Daytime convective development over land: the role of surface forcing

Wojciech W. Grabowski

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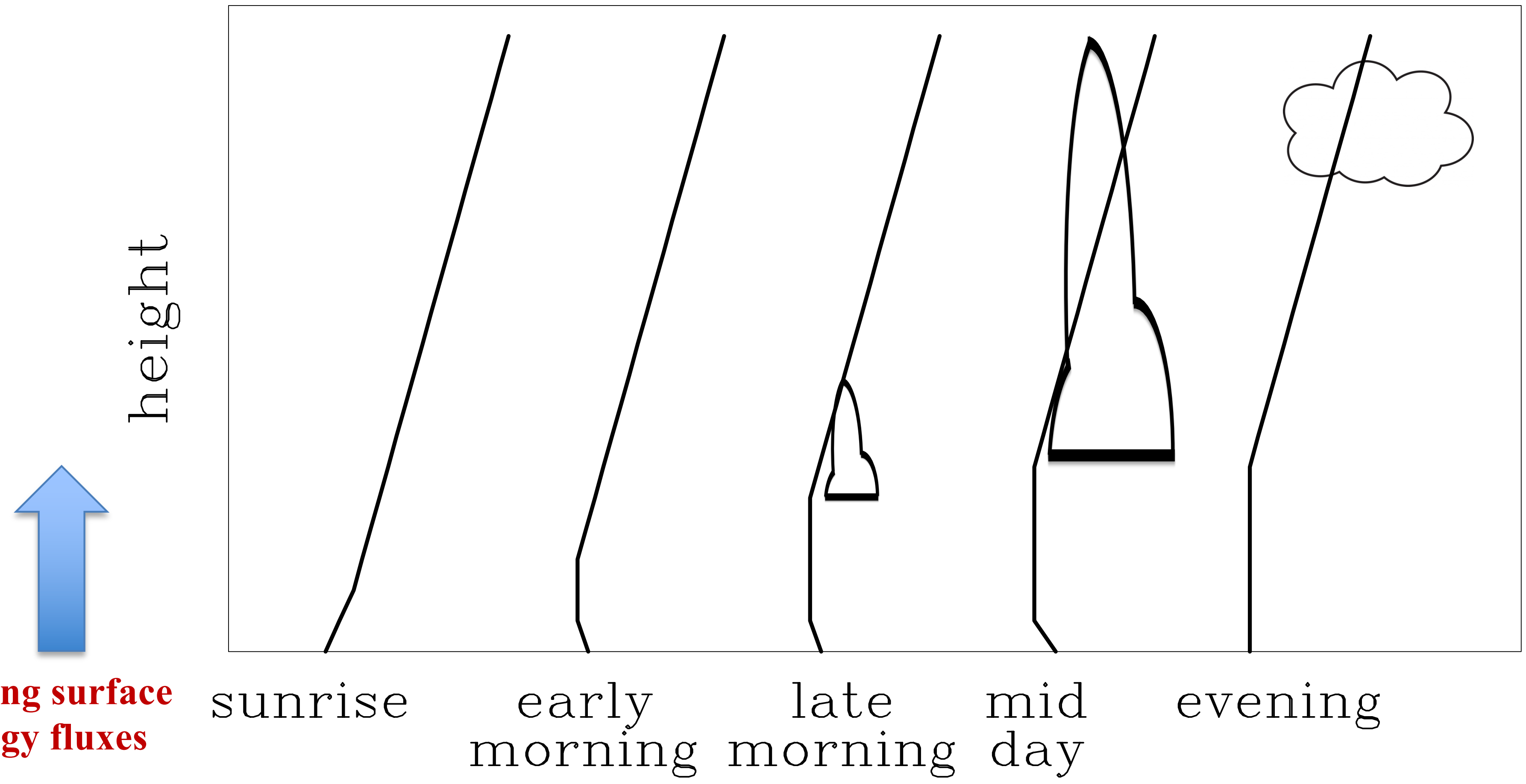
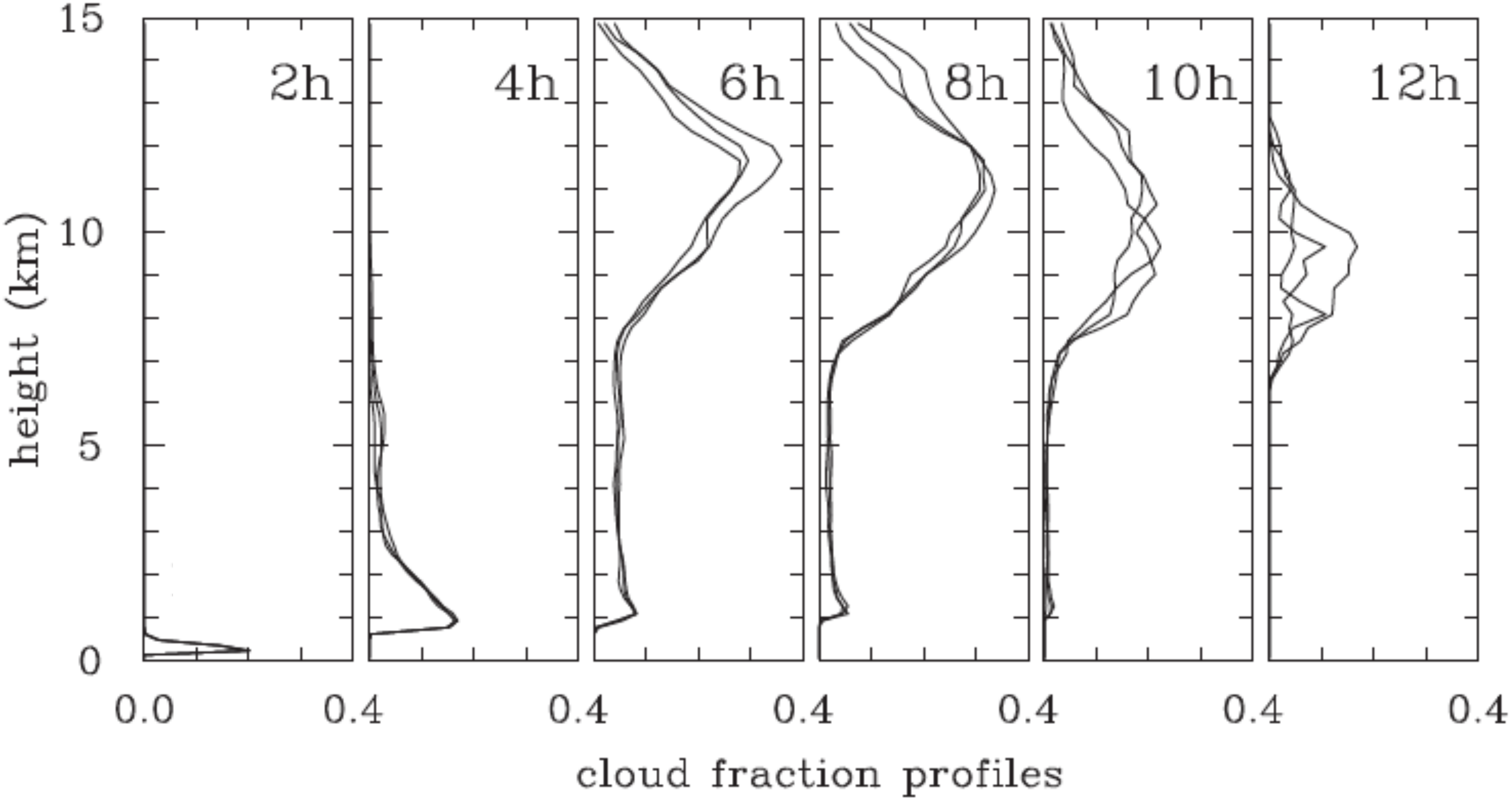
Diurnal cycle of convection (from dry to moist shallow and deep) is the strongest mode of short-term variability over the tropical, subtropical, and summertime midlatitude continents.

daytime convective development over land
(potential temperature profiles)



sunrise at 0h…



Simulated convective development over Amazonian rain forest driven by evolving surface sensible and latent heat fluxes (Grabowski et al. QJ 2006, Grabowski JAS 2015)

Diurnal cycle of convection (from dry to moist shallow and deep) is the strongest mode of short-term variability over the tropical, subtropical, and summertime midlatitude continents.

This comes from diurnal cycle of solar insolation and relatively low soil heat capacity when compared to the oceans.

Solar energy absorbed at the surface is passed to the atmosphere and drives of atmospheric convection. Soil storage is usually small.

The energy can be passed as either sensible or latent (water) surface heat flux. This talk is about the impact of the partitioning of the total energy flux into its sensible and latent components for the diurnal cycle of atmospheric convection.

Atmos. Chem. Phys., 18, 7473–7488, 2018
https://doi.org/10.5194/acp-18-7473-2018

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Convective environment in pre-monsoon and monsoon conditions over the Indian subcontinent: the impact of surface forcing

Lois Thomas[1], **Neelam Malap**[1], **Wojciech W. Grabowski**[2,3], **Kundan Dani**[1], **and Thara V. Prabha**[1]

[1]Indian Institute of Tropical Meteorology, Pune, India
[2]National Center for Atmospheric Research, Boulder, Colorado, USA
[3]Institute of Geophysics, Faculty of Physics, University of Warsaw, Warsaw, Poland

Lois visited NCAR in summer of 2016 as an undergraduate student.

Thara Prabha suggested that I find something for her to work on. I decided to put her on sounding analysis using a simple rising parcel model. The above paper was a result of her analysis and our subsequent email exchanges…

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LCL (lifting condensation level)
~cloud base

Pre-monsoon and monsoon mid-day soundings released from Pune, India

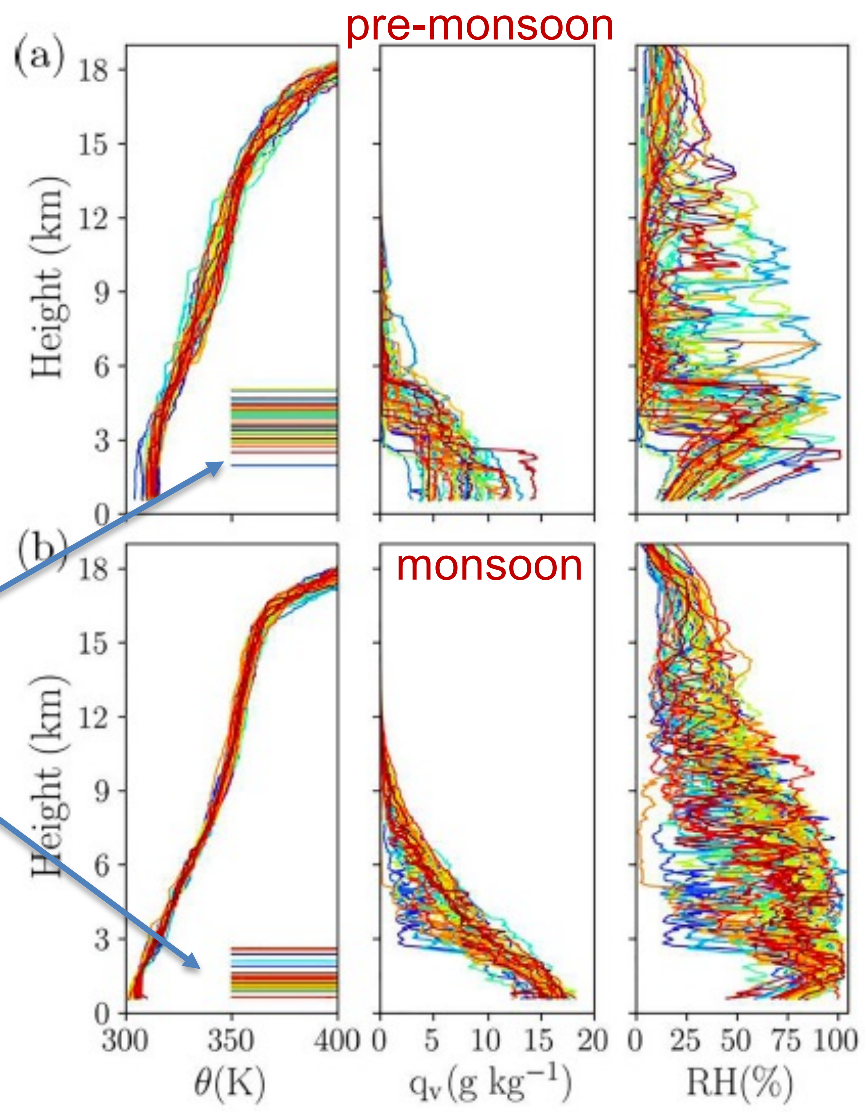

Figure 1. Profiles of potential temperature (θ), water vapour mixing ratio (q_v), and relative humidity (RH) for **(a)** pre-monsoon and **(b)** monsoon soundings. Different colours represent different soundings, with a total of 42 soundings for both cases. The horizontal lines in the left-hand panels are LCL heights, with the same colours as the corresponding profile.

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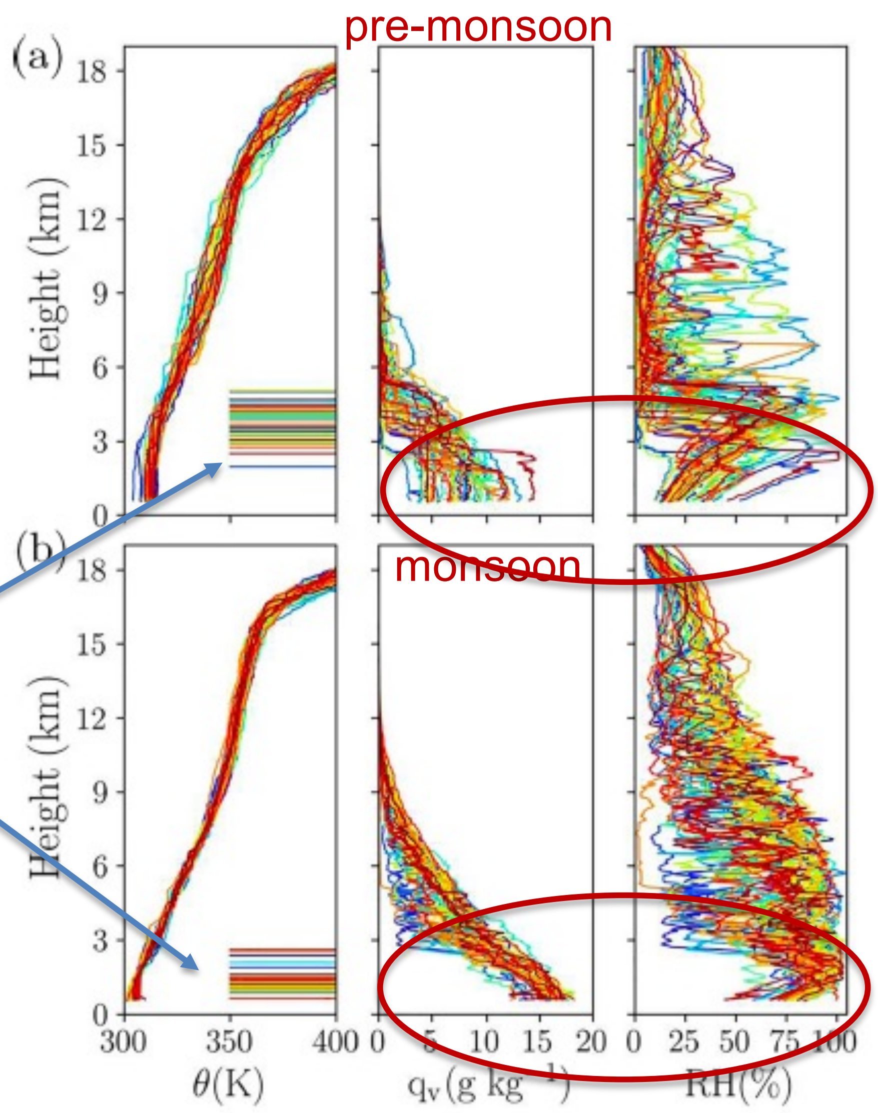

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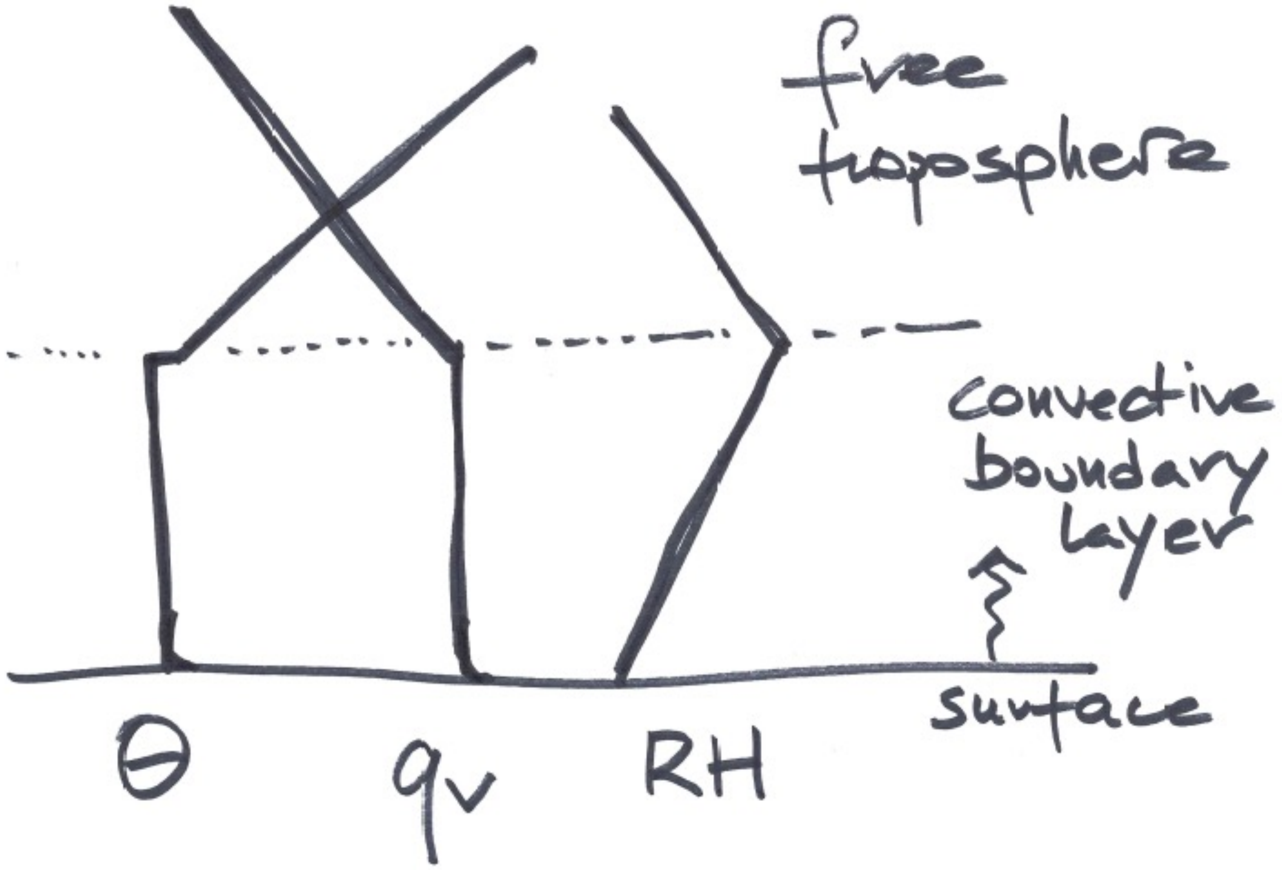
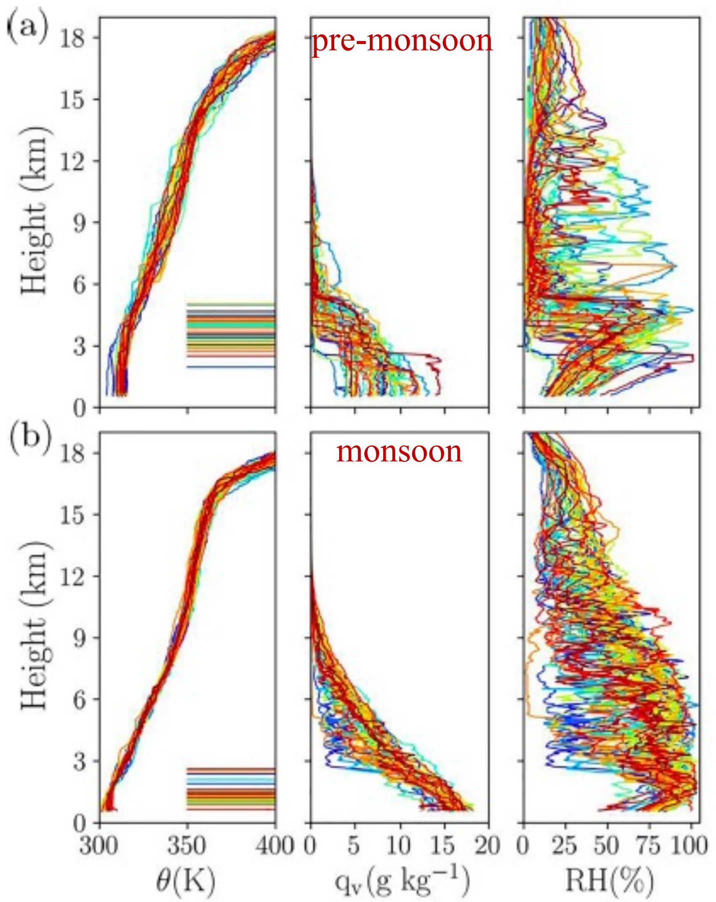
Assuming mixed-layer boundary layer gives:

$$RH_s = \frac{p_s}{p_{LCL}} \exp\left(- \frac{L_v \; g \; z_{LCL}}{c_p \; R_v \; T_{LCL} \; T_s} \right)$$





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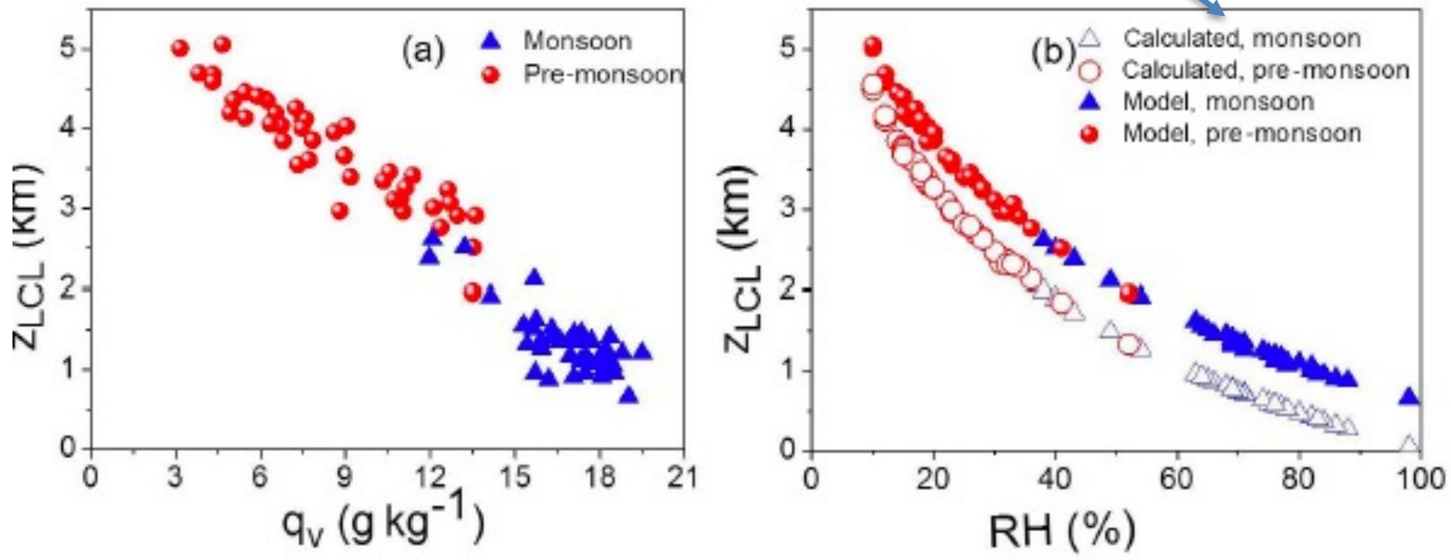


Surface buoyancy flux as a function of the surface Bowen ratio:

$\theta_v = \theta(1 + \varepsilon q_v)$, $\varepsilon \sim 0.22$, virtual potential temperature

Surface buoyancy flux BF: $BF = <w\Theta_v> = <w\Theta> + \Theta_o \varepsilon <w\, q_v>$

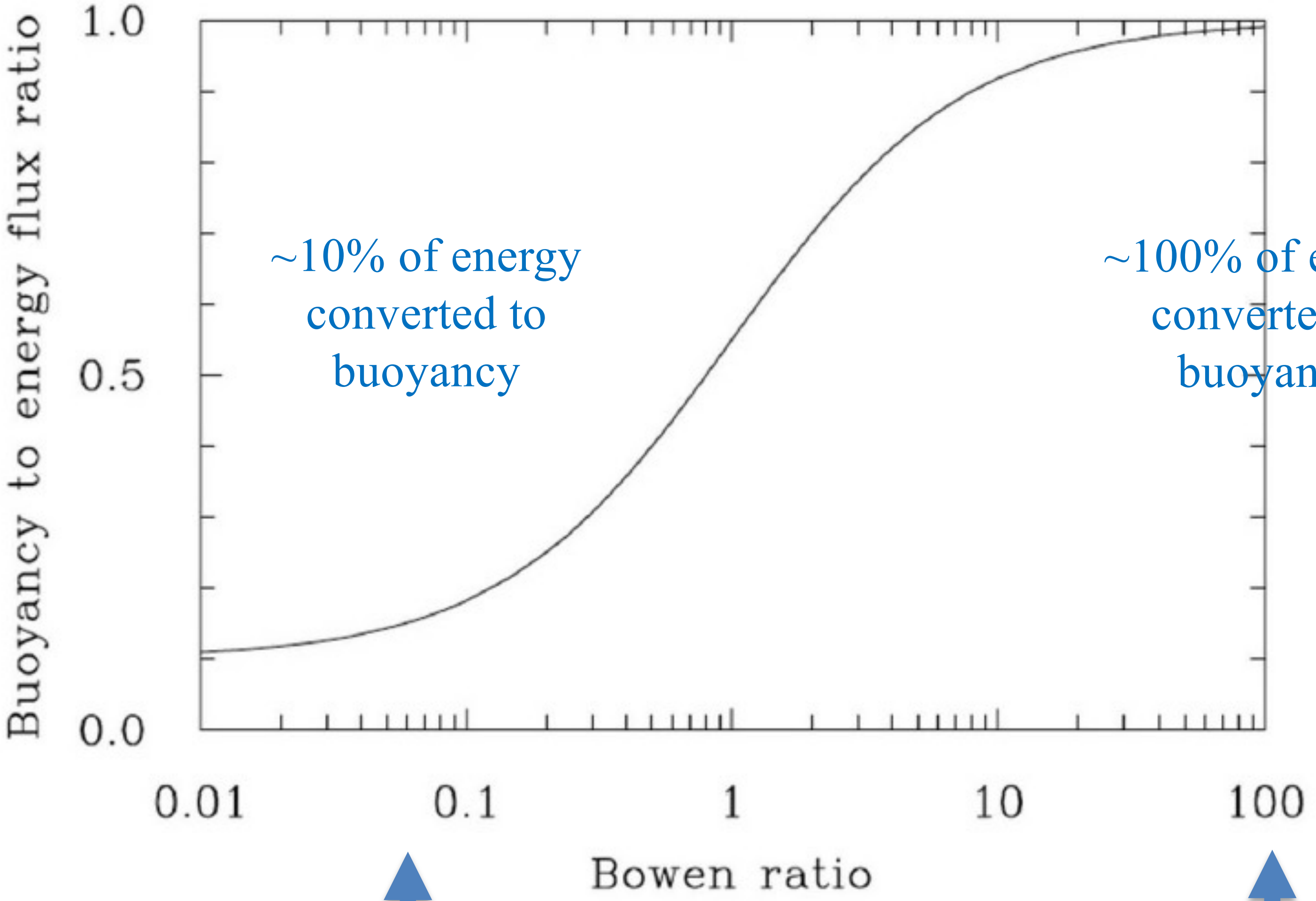
Moist static energy: $s = c_p\, \Theta + L\, q_v$

Surface moist static energy flux EF: $EF = <w\Theta> + L/c_p <w\, q_v>$

$BF/EF = (\alpha + B)/(1 + B)$ buoyancy to energy ratio

$\alpha = \Theta_o\, \varepsilon\, c_p /L \approx 0.1$

$B = c_p <w\Theta>/L <w\, q_v>$ - Bowen ratio, sensible to latent heat flux ratio



~10% of energy converted to buoyancy

~100% of energy converted to buoyancy

sensible to latent heat flux ratio

ocean:
~100 Wm^{-2} latent,
~10 Wm^{-2} sensible

desert:
~0 Wm^{-2} latent,
~1000 Wm^{-2} sensible

BL a few hundred m deep

BL growing to several km deep

Thomas et al. *ACP* 2018

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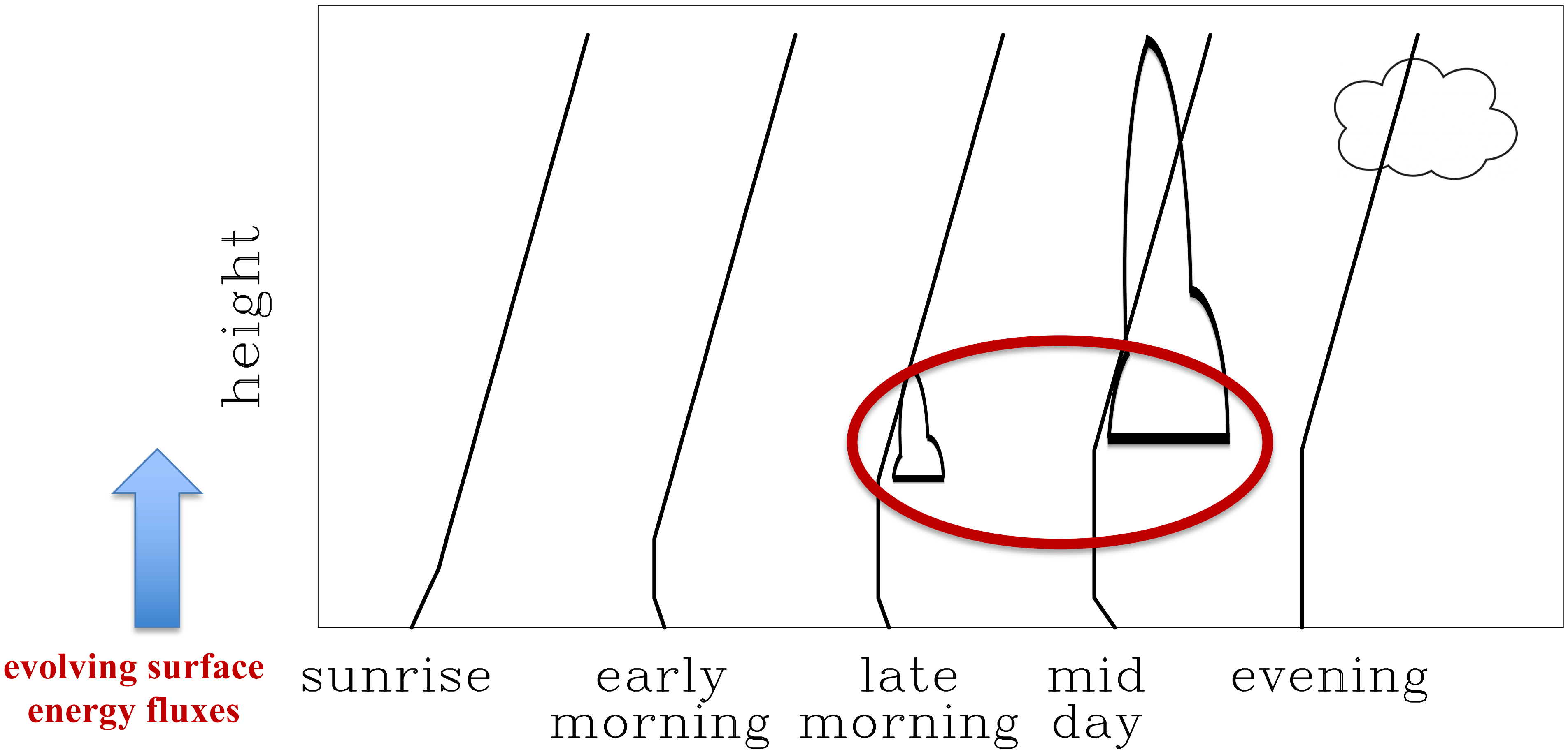


VOLUME 79 JOURNAL OF THE ATMOSPHERIC SCIENCES FEBRUARY 2022

Influences of Environmental Relative Humidity and Horizontal Scale of Subcloud Ascent on Deep Convective Initiation

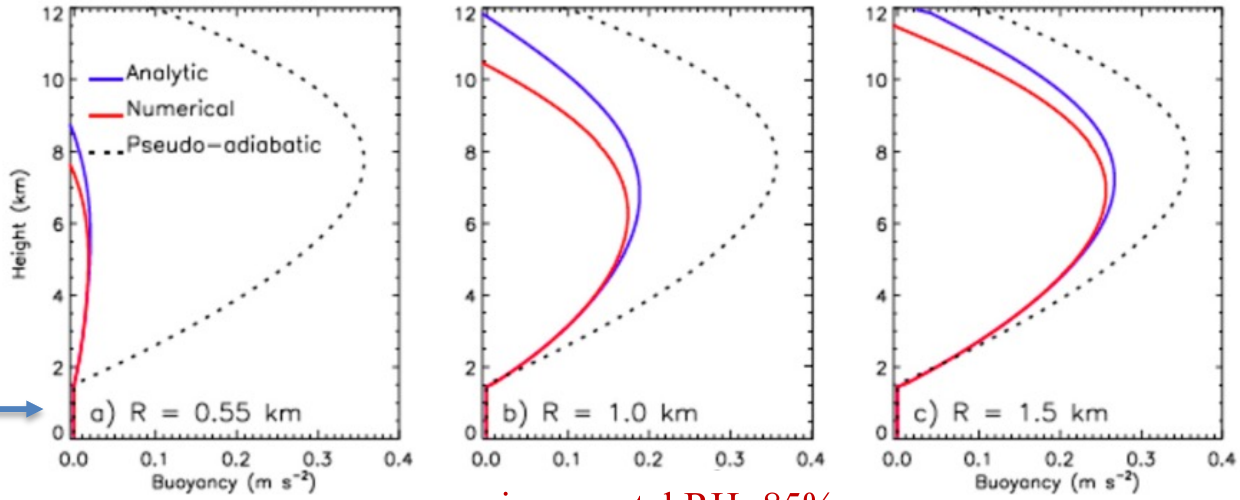
HUGH MORRISON,[a,b] JOHN M. PETERS,[c] KAMAL KANT CHANDRAKAR,[a] AND STEVEN C. SHERWOOD[b]

[a] *National Center for Atmospheric Research, Boulder, Colorado*
[b] *Climate Change Research Centre, ARC Centre of Excellence for Climate Extremes, University of New South Wales, Sydney, Australia*
[c] *Department of Meteorology, Naval Postgraduate School, Monterey, California*

(Manuscript received 1 March 2021, in final form 28 July 2021)

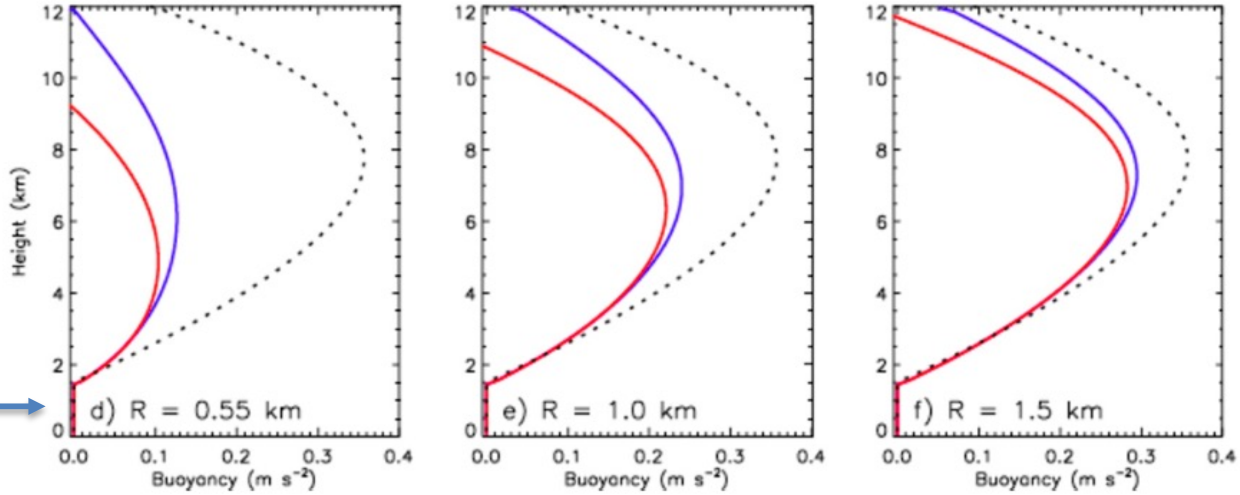
environmental RH=42.5%

Radius of the initial perturbation



environmental RH=85%

Radius of the initial perturbation



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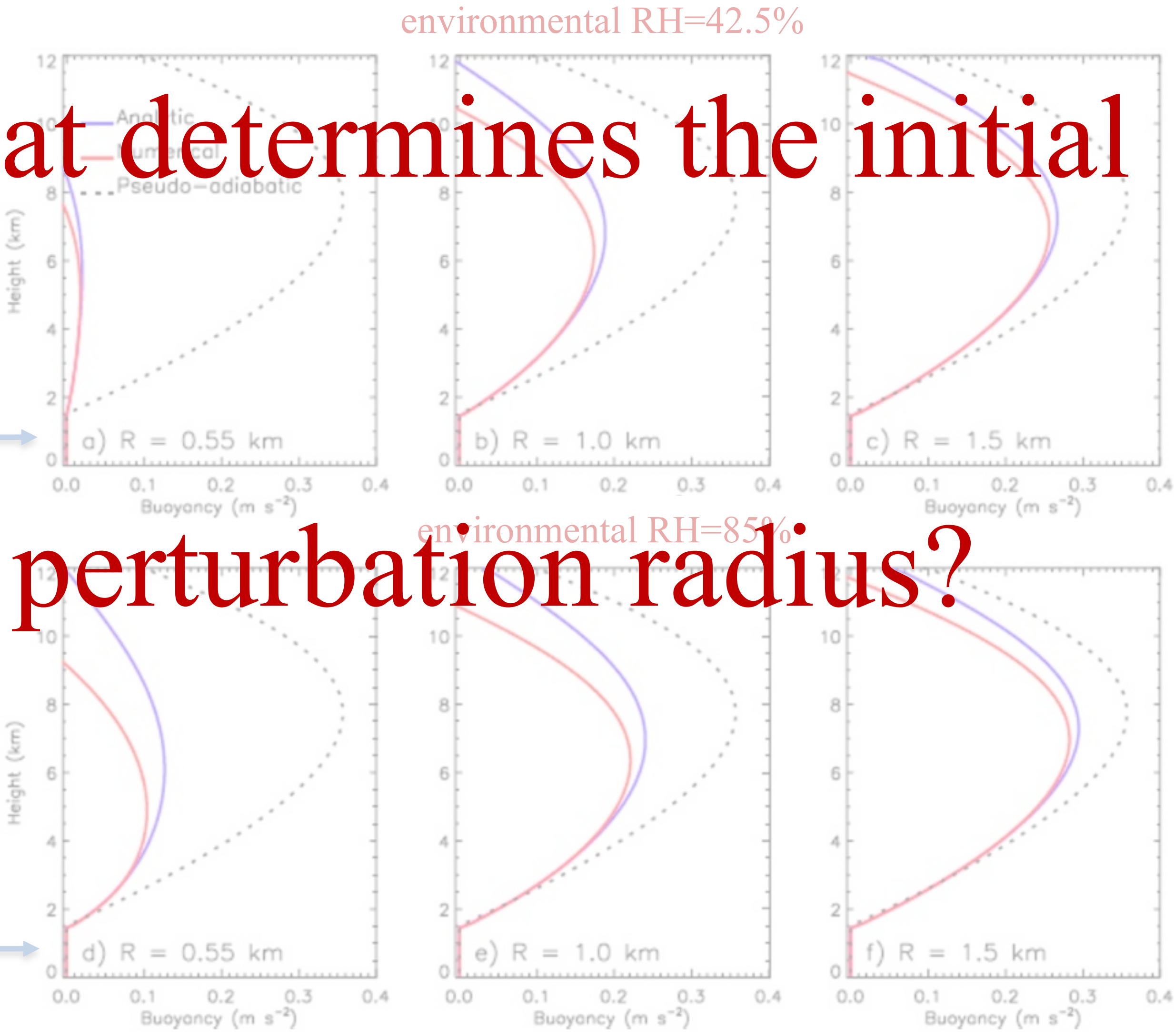
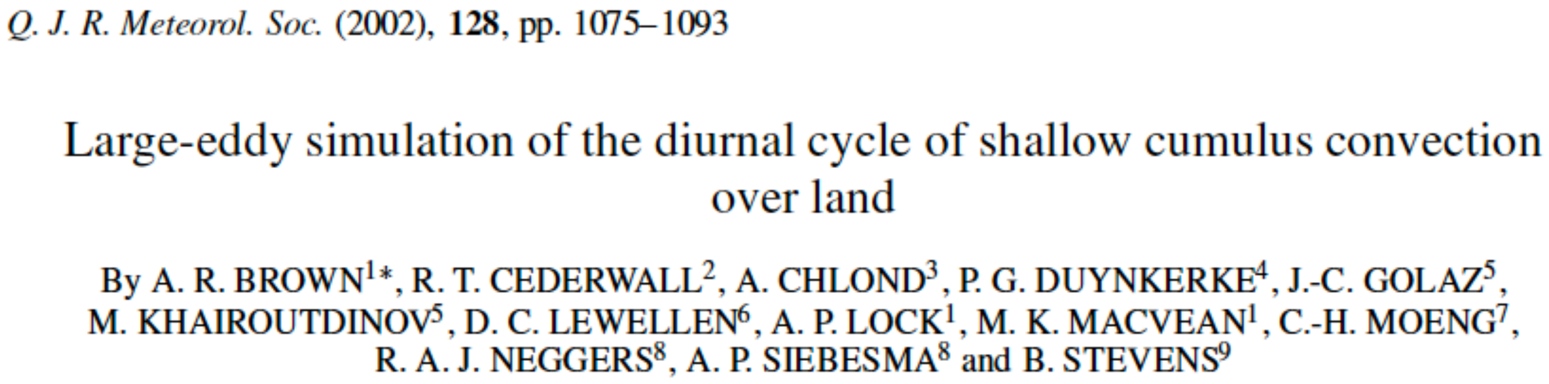
What determines the initial perturbation radius?



Radius of the initial perturbation

Radius of the initial perturbation

Shallow convection:



Q. J. R. Meteorol. Soc. (2002), **128**, pp. 1075–1093

Large-eddy simulation of the diurnal cycle of shallow cumulus convection over land

By A. R. BROWN[1]*, R. T. CEDERWALL[2], A. CHLOND[3], P. G. DUYNKERKE[4], J.-C. GOLAZ[5],
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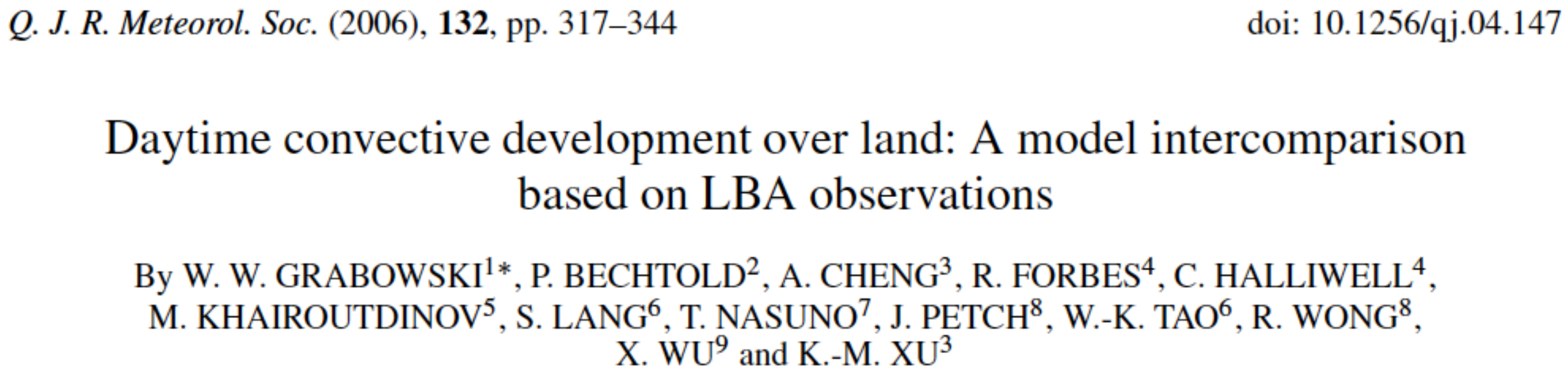
Deep convection:



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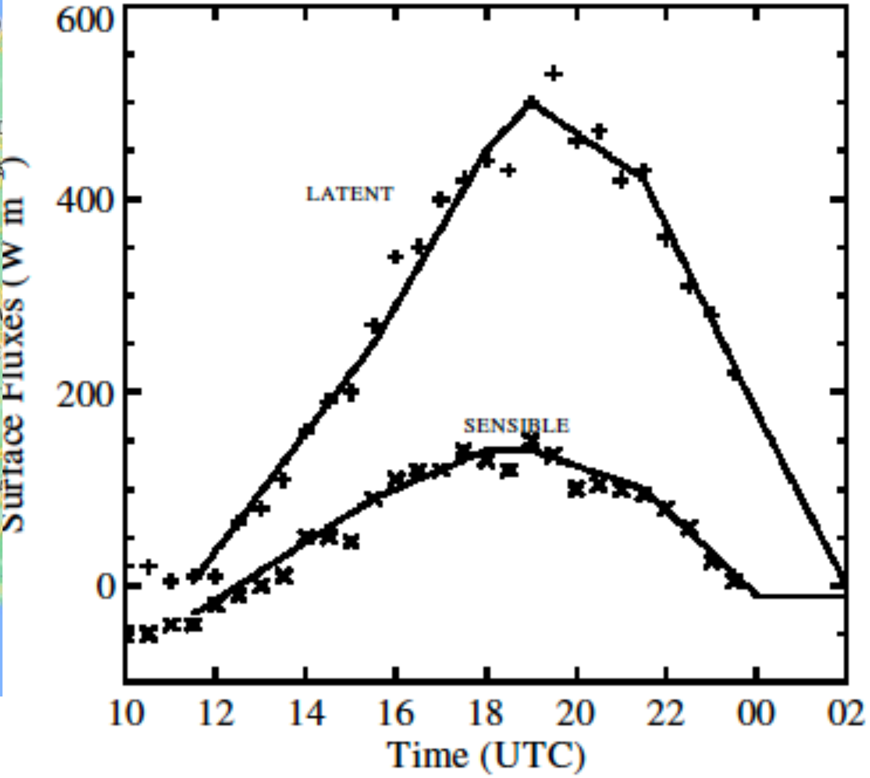
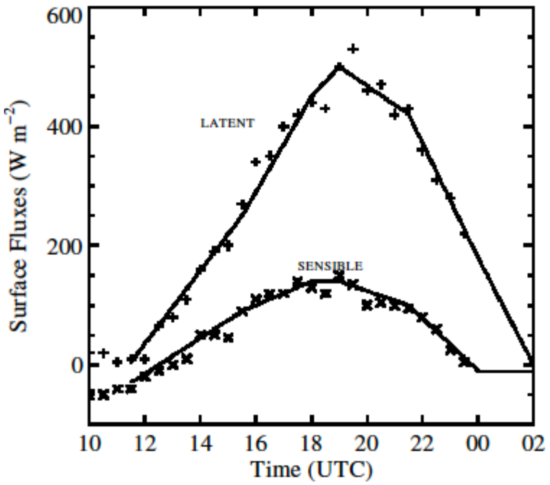


Local time: UTC - 6



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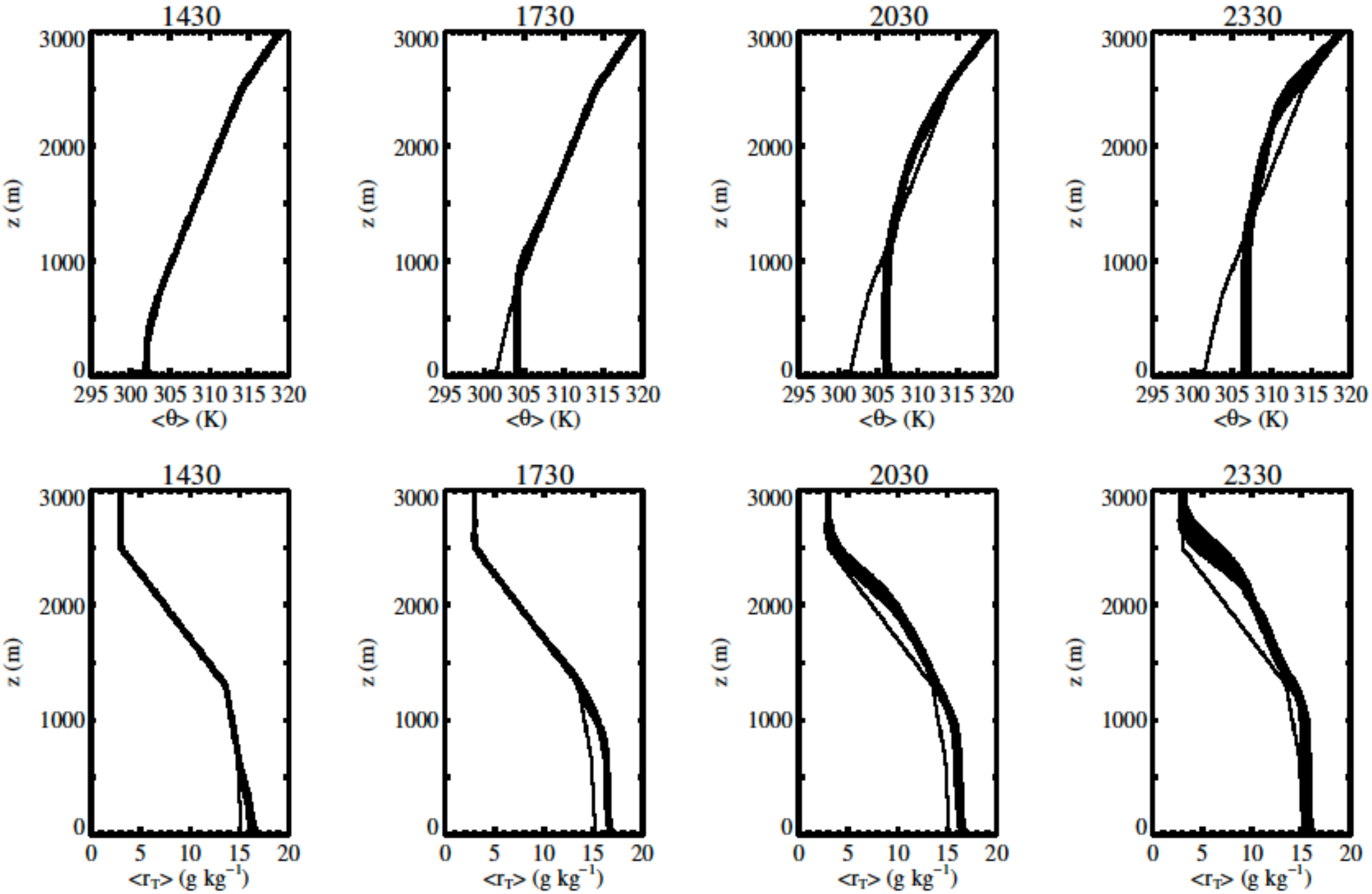
Example of simulations results from 8 models:

potential temperature

water vapor mixing ratio



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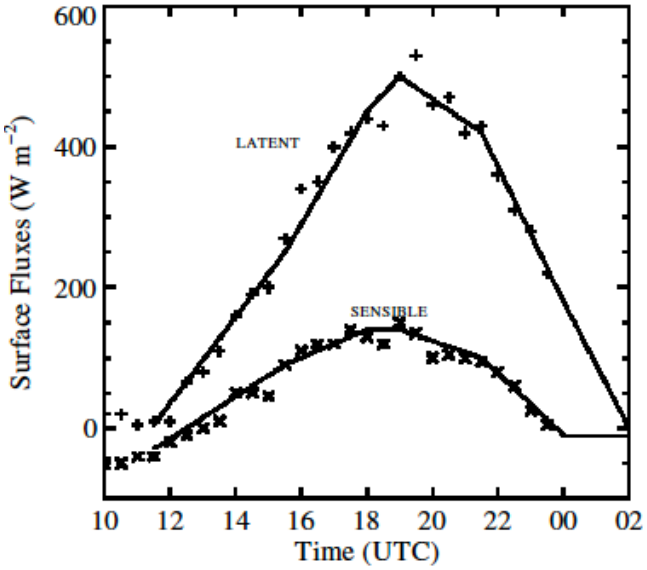
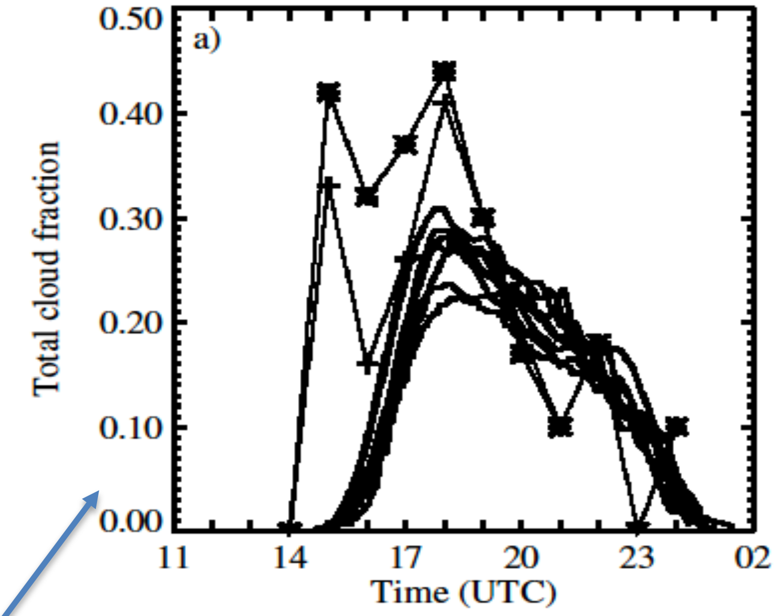
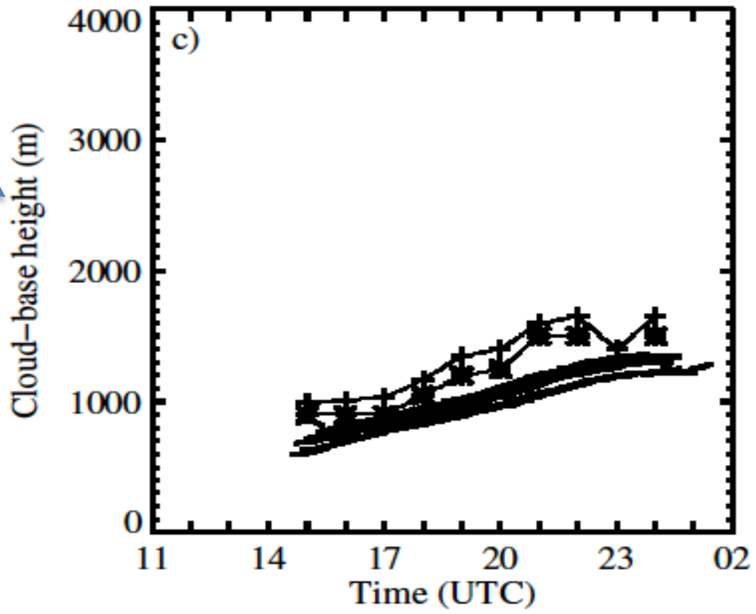


simulations
vs
observations:

evolutions of
cloud cover
and cloud
base height



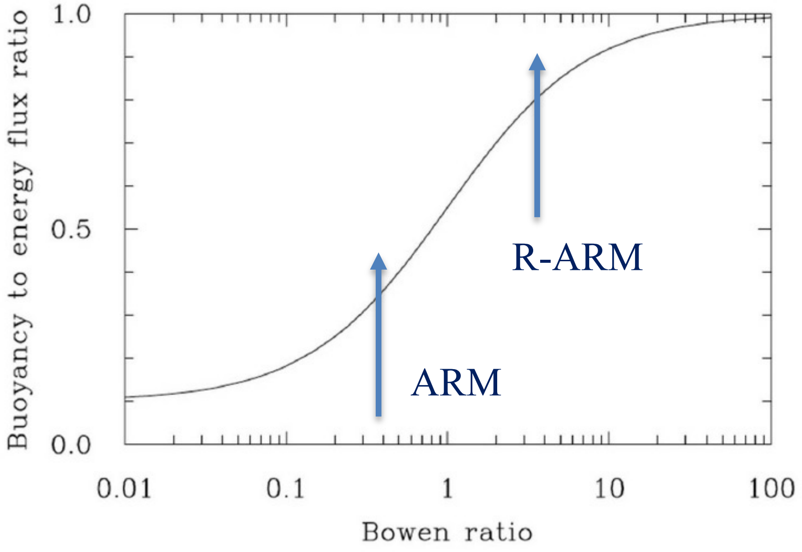


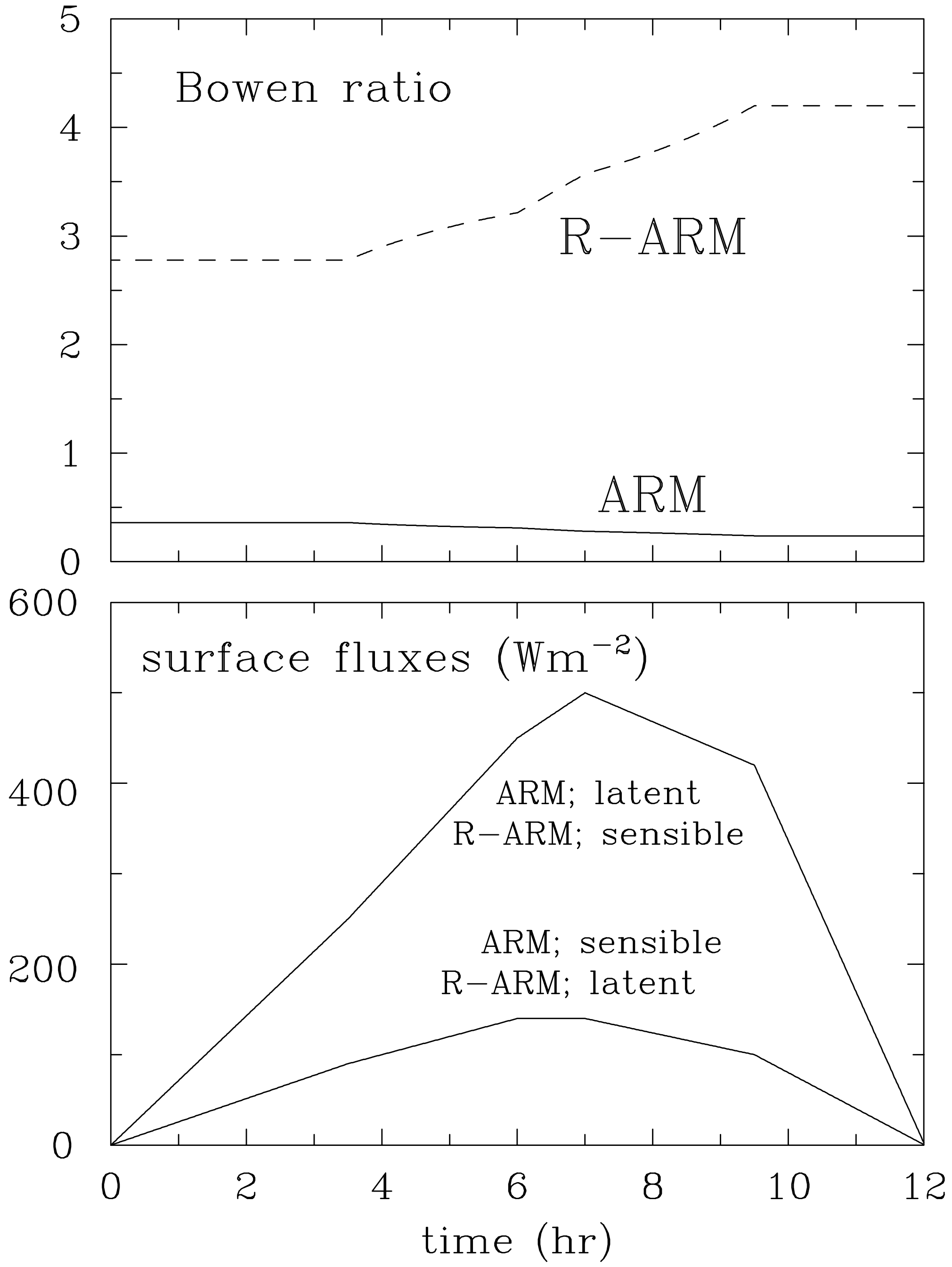
Local time is UTC minus 6 hours

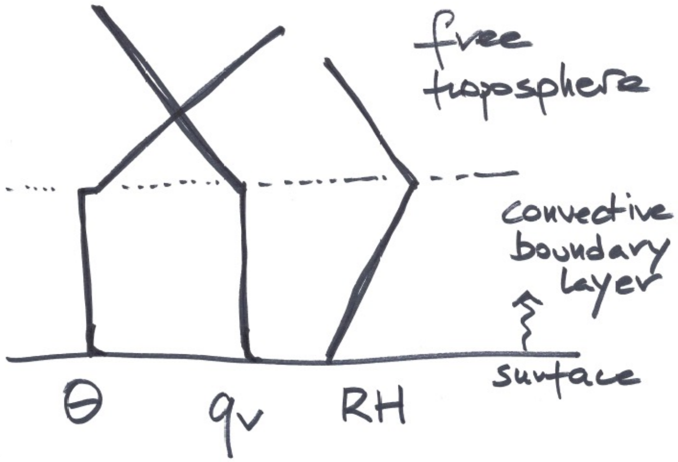
The idea: replace sensible and latent surface heat fluxes to illustrate the role of surface forcing:

ARM – as in Brown et al.

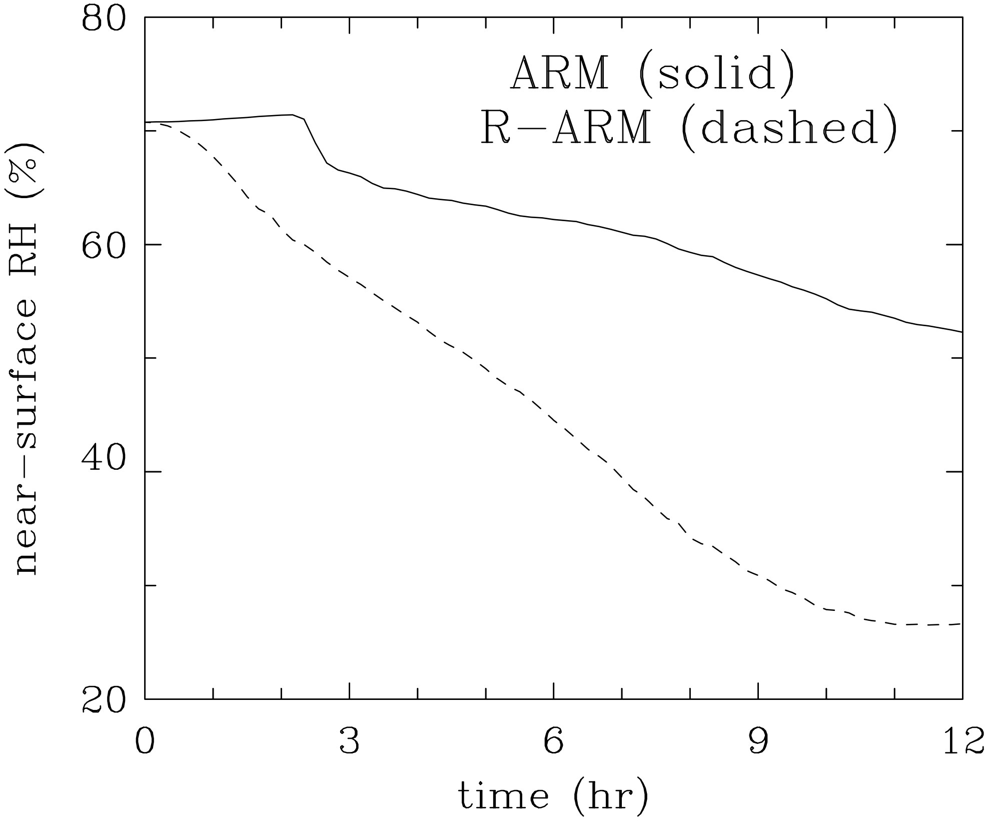
R-ARM – fluxes replaced (latent becomes sensible; sensible becomes latent)

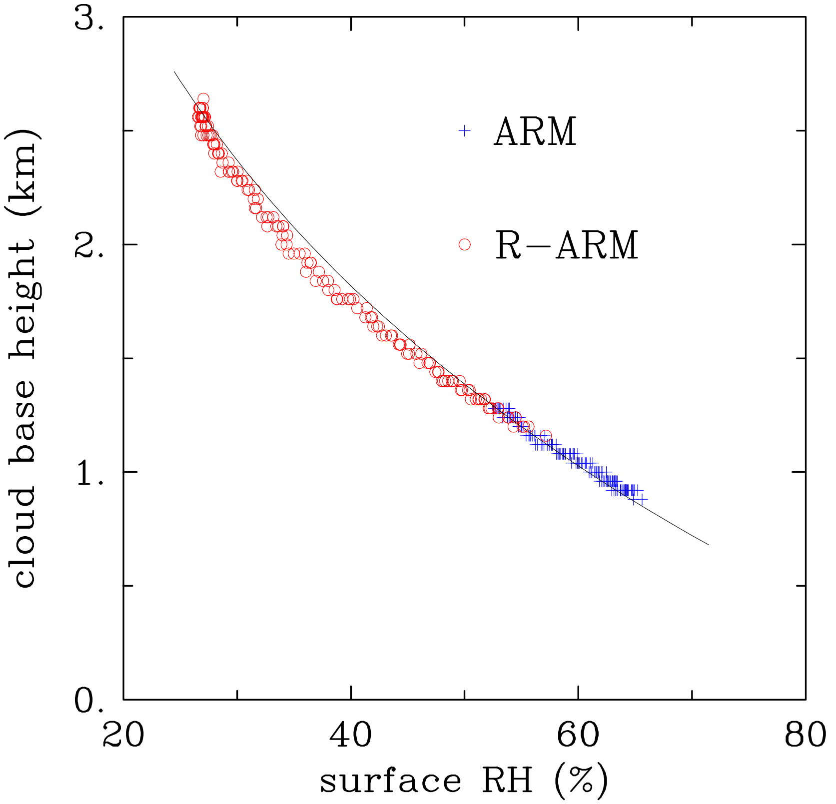






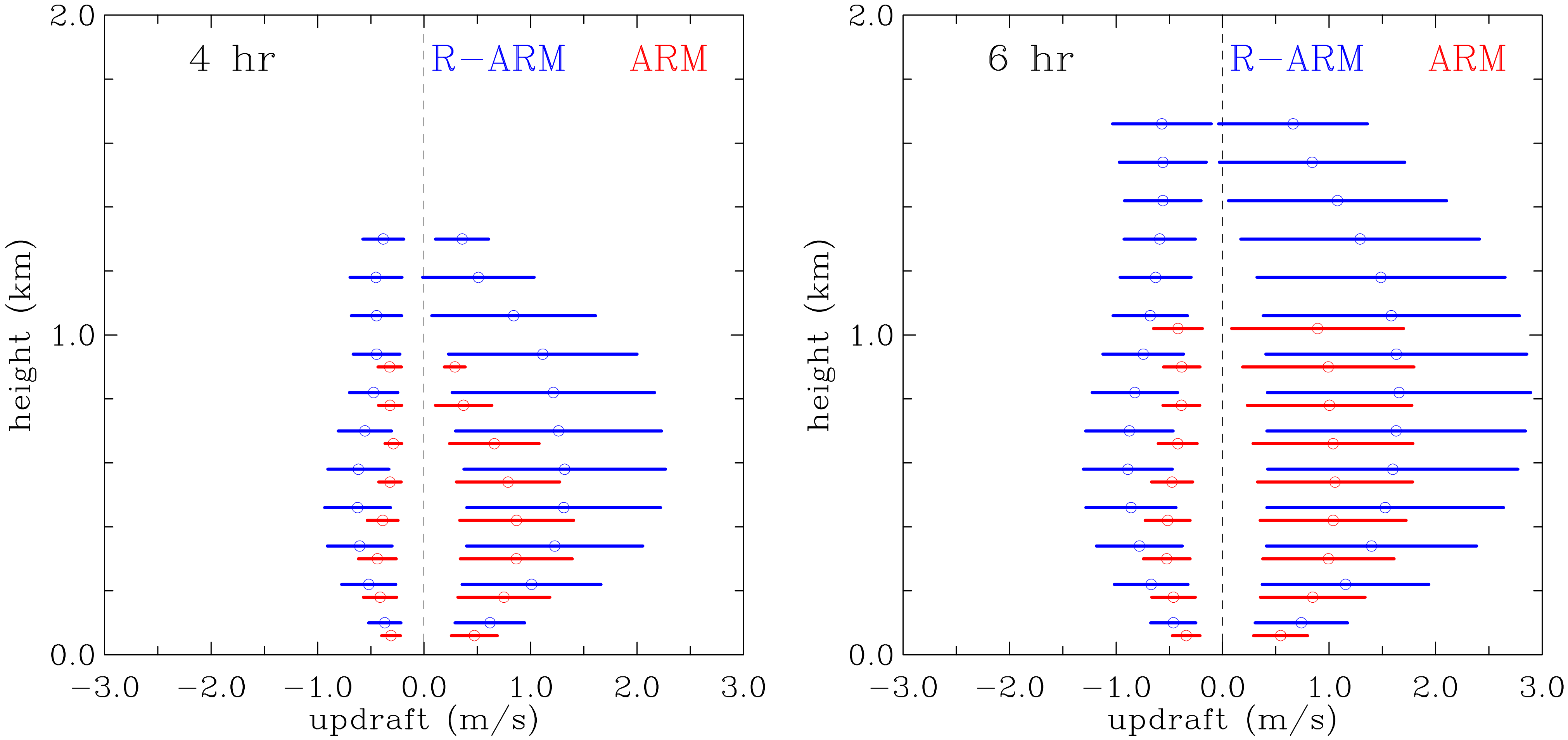
$$RH_s = \frac{p_s}{p_{CB}} \exp\left(-\frac{L_v\; g\; z_{CB}}{c_p\; R_v\; T_{CB}\; T_s}\right)$$

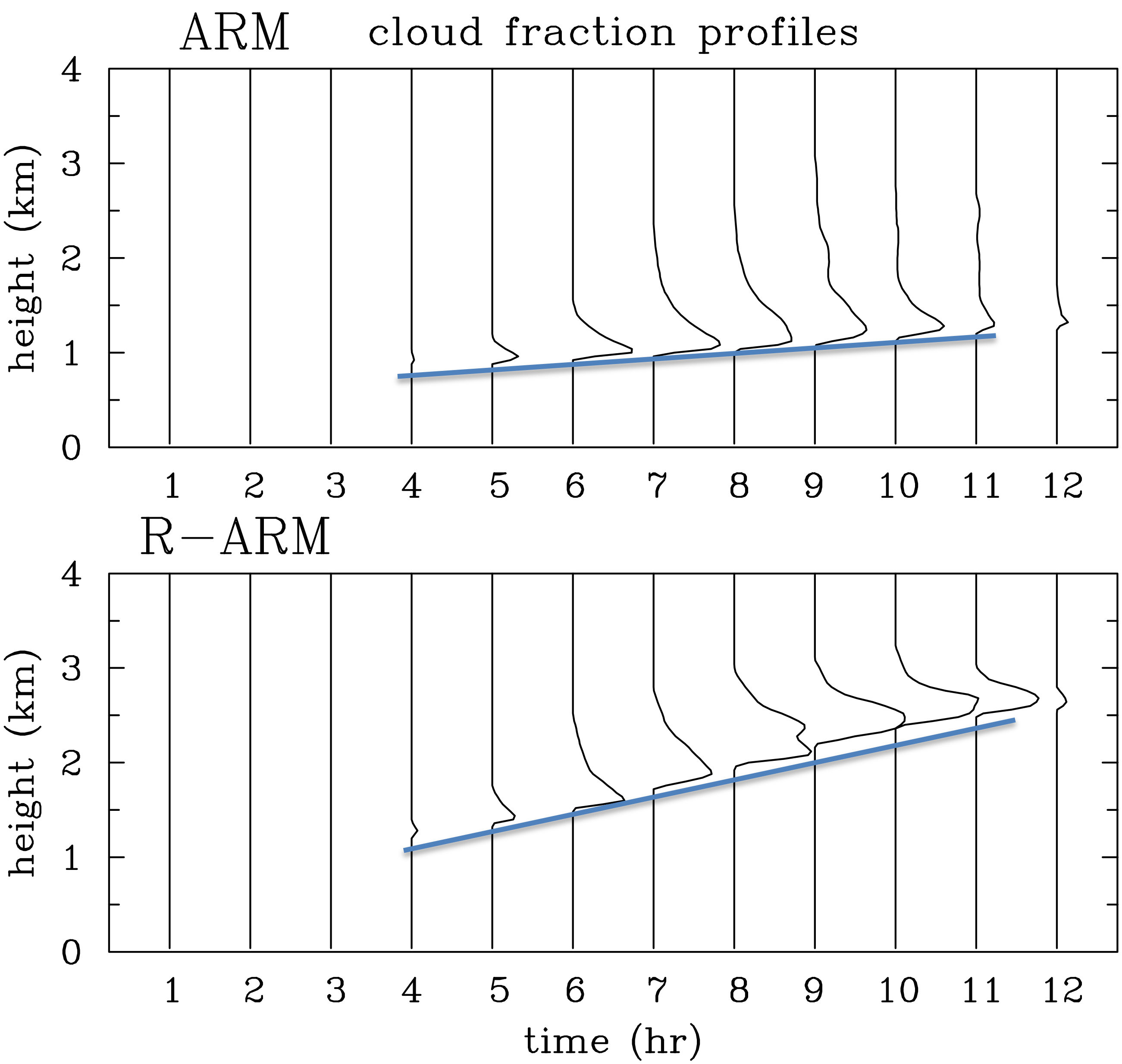




Vertical velocity statistics within convective boundary layer
updrafts: > 0.2 m/s; downdrafts: < -0.2 m/s

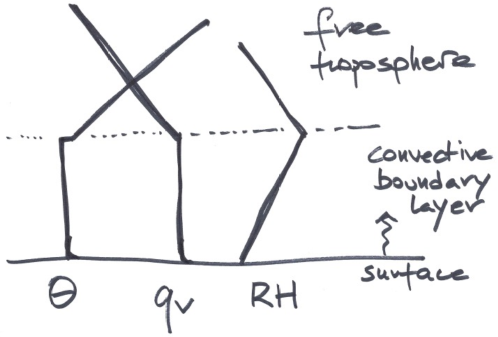
(circle– mean; bar – mean plus/minus one standard deviation)

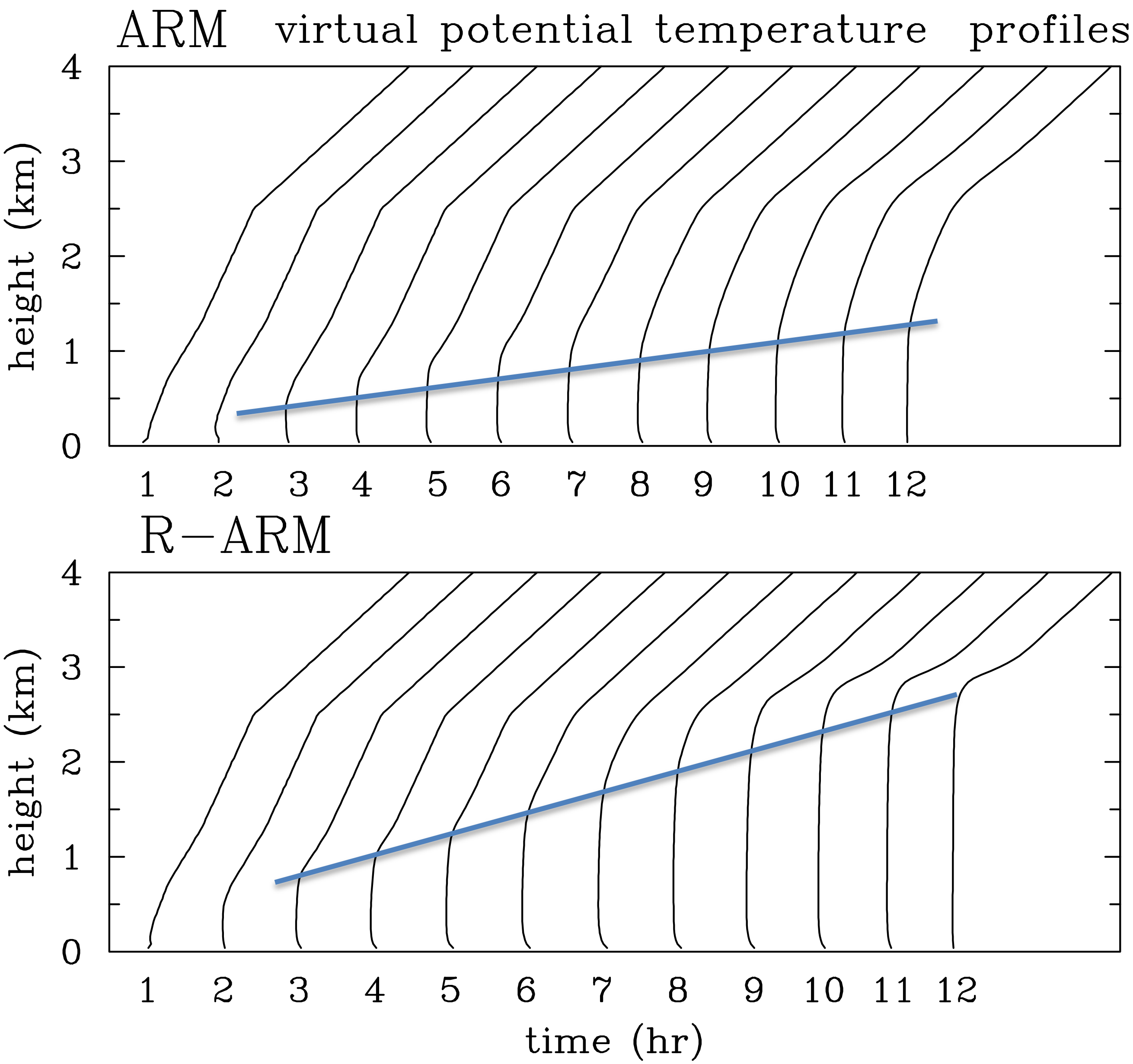


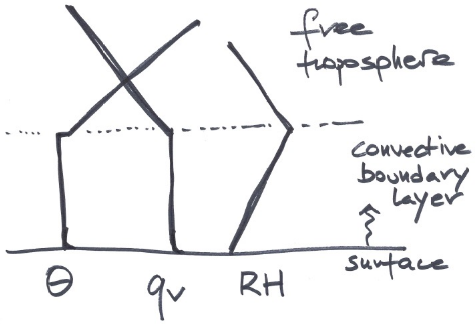


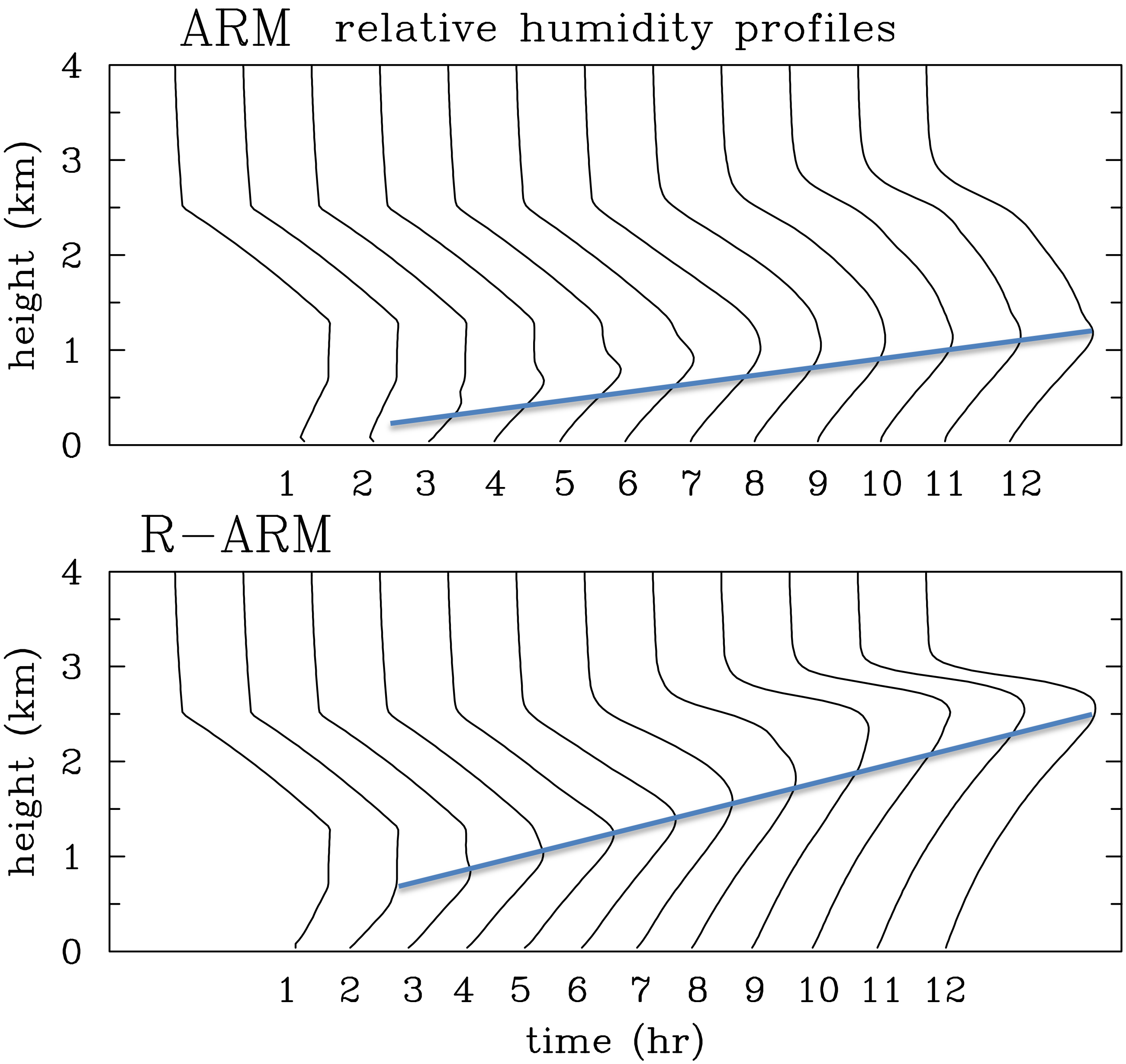
ARM cloud fraction profiles

R−ARM

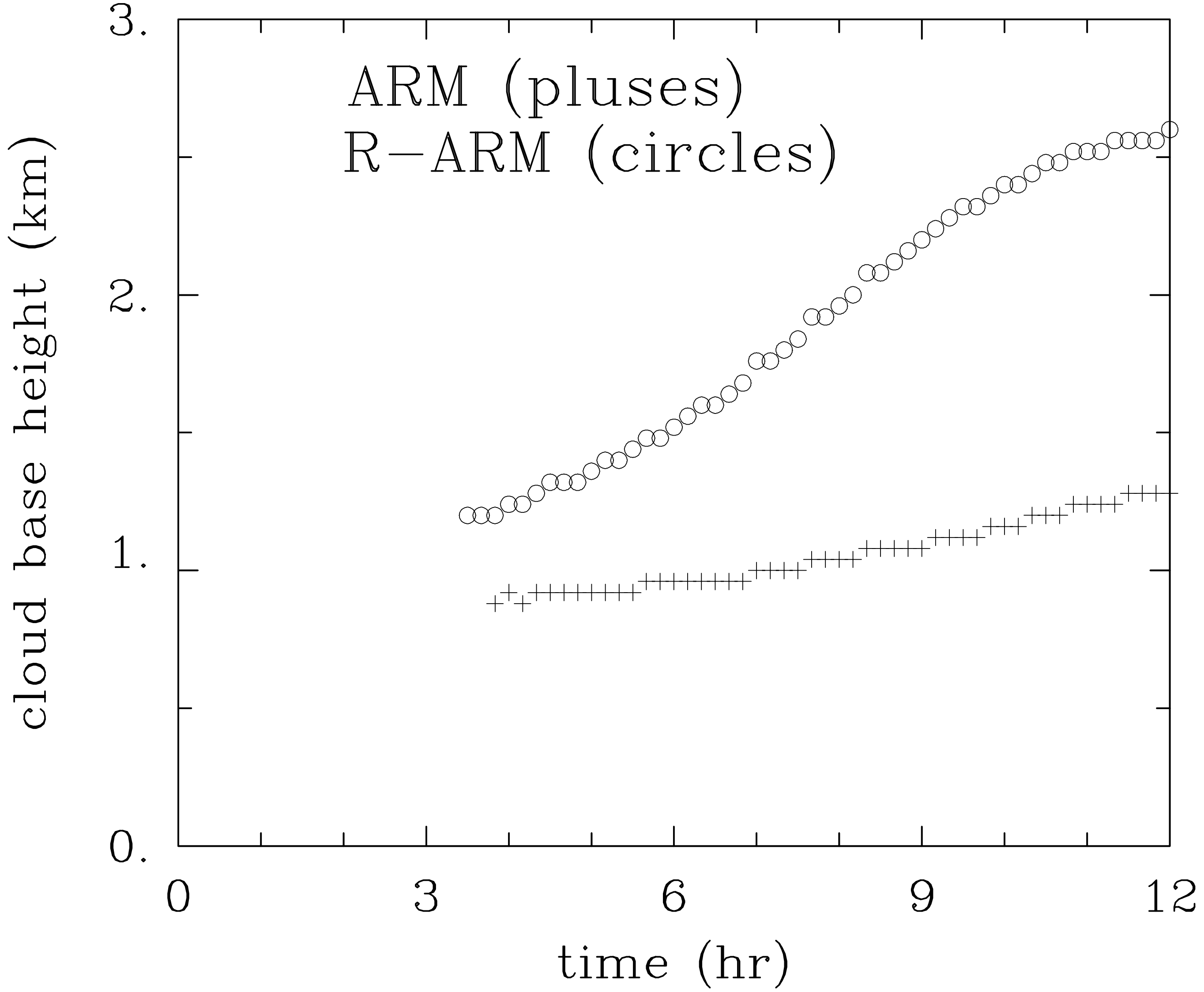

free troposphere
convective boundary layer
surface
Θ
qv
RH

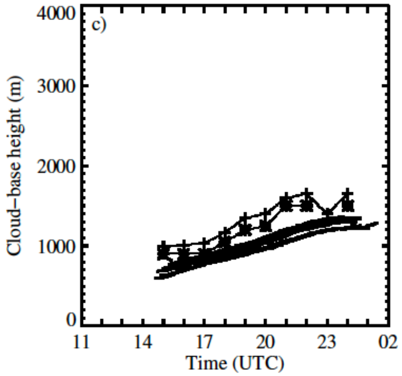

ARM virtual potential temperature profiles
height (km)
0
1
2
3
4
1
2
3
4
5
6
7
8
9
10
11
12
R−ARM
height (km)
0
1
2
3
4
1
2
3
4
5
6
7
8
9
10
11
12
time (hr)


free troposphere
convective boundary layer
surface
θ
qv
RH


ARM relative humidity profiles
R−ARM
height (km)
0
1
2
3
4
1
2
3
4
5
6
7
8
9
10
11
12
time (hr)

Evolution of the cloud base height

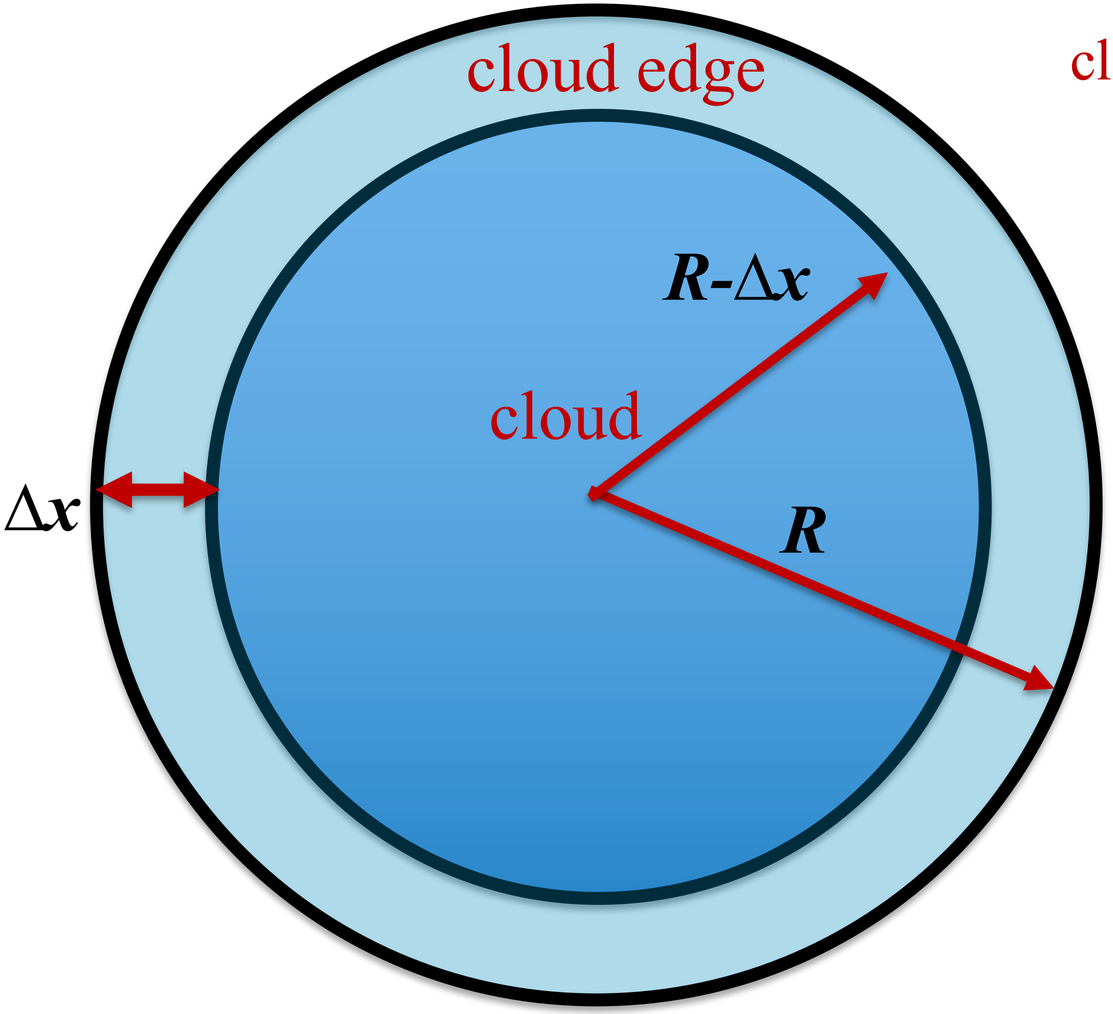




Estimation of the mean cloud width (for an ensemble of clouds) at a given height: (Grabowski et al. AG 2011; EULAG Special Issue)

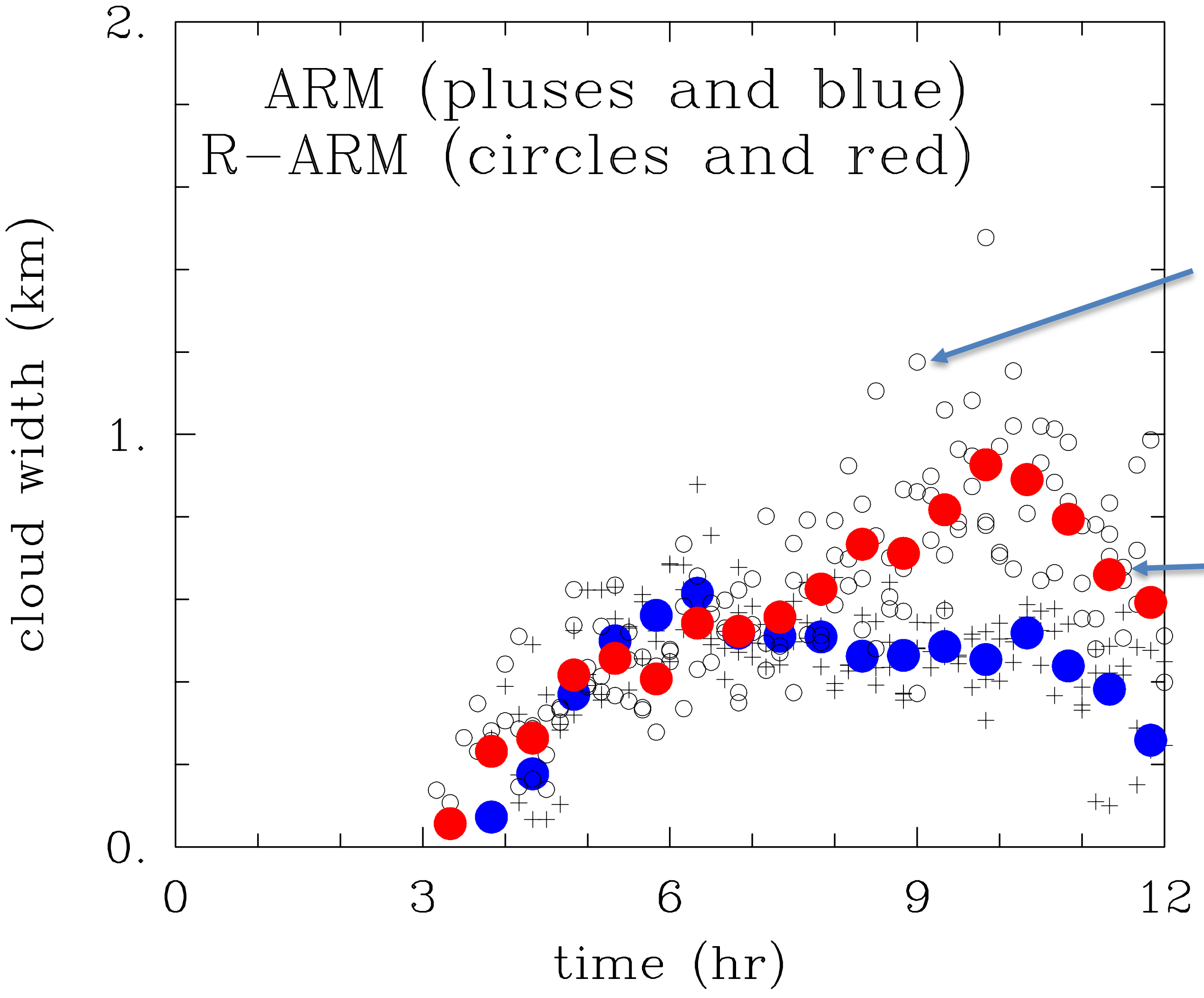
cloud edge – cloudy, with non-cloudy neighbor

cloud – all cloudy points



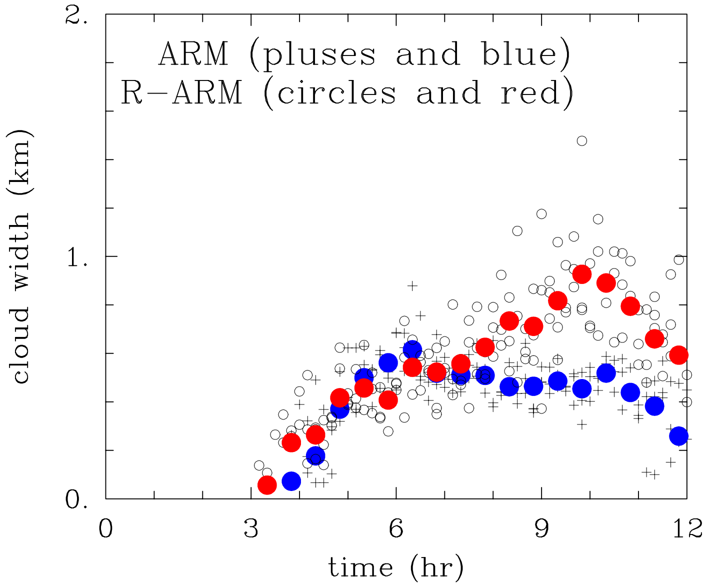
$$s = (R - \Delta x)^2 / R^2$$

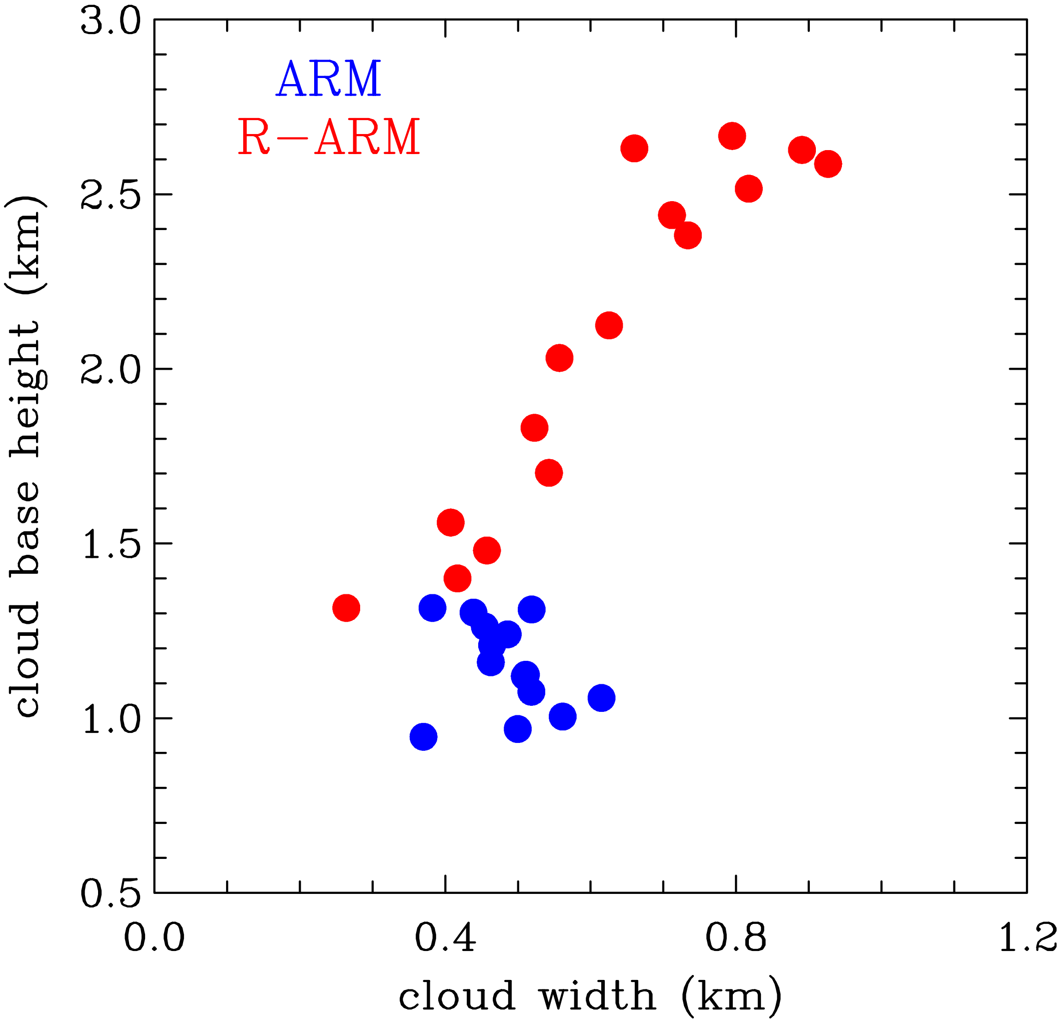
$$R = \Delta x / (1 - s^{1/2})$$



snapshot from
ensemble member

ensemble- and
30-min averages



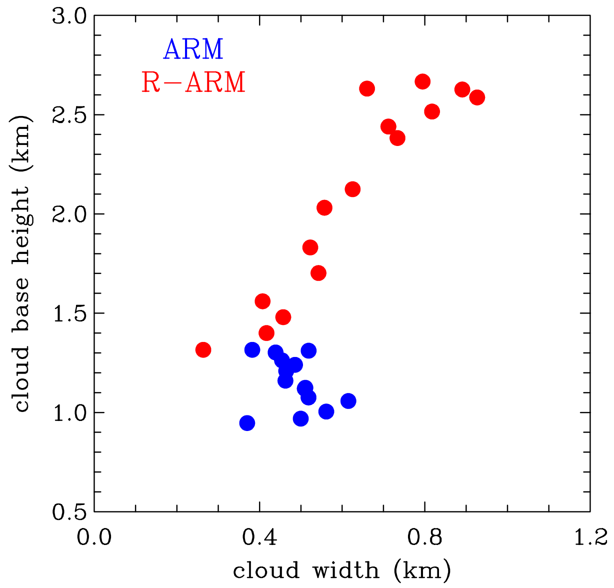


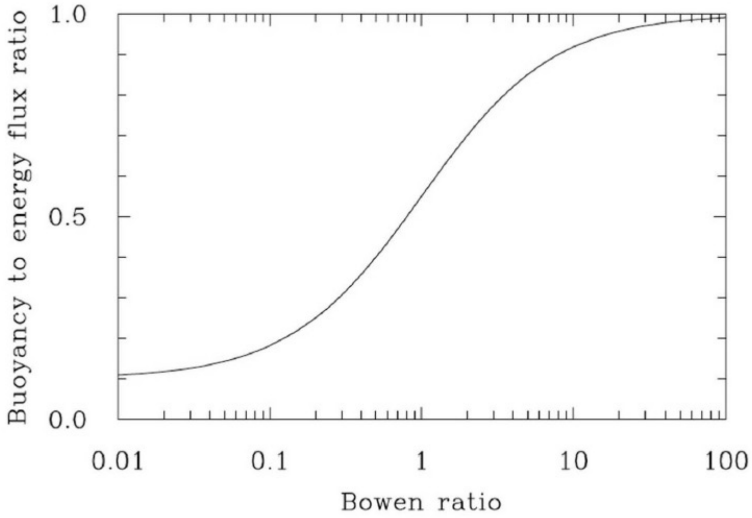
Mean cloud width seems to increase with the cloud-base height, especially for a deep boundary layer….

Summary for shallow convection simulations:

Surface buoyancy flux in morning hours determines the growth rate of the convective boundary layer. Surface buoyancy flux depends on the surface flux Bowen ratio.

Cloud width at the cloud base (i.e., the size of the sub-cloud ascent) seems to increase with the increase of the boundary layer depth.





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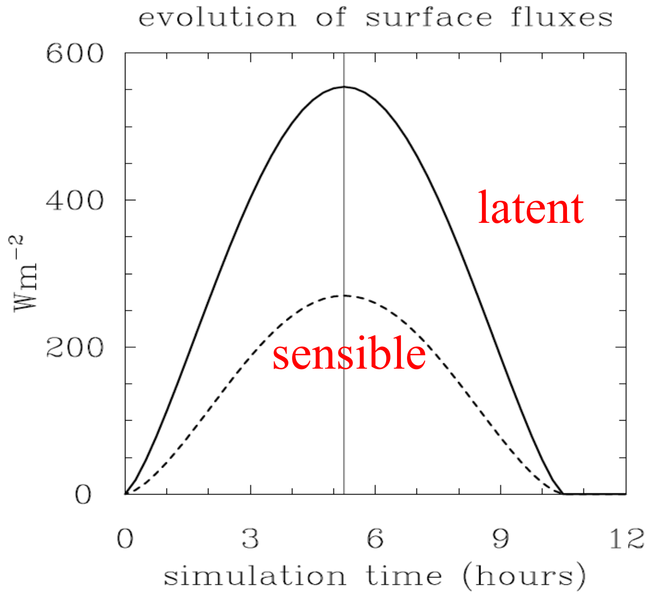
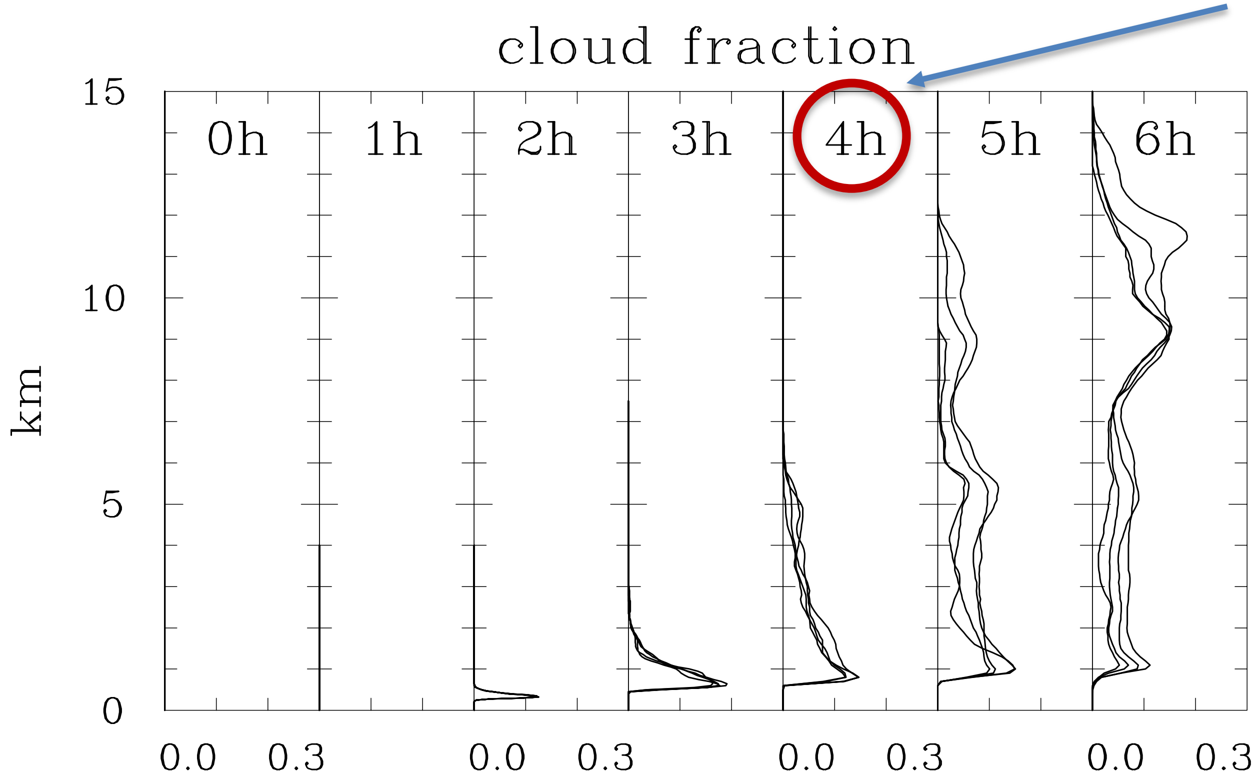
X. WU[9] and K.-M. XU[3]



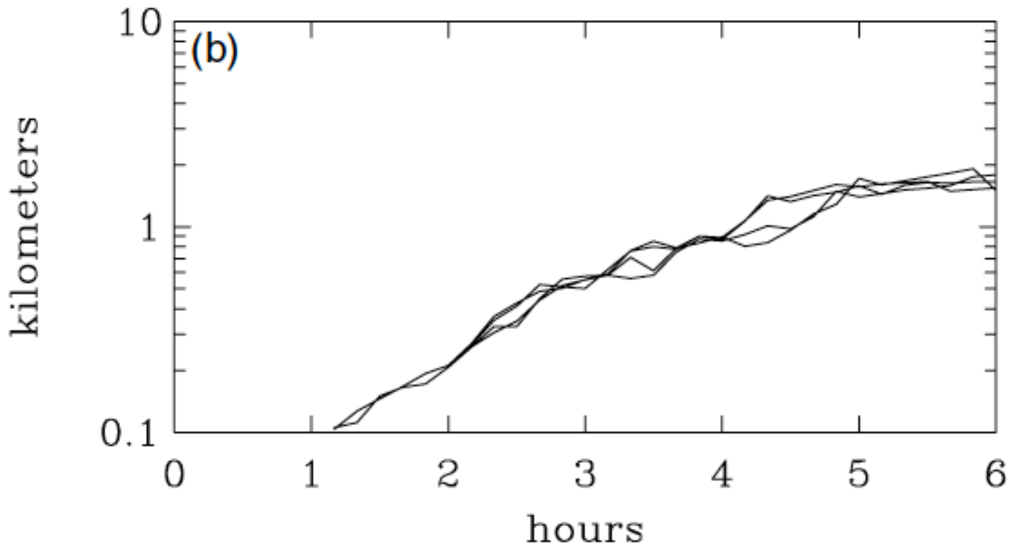
Daytime development of scattered ("popcorn") deep convection based on observations in Amazonia

Results from benchmark ensemble simulations:

in transition from shallow to deep



evolution
of cloud
fraction
profiles



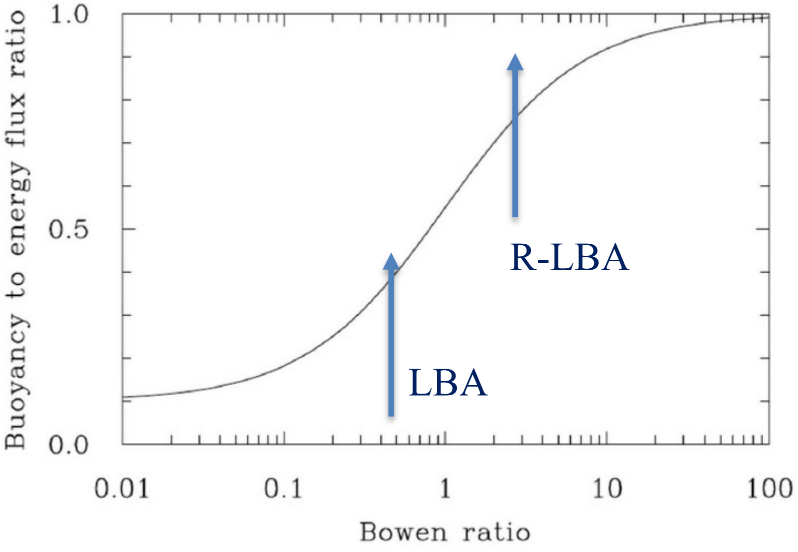
evolution of
cloud width

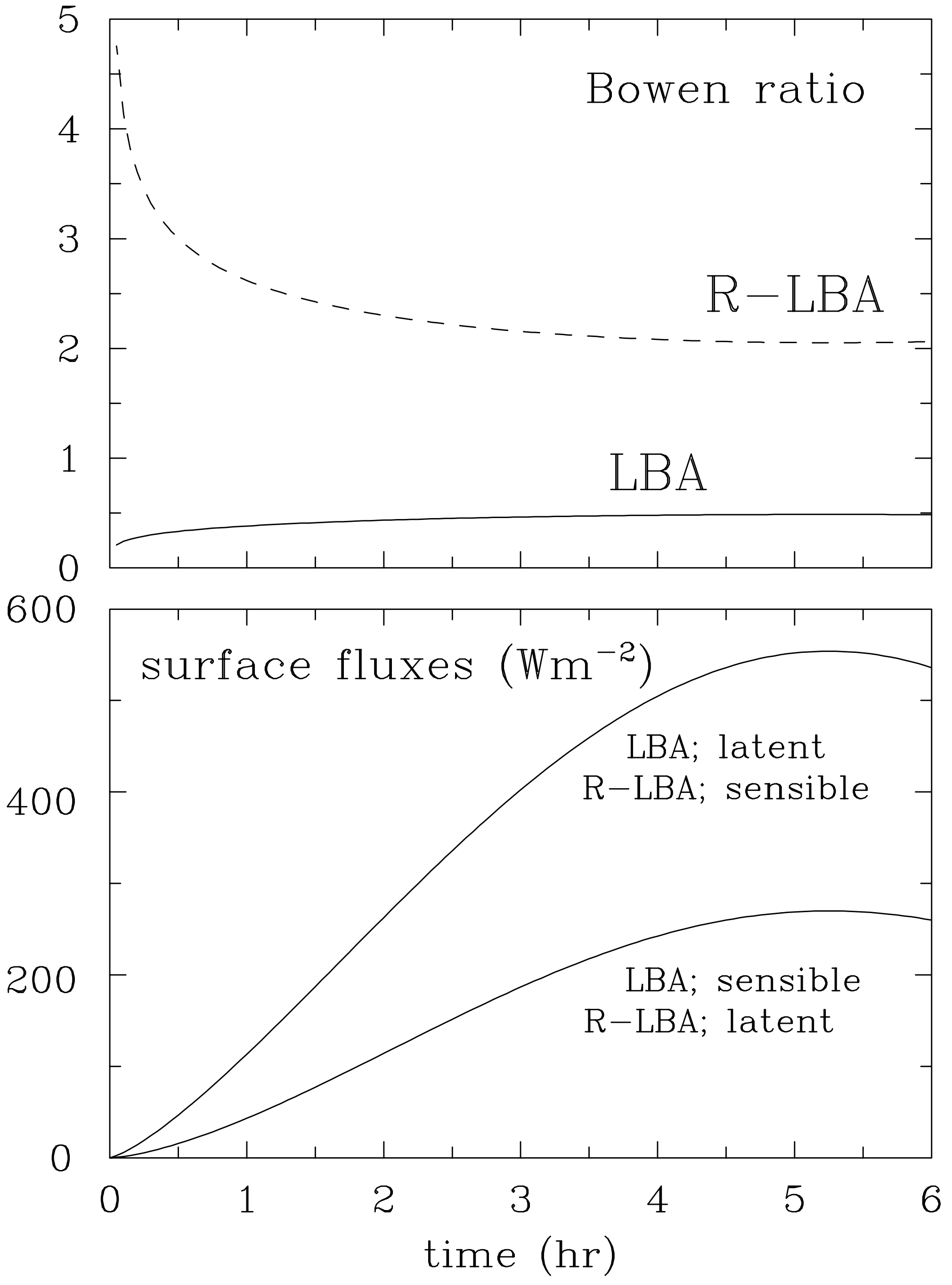
Grabowski et al. (QJ 2006)

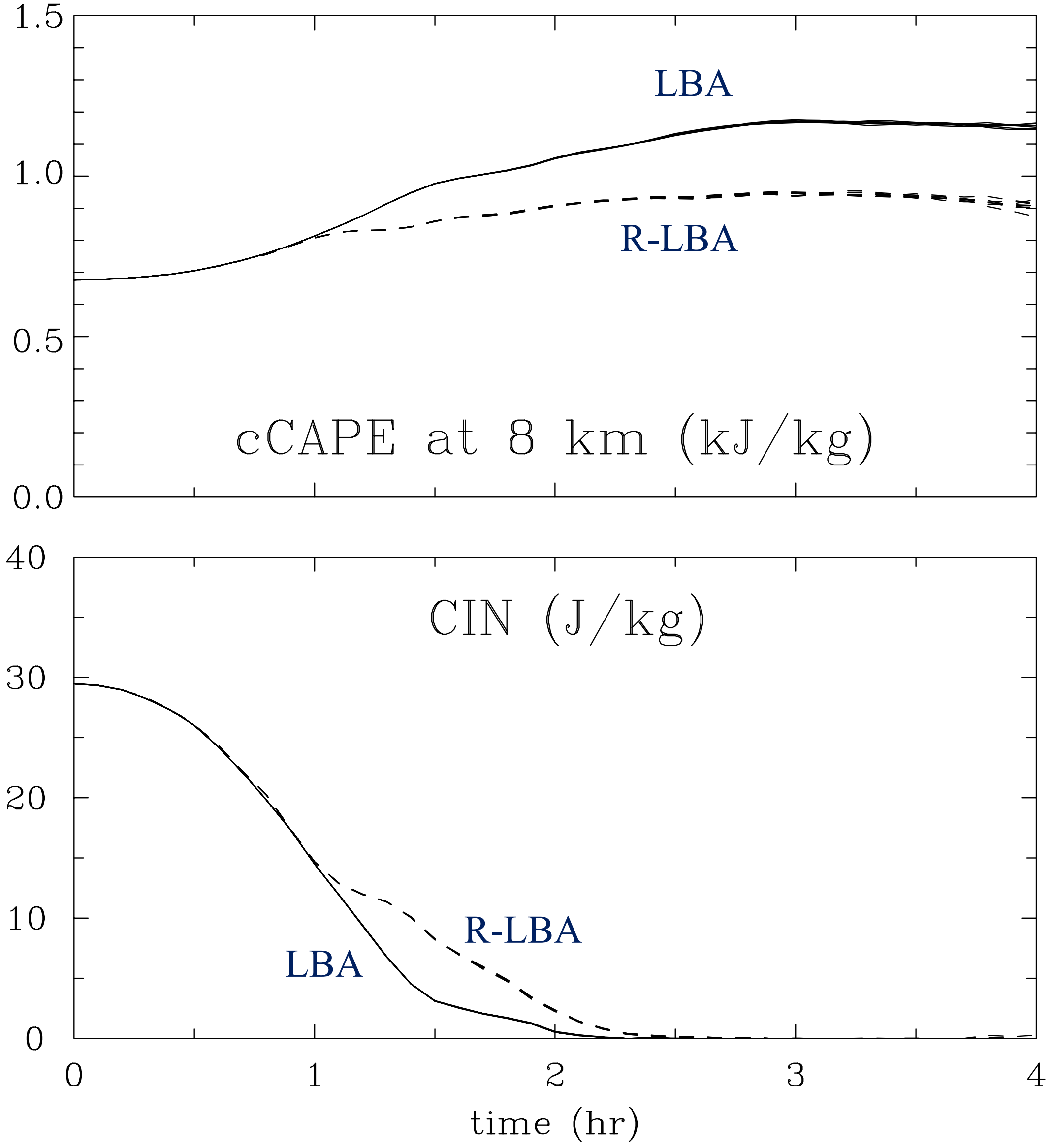
The idea: replace sensible and latent surface heat fluxes to illustrate the role of surface forcing:

LBA – as in Grabowski et al.

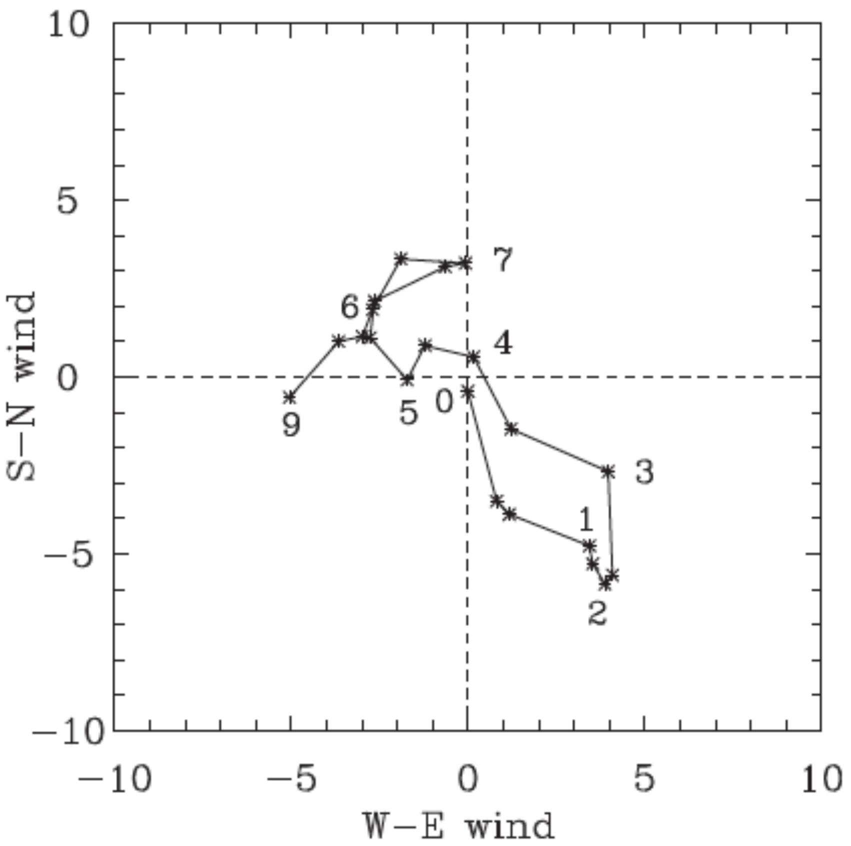
R-LBA – fluxes replaced
(latent becomes sensible;
sensible becomes latent)







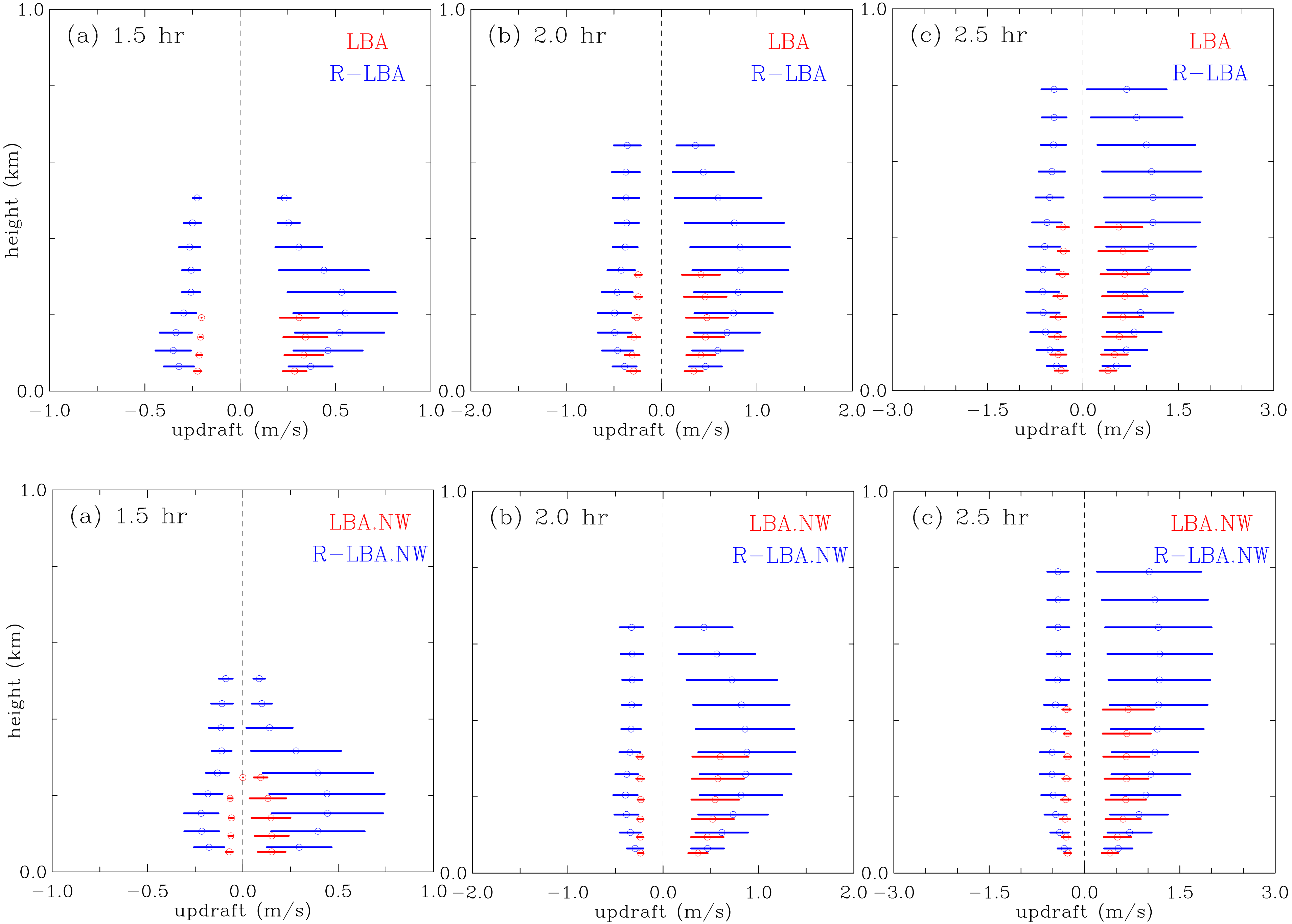
evolution of cumulative CAPE (cCAPE) and convective inhibition (CIN)

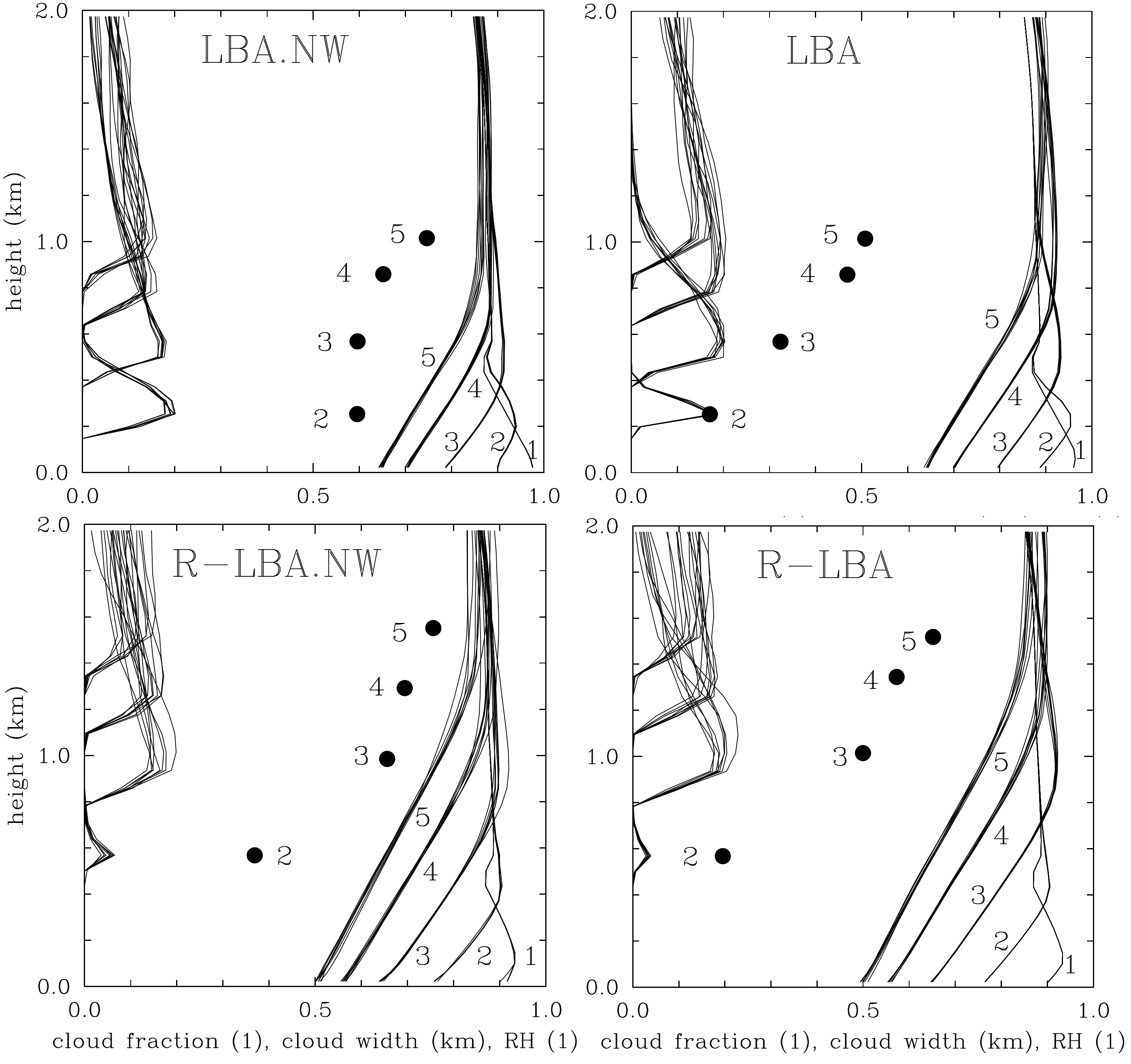


LBA wind profile from observations maintained through relaxation
(arguably inconsistent with BL evolution…)
Because of that, simulations with no wind are added.

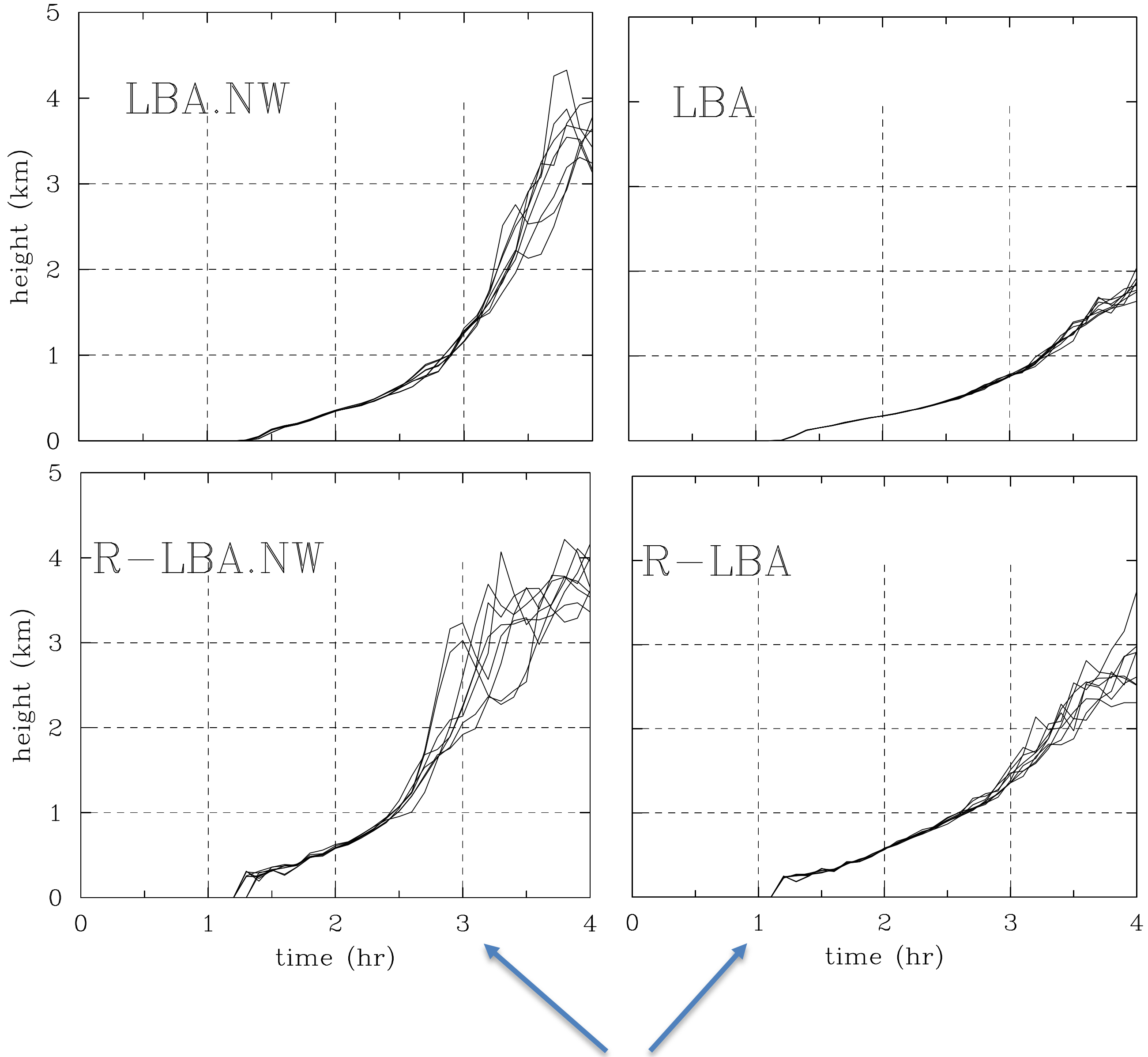
LBA, R-LBA – wind profiles as above
LBA.NW, R-LBA.NW – simulations with no mean wind

Updraft statistics in ensemble of LES simulations:



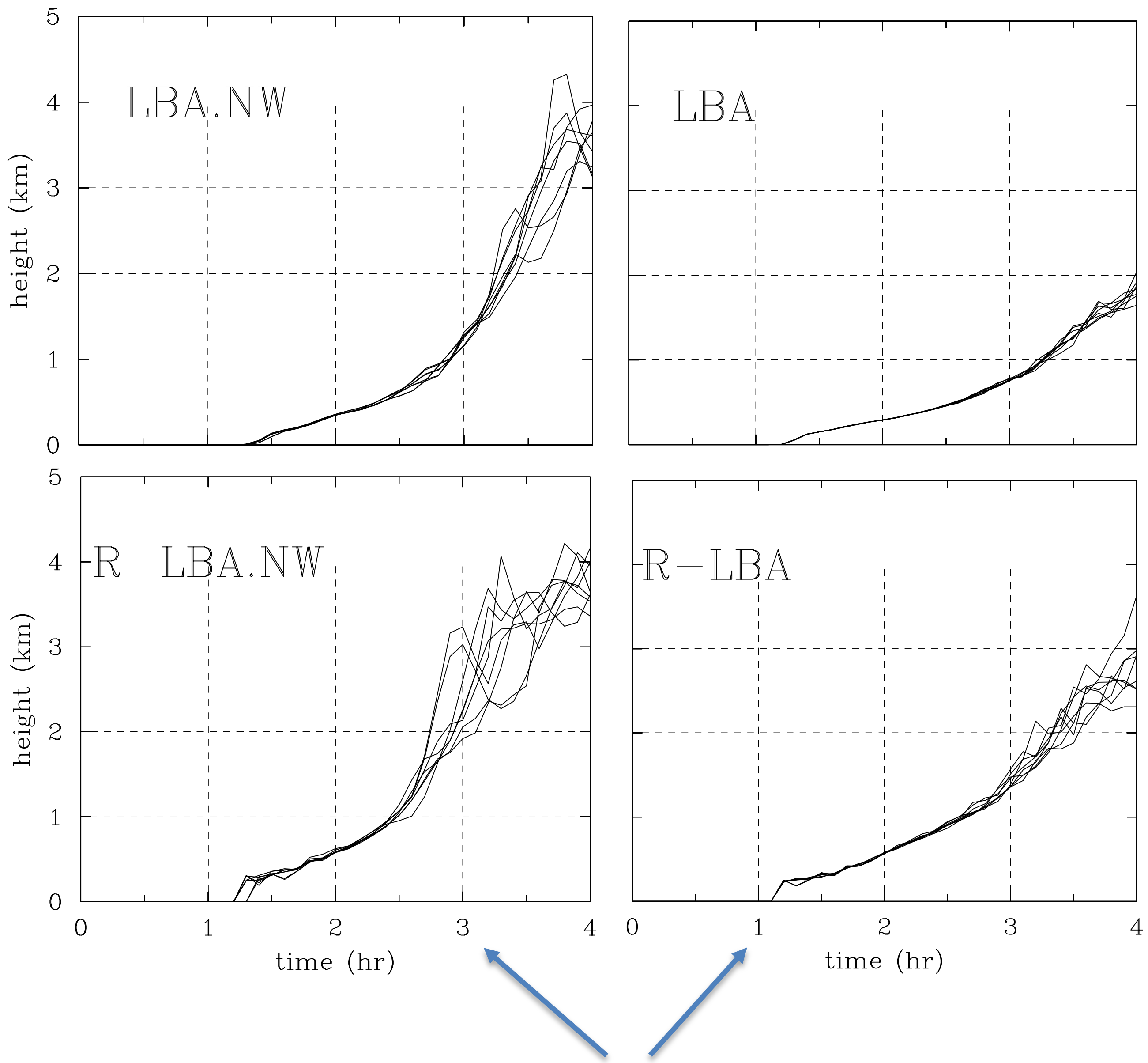

LBA.NW
LBA
R−LBA.NW
R−LBA
height (km)
0.0
1.0
2.0
0.0
0.5
1.0
1
2
3
4
5
cloud fraction (1), cloud width (km), RH (1)
cloud fraction (1), cloud width (km), RH (1)

Evolution of the height of cloud condensate center of mass



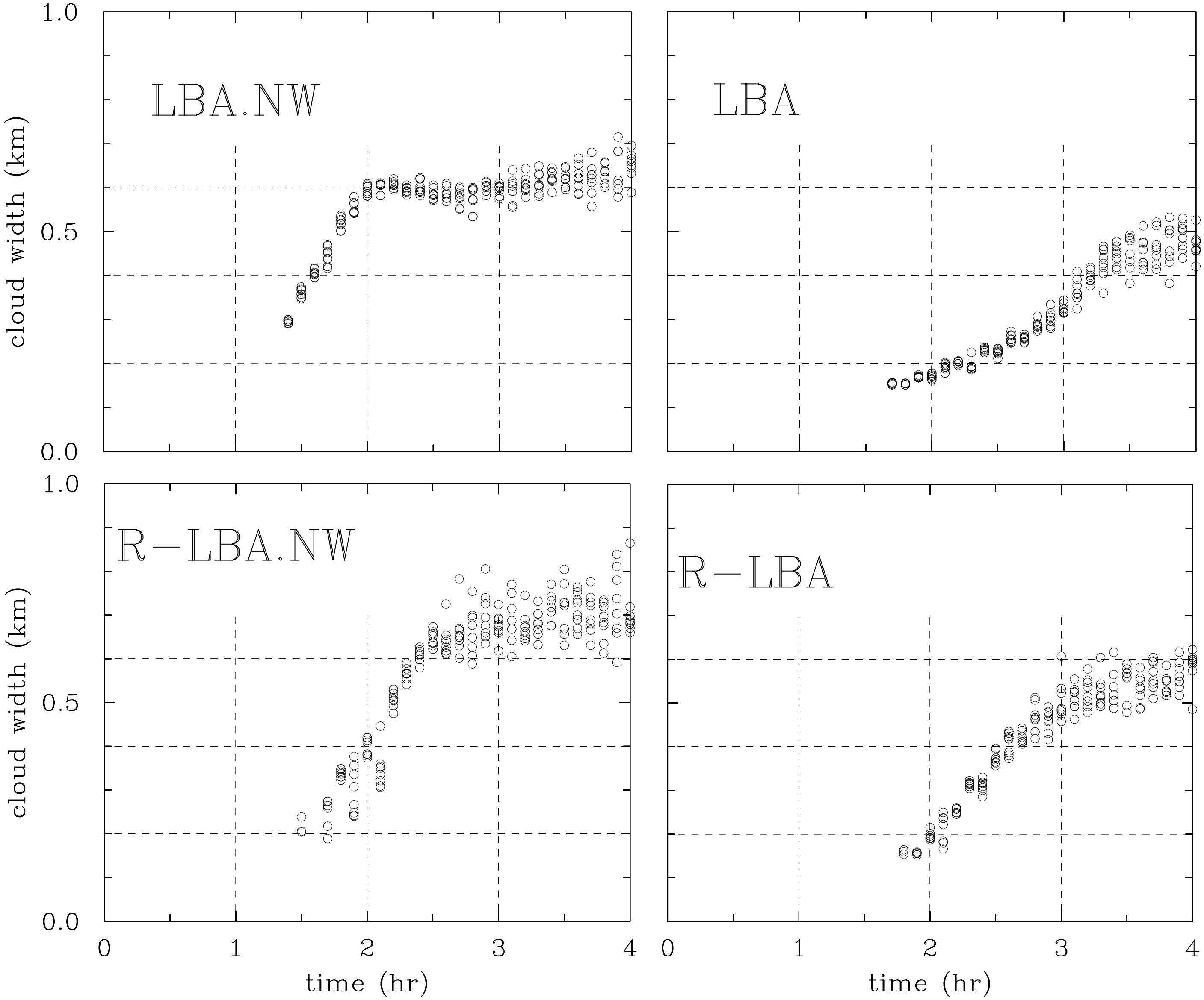
Earlier transition from shallow to deep in “no wind” (NW) cases…

Evolution of the height of cloud condensate center of mass

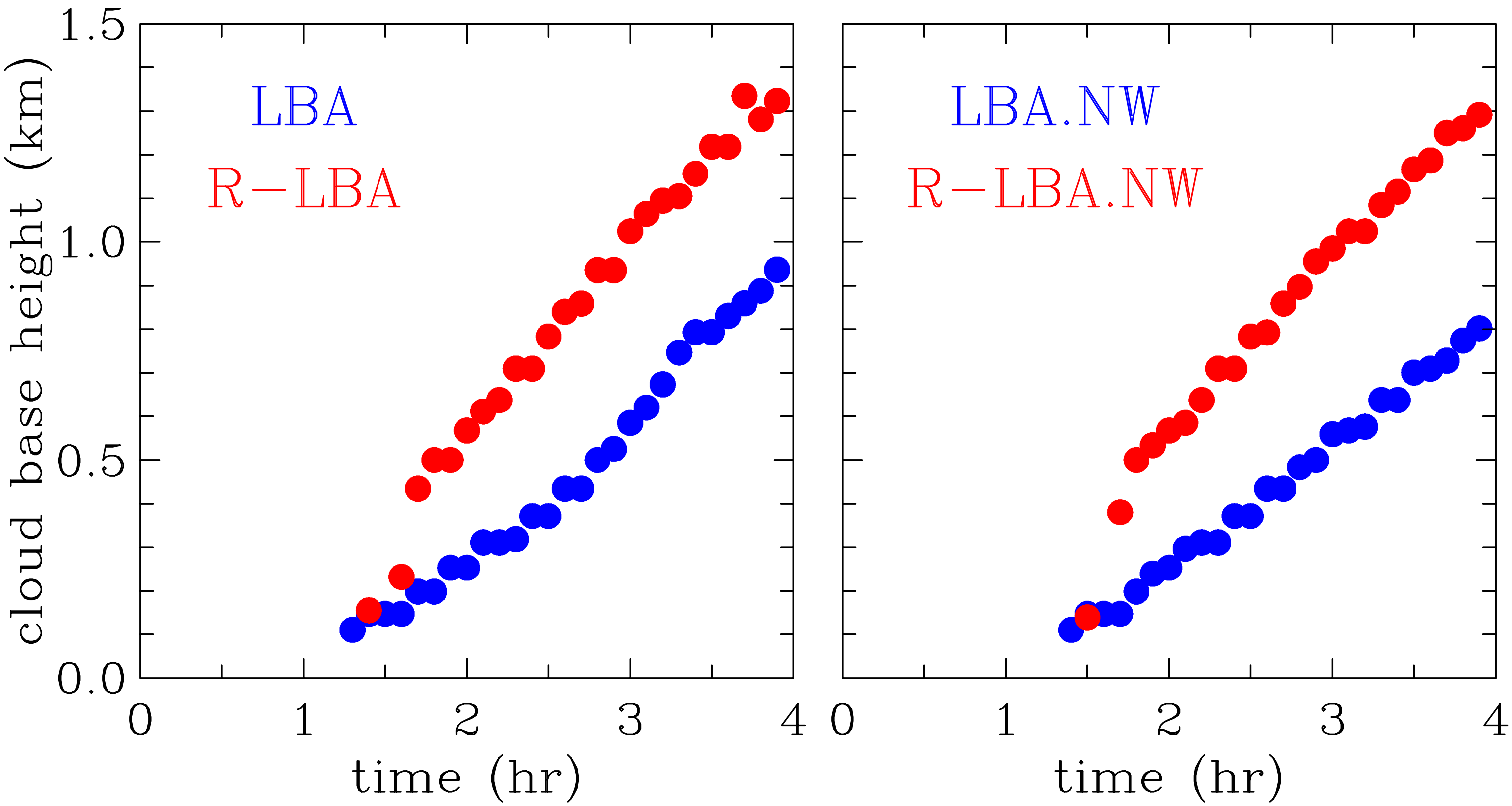


Cases with reversed surface fluxes (R) start higher and rise faster…

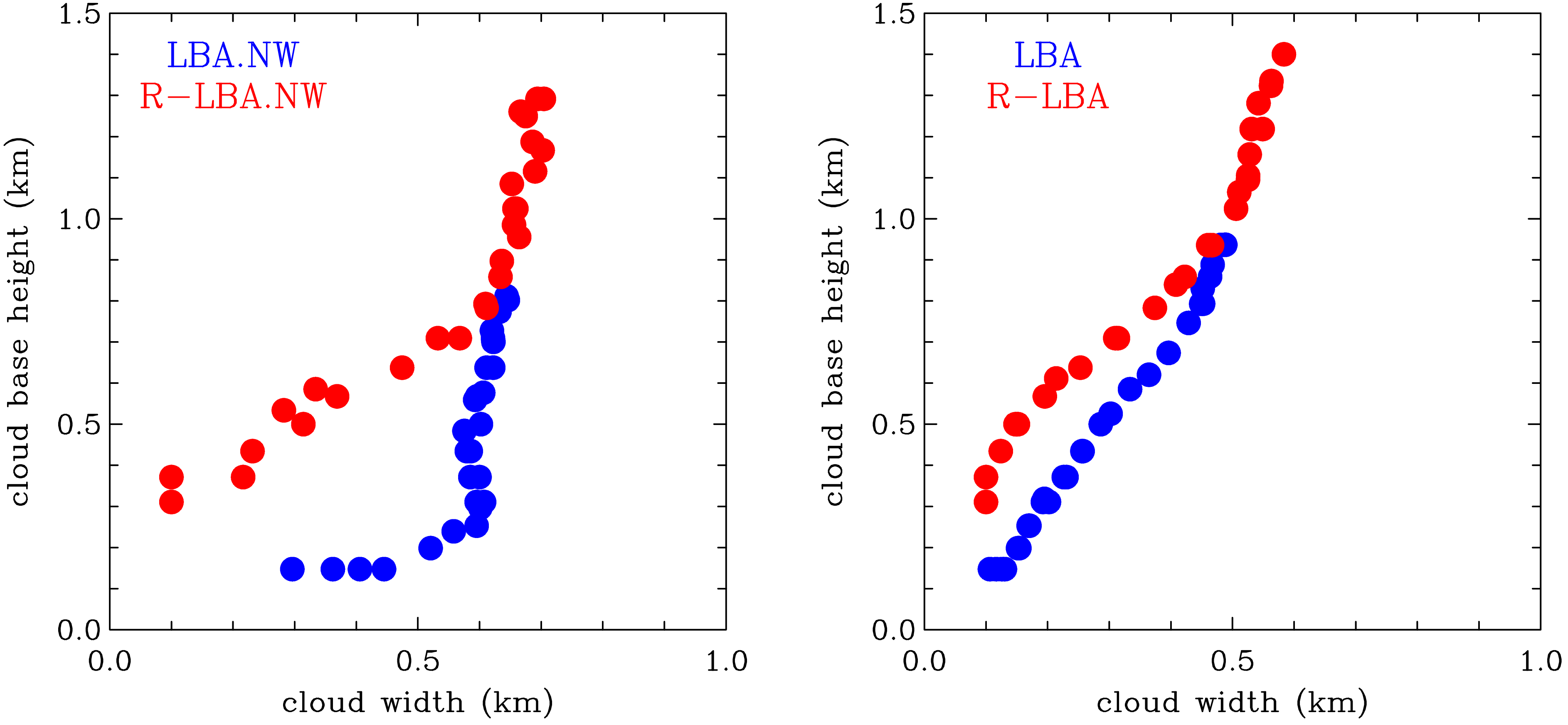
Evolution of the cloud width in all ensemble members (at the maximum of the cloud fraction, near the cloud base)



Evolution of the cloud base height



Cloud width versus cloud base height



Summary for deep convection simulations:

Surface buoyancy flux in morning hours determines the growth rate of the convective boundary layer. Surface buoyancy flux depends on the surface flux Bowen ratio.

Cloud width at the cloud base (i.e., the size of the sub-cloud ascent) seems to increase with the increase of the boundary layer depth.

Transition to deep convection takes place earlier with reversed surface fluxes (R simulations) and even faster in no-wind (NW) simulations.