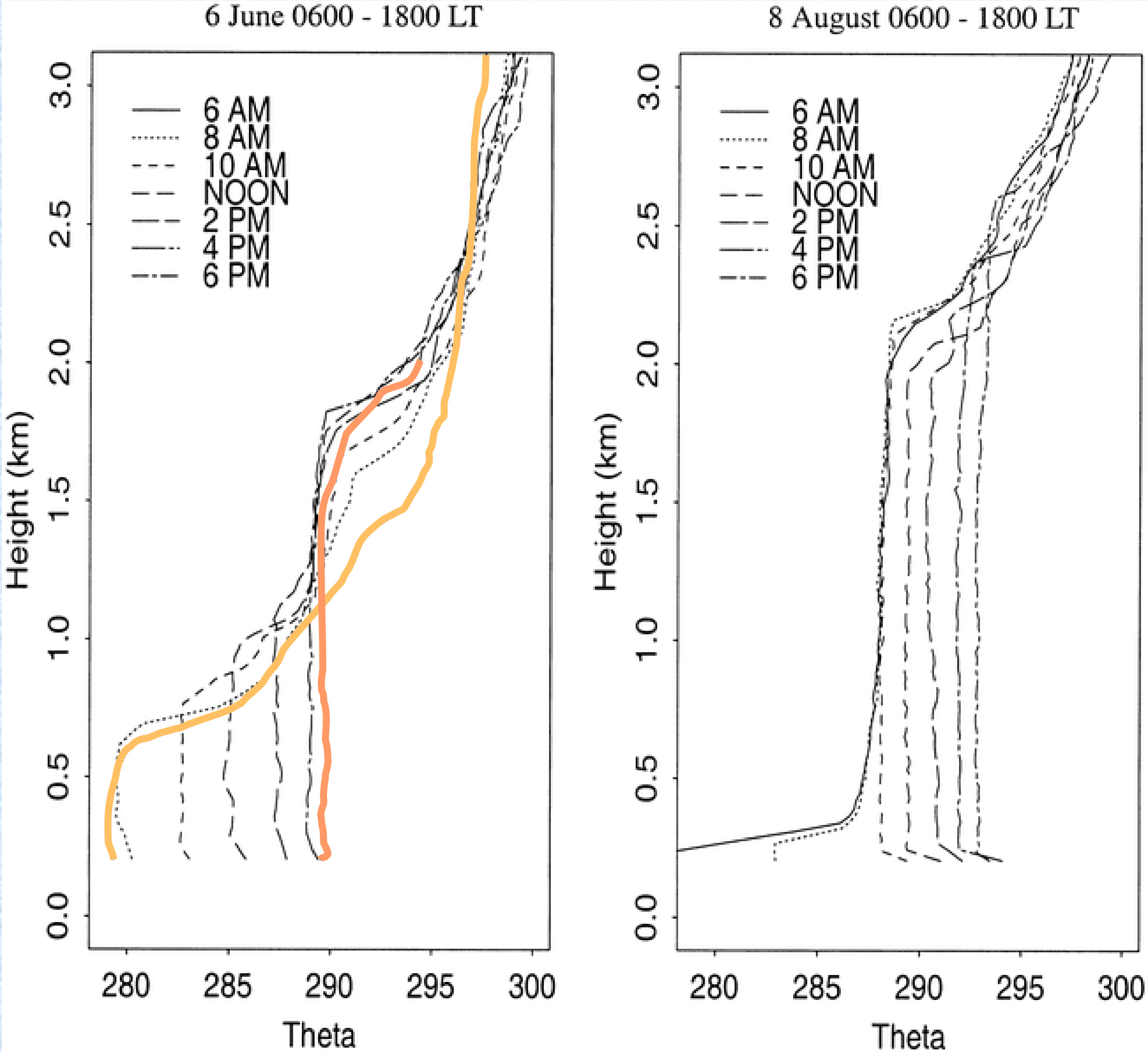
$$\overline{w'\theta'}_v(h) \approx -0.2\,\overline{w'\theta'}_v(0)$$

from Garrat (1992)

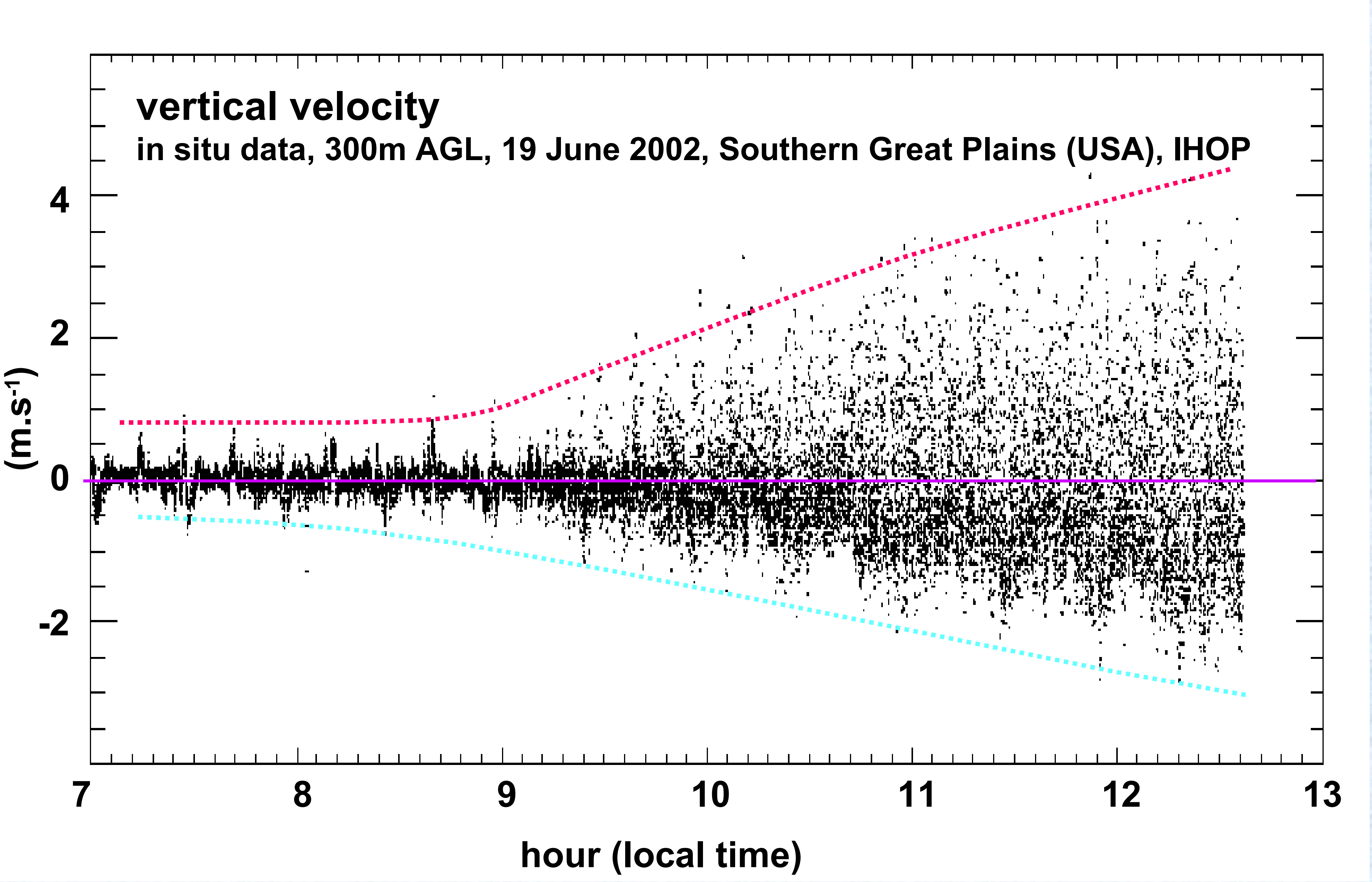


Convective mixed layer evolution illustrating more rapid deepening if entrainment is assumed to be penetrative (β = 0.2), compared to encroachment (β = 0).

every day, a new convective boundary layer is growing

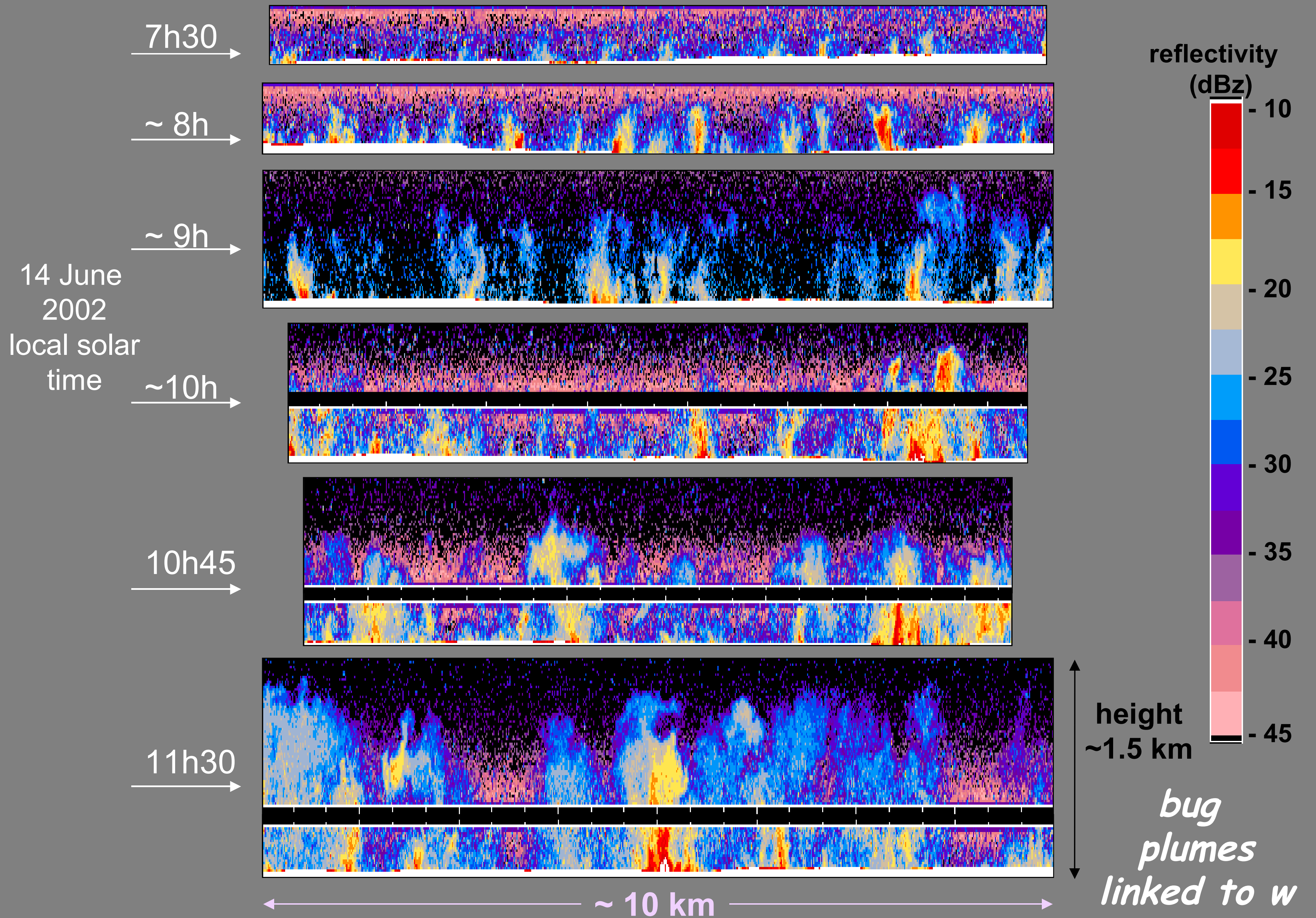


Freedman & Fitzjarrald (2001)



Couvreux et al. (2004)

Boundary layer development: radar data (t-x,z), courtesy of B. Geerts



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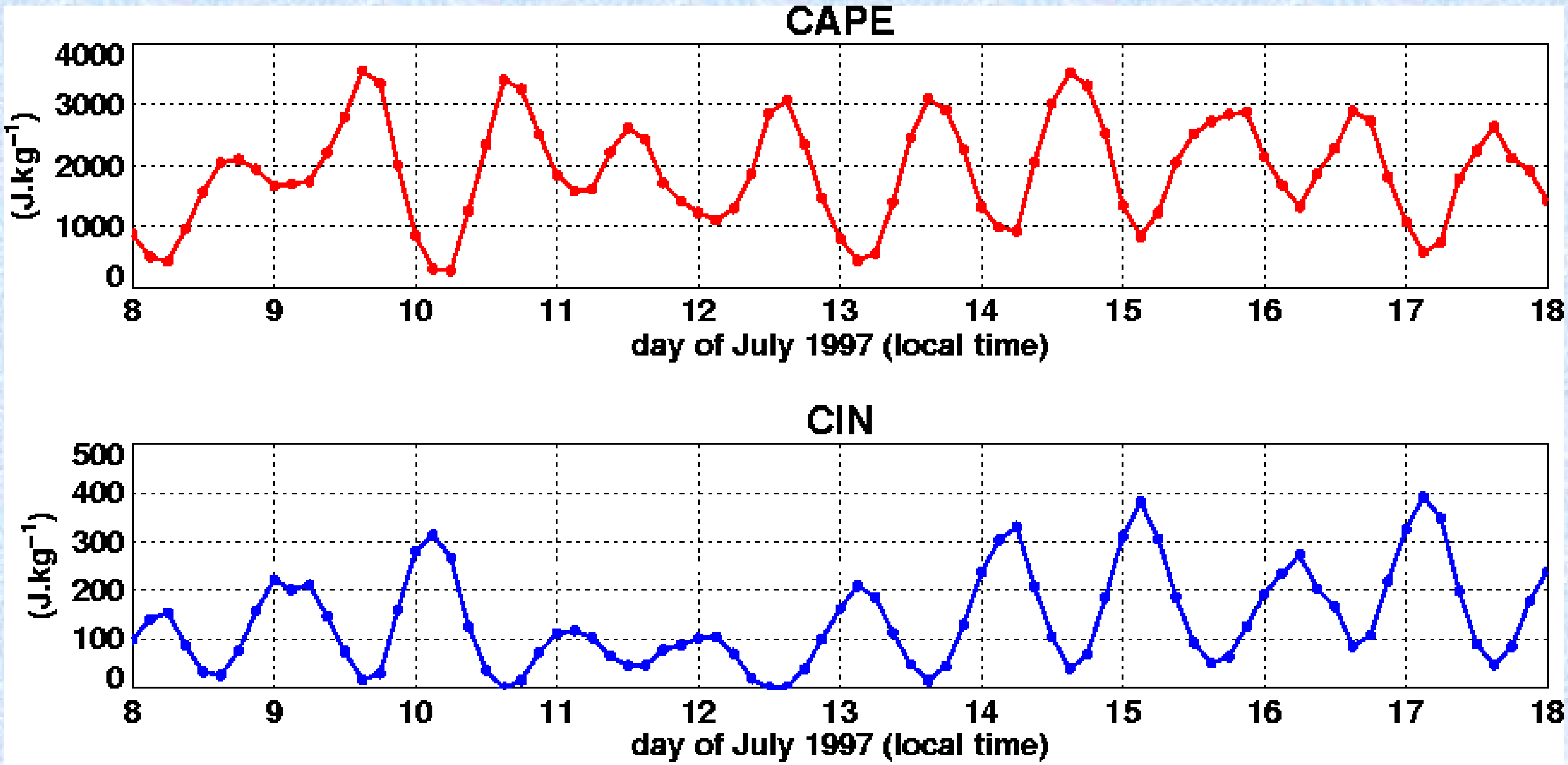
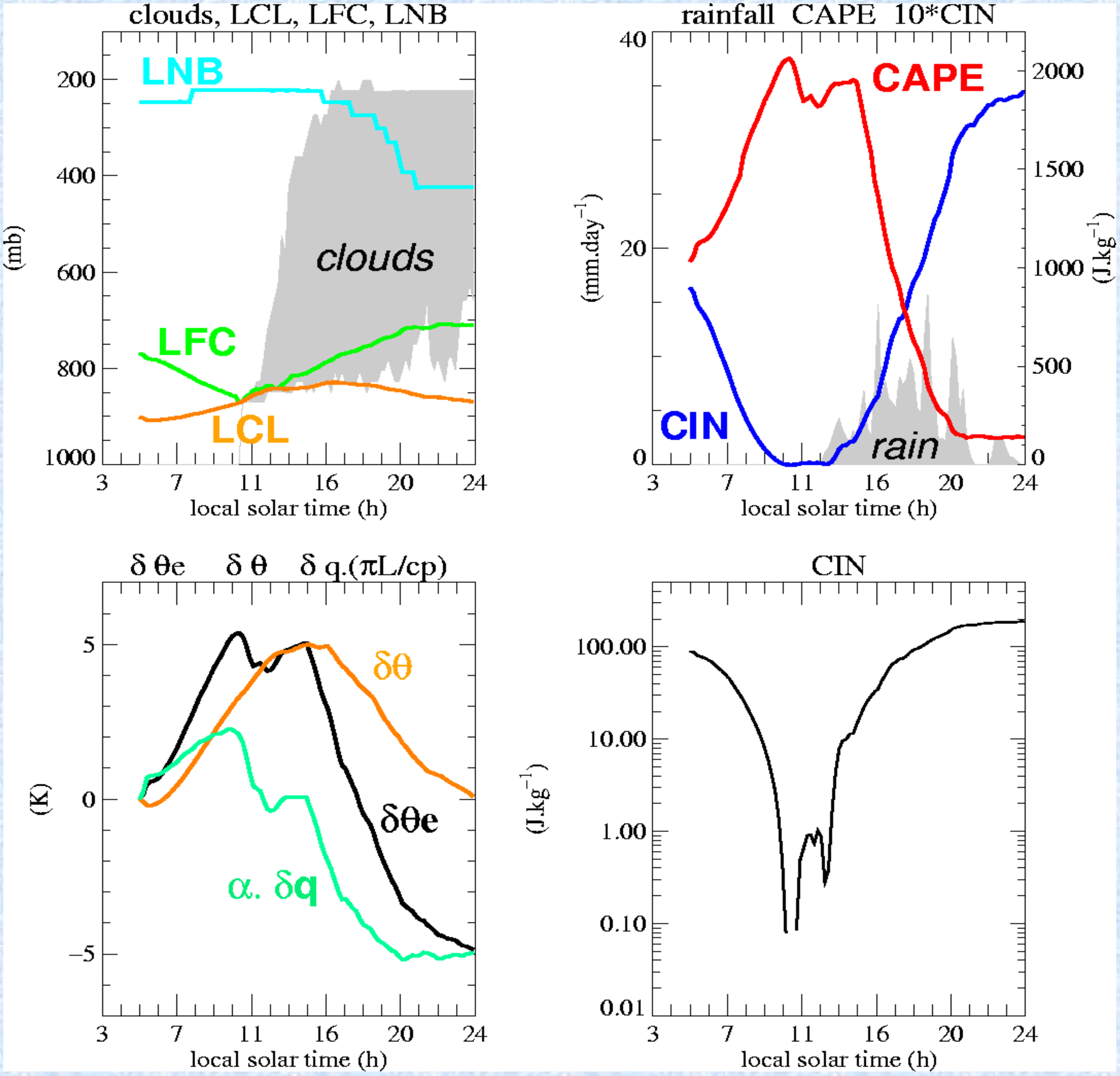
mechanisms for the diurnal cycle of convection over land

boundary layer destabilization by daytime insolation
(i.e. local mechanism) as a major explanation

see Wallace (1975)



an illustrative example, CAPE & CIN variation over the Southern Great Plains (USA) in summer (computed from the 3-hourly dataset provided by Zhang - cf. Zhang et al. 2001)



CRM results
Guichard et al. (2004)

a number of questions remains...

build up of convection :

which factors control the lenght of this phase?

role of buoyancy, wind shear, moisture...

role of processes occuring during nighttime?

impact of the life cycle of MCS or even larger systems *(Carbone et al. 2002)* **?**

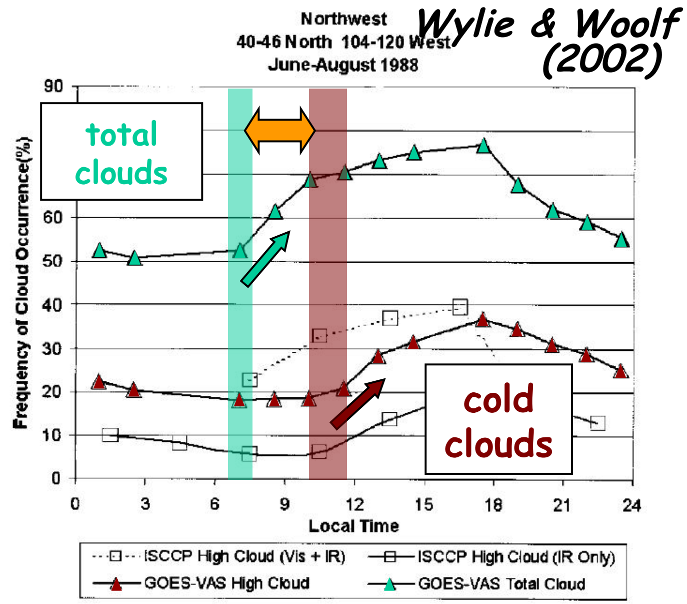


FIG. 4. The frequency of clouds in the northwestern United States during Jun–Aug 1988.

continental scale of the diurnal cycle of deep convection?

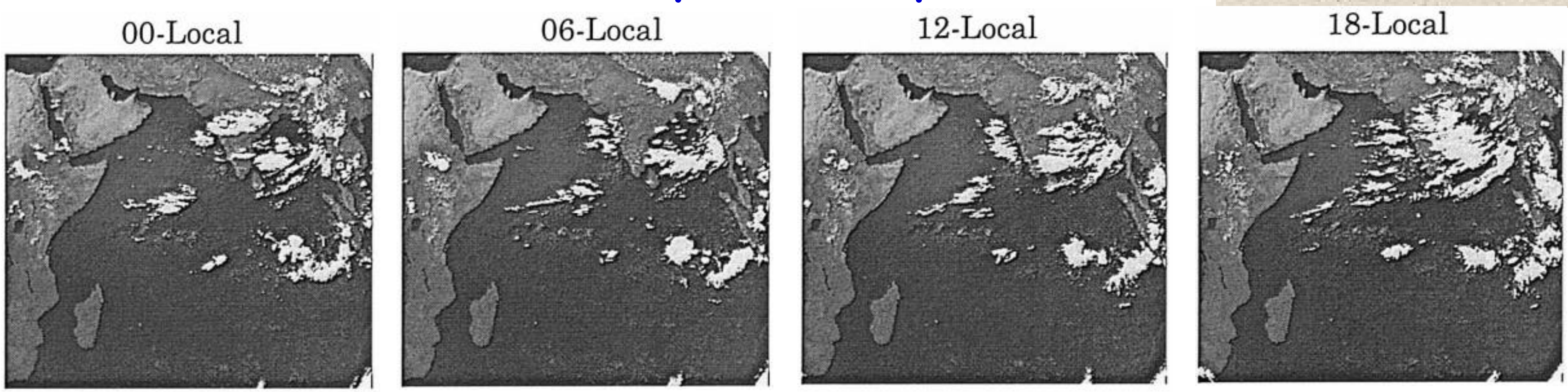


FIG. 3. Diurnal fields of OLR for deep convection (for cloud-top temperatures less than −40°C) for 27 July 1998. The four panels show OLR fields for 0000, 0600, 1200, and 1800 LT (*local time* refers to approximate local time over central India).

Krishnamurti & Kishtawal (2000)

mechanisms for the diurnal cycle of convection over ocean

radiation – dynamics – convection interactions
differential heating between cloud free and cloudy area, inducing day-night differences in vertical motions (Gray & Jacobson 1977)

radiation-convection interactions
in the upper part of clouds more solar absorption during daytime (stabilization) and more cooling during nighttime (destabilization) (Randall et al. 1991)

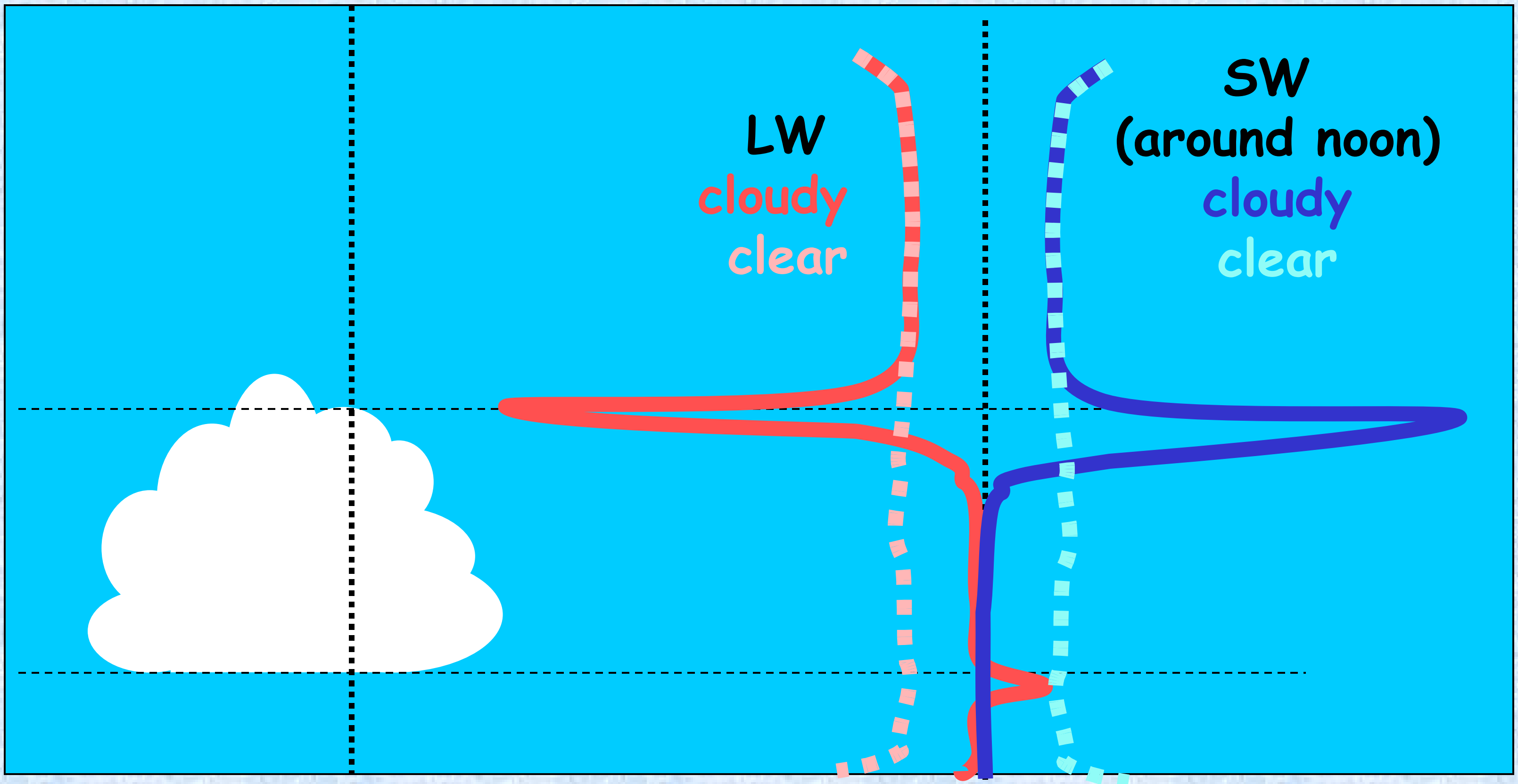
remote influence of continents
land breeze, & more recently, gravity wave forcing,Yang and Slingo (2000), Mapes et al. (2003)

+ role of diurnal tides emphasized in some past studies

more recently, larger role devoted to surface processes
complex mechanisms involving surface diurnal cycle and MCS life cycle
e.g., Chen et al. (1997) also, variation of the diurnal cycle of rainfall depending on the regimes during COARE (experiment over the tropical Pacific) e.g. Parsons et al. (2000)

a few CRM analyses have been done (Liu et al., Sui et al.); more could be done
we are far from a consensus... + it is very likely that more than one of the above mechanisms are responsible for the observed diurnal cycle over ocean...

schematic profiles of LW and SW radiative heating rates under clear and cloudy (one cloud only there) conditions



(typical values for clear sky) ⟶ -2 0 2 *(K. day^{-1})*

top of clouds: SW & |LW| up to several tens of K.day^{-1}

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<u>See also, among others</u>

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