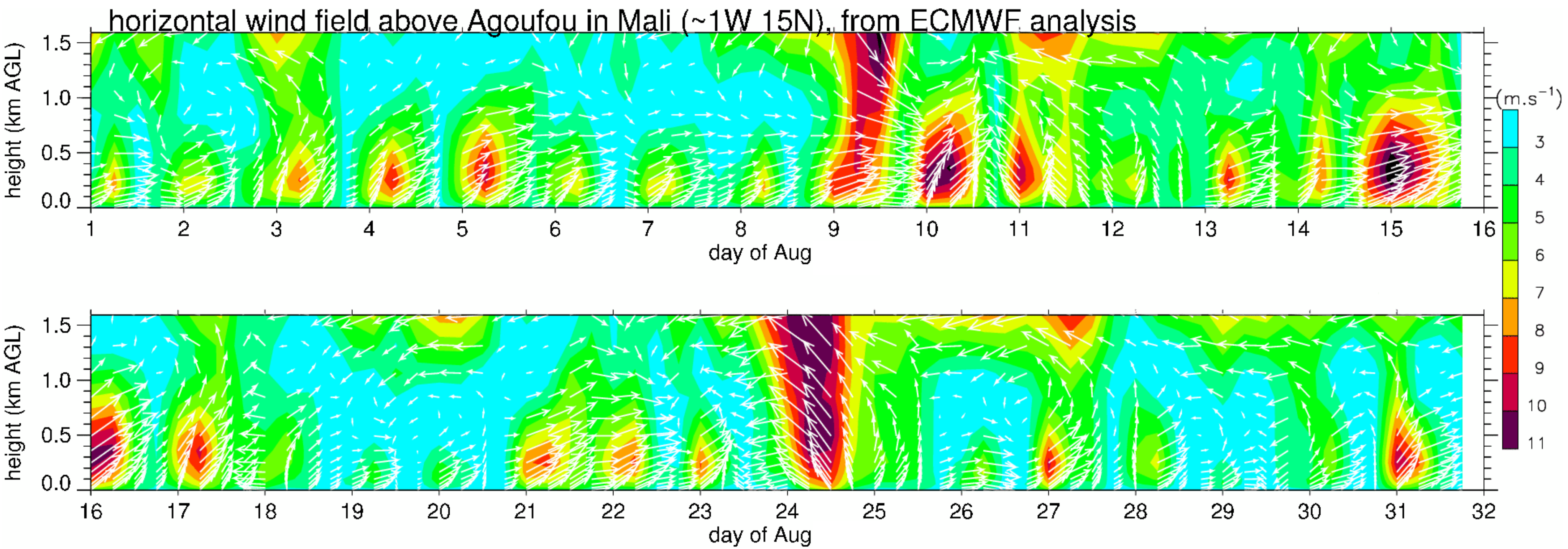
What can we learn from AMMA about physical processes and models?

Françoise Guichard

CNRM-GAME, CNRS & Météo-France, Toulouse



OUTLINE

1) broad context

2) modelling

- large scale *[GCMs along a N-S transect, AMMA-CROSS]*
- mesoscale *[comparison of mesoscale simulations of an MCS]*

(documenting current state, pointing to specific issues)

3) analysis of data *[surface climate and radiative budget)]*

- seasonal & diurnal cycle in the Sahel, interannual variability
- contrasting Sahelian & Soudanian sites

(including comparison with ECWMF IFS)

4) summary

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***A**frican **M**onsoon **M**ultidisciplinary **A**nalyses*

***A**nalyses **M**ultidisciplinaires de la **M**ousson **A**fricaine*

***A**frikanischer **M**onsun: **M**ultidisziplinäre **A**nalysen*

***A**nalisis **M**ultidiciplinar de los **M**onzones **A**fricanos*

International program with European, African & individual countries components

multi-(time & space) scales approach / multidisciplinary *(Redelsperger et al. 2006)*

atmospheric and surface processes, hydrology, vegetation, aerosols, chemistry…

long observation period (LOP), extended (EOP) 2005-2007 & special (SOPs) 2006

reinforcement of the existing sounding network, surface stations (flux, GPS…)

SOP: aircrafts, enhanced frequency of soundings, radars, AMF, lidars, balloons…

Lebel et al. (2008)

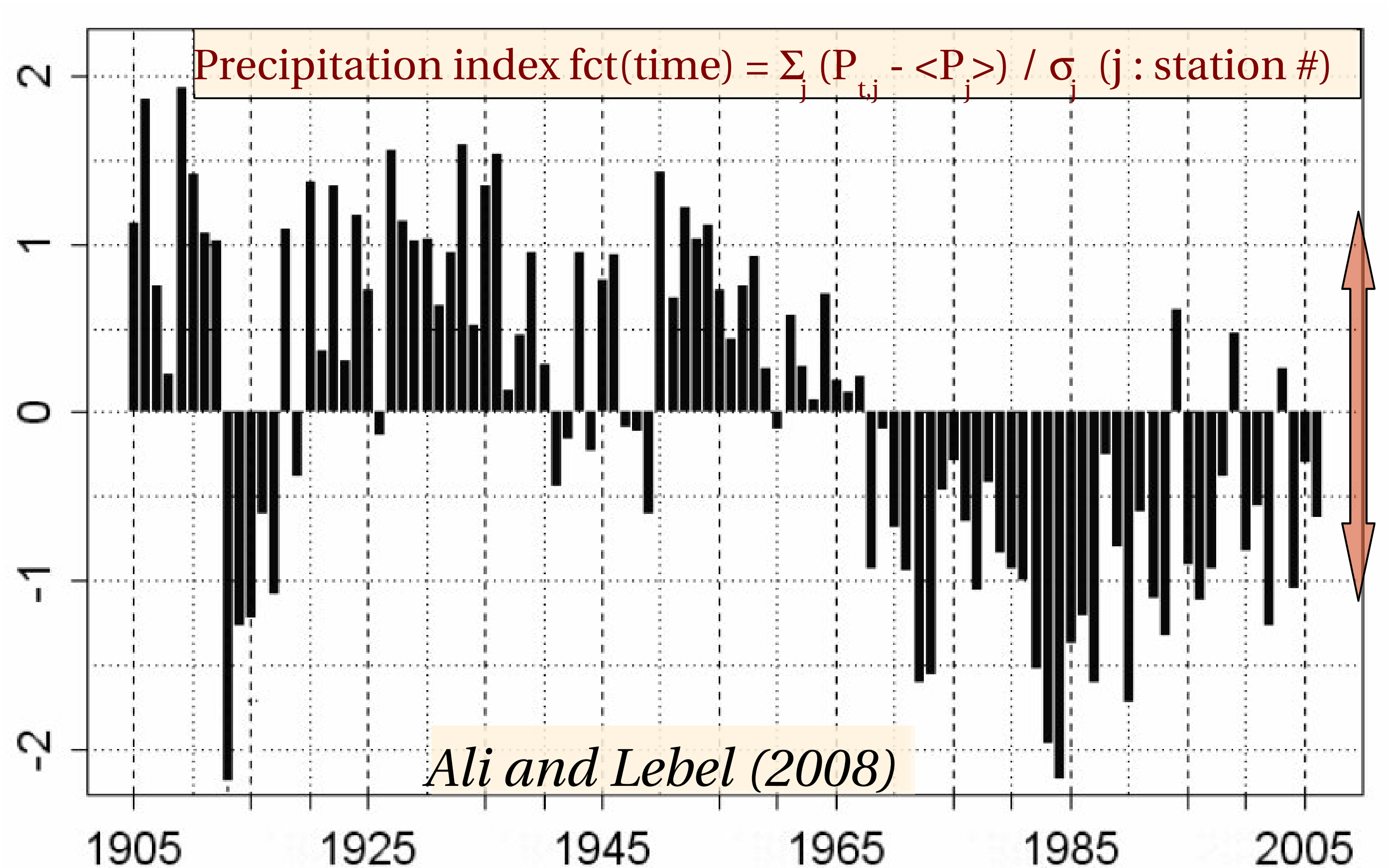
few routine observations and field campaigns over West Africa

GATE 1974, COPT 1981, HAPEX-Sahel (1992), JET 2000 , limited in time & space

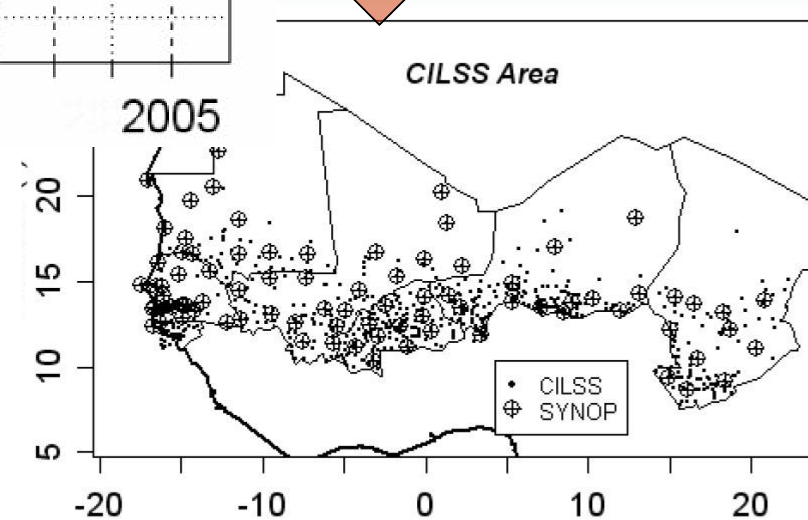
a widening of the size of the research community involved (obs & model)

Rainfall variability at different scales : a major motivation of AMMA

« most dramatic example of multidecadal variability » (Hulmes 2001)



20-30 % decrease



causes not yet fully understood / explained

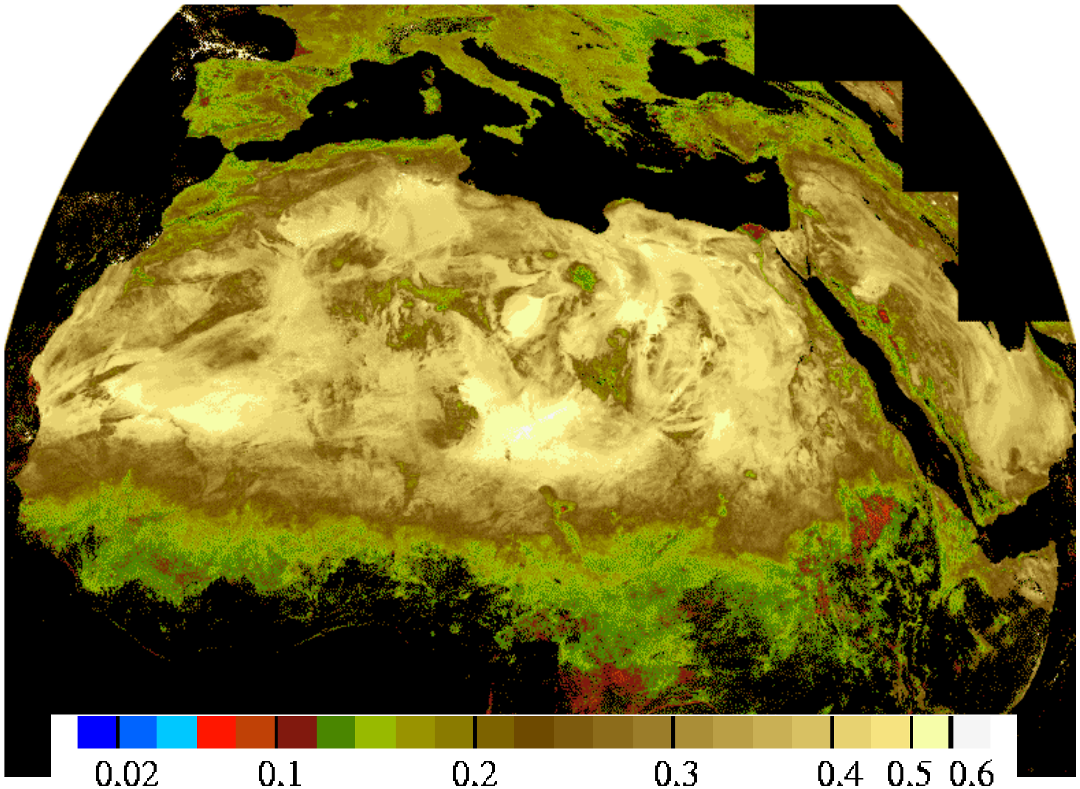
land changes versus ocean influences

climatic projections diverge *(Cook & Vizi 2006)*

context: rainfall critical , Sahel *means* shore

Specific features at large scale

albedo June 1996 EUMETSAT/JRC



at the surface

vegetation, albedo, rainfall...

in the atmosphere

e.g. the African easterly jet (AEJ)
present the Summer

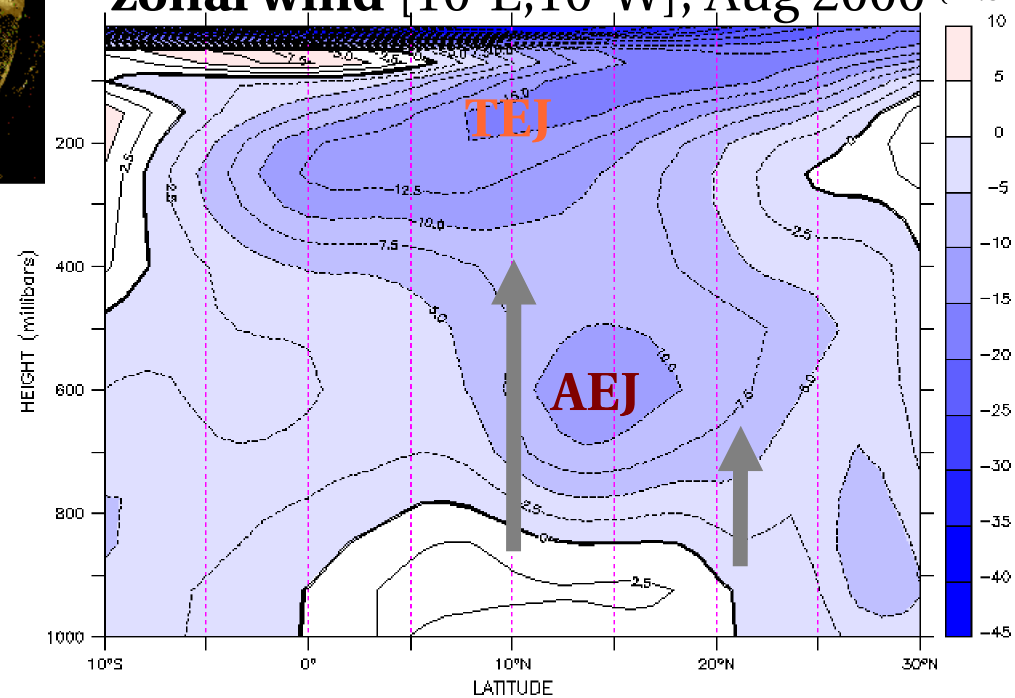
well defined strong meridional gradients

seasonal cycle , jumps
interannual variability

- *inspired several studies based on a 2D modelling approach*
  - Zheng & Eltahir (1998)
  - Peyrille et al. (2007)
- *motivated AMMA-CROSS*
  - Hourdin et al. (2008)

ERA40

zonal wind [10°E,10°W], Aug 2000 (m.s^{-1})



moist convection over West Africa

spectacular. .. but also very "rich"

- very deep convection, intense lightning, transport of dusts/aerosols

- importance of MCSs: explain ~70-80% of the precipitation *(Mathon et al. 2002)*
  - strong interactions between convection & synoptic African easterly waves
  - coupled to patchiness of rainfall, down to 10 km scale at seasonal timescales

    (Taylor & Lebel 1998) links/couplings with surface & boundary layer processes?

- deep convection & weak rainfall, which significance of rainfall evaporation?

- strong diurnal cycles
  - of moist convection & clouds
  - of thermodynamics & dynamics of the low levels *(Parker et al. 2005)*
  - for rainfall: region/season dependent, involves propagation of MCSs

surface & **low atmospheric levels**

♦ thought to be key elements of the West African monsoon
starting from Charney (1975), Gong & Eltahir (1996)

- ≠ space and time scales (paleo to diurnal, meso scales)
- ≠ mechanisms of surface-atmosphere interactions

♦ mechanisms not well known/quantified , not all known

♦ not much studies on low clouds & aerosols

♦ hypotheses, controversies in past decades
academic & GCM-based studies, useful but few data available for guidance / testing

factors controlling surface fluxes & their variations ?
limited dataset from SEBEX/HAPEX-Sahel

More broadly, in brief & partial, about **AMMA, processes and models**

- monsoon system , strong couplings among dynamic & physical processes
- a variety of surface, boundary layer and convective regimes *in space and time*
- processes over ***lands*** : tropical (Soudanian), semi-arid (Sahel) to desertic (Sahara)

- emergence of new ideas/questions

  African easterly waves, their nature, initiation, e.g., Thorncroft et al. (2008)

  significance of processes at mesoscale: which ones? where? when? for what?

  e.g. mesoscale circulations (Taylor *et al.* 2007), convective outflows, coupling between convective and aerosol-related processes (uplift, radiative ppties)...

- need to assess more precisely the performances & limitations of models

  interannual, seasonal, intraseasonal, diurnal cycles and water cycle

- need to analyse the large amount of data collected

  guidance, discriminate between mechanisms that are actually operating versus others

"what can we learn", not what we learnt [already]...

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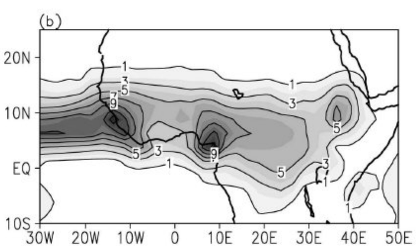
modelling at large scale

<u>ocean coupled IPCC runs</u>

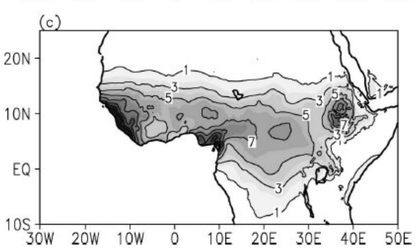
Cook and Vizi (2006)

a critical location for models which perform much better elsewhere

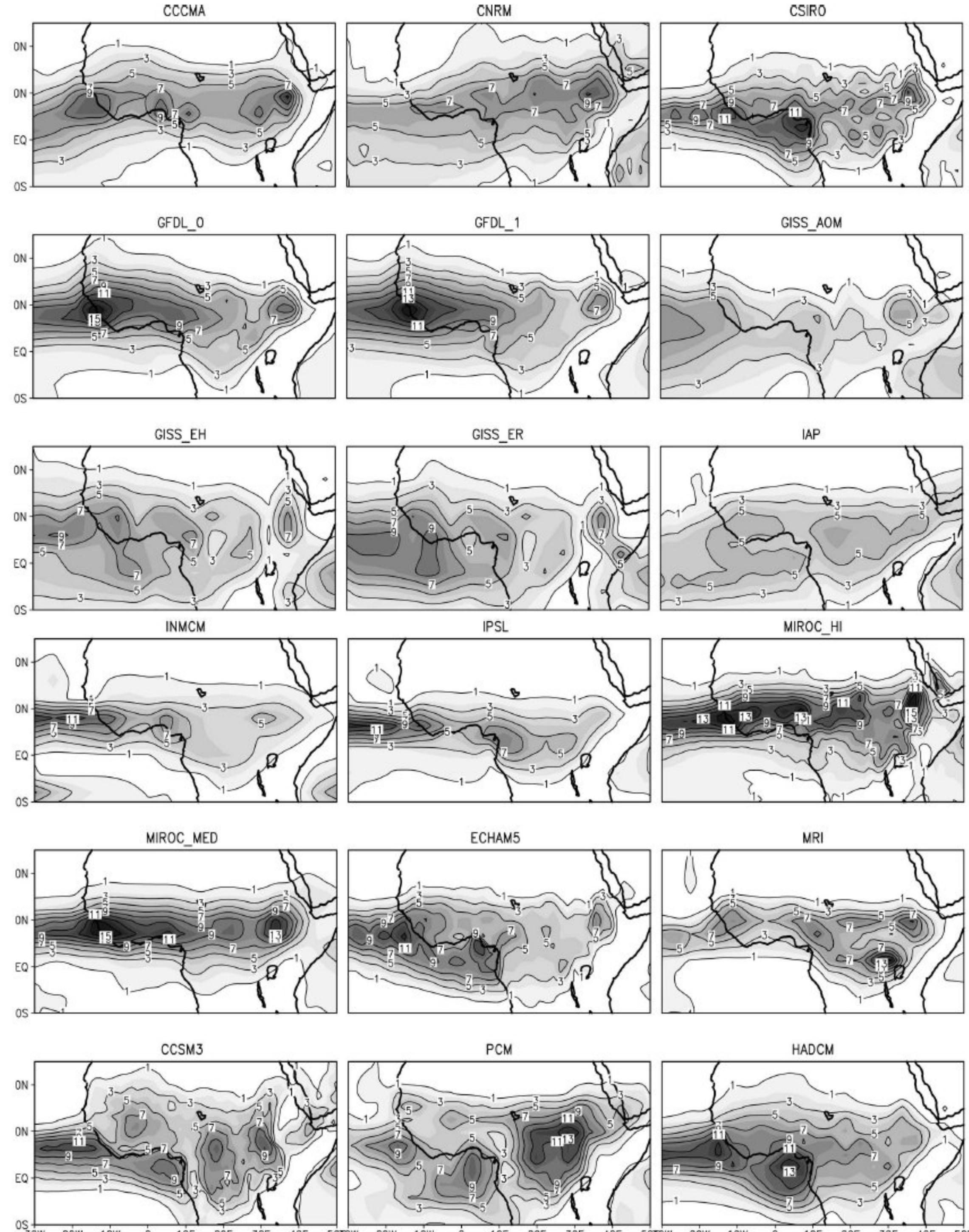
JJAS 1979-2005 (CMAP)



JJAS 1961-1990 (CRU)



JJAS 1949-2000

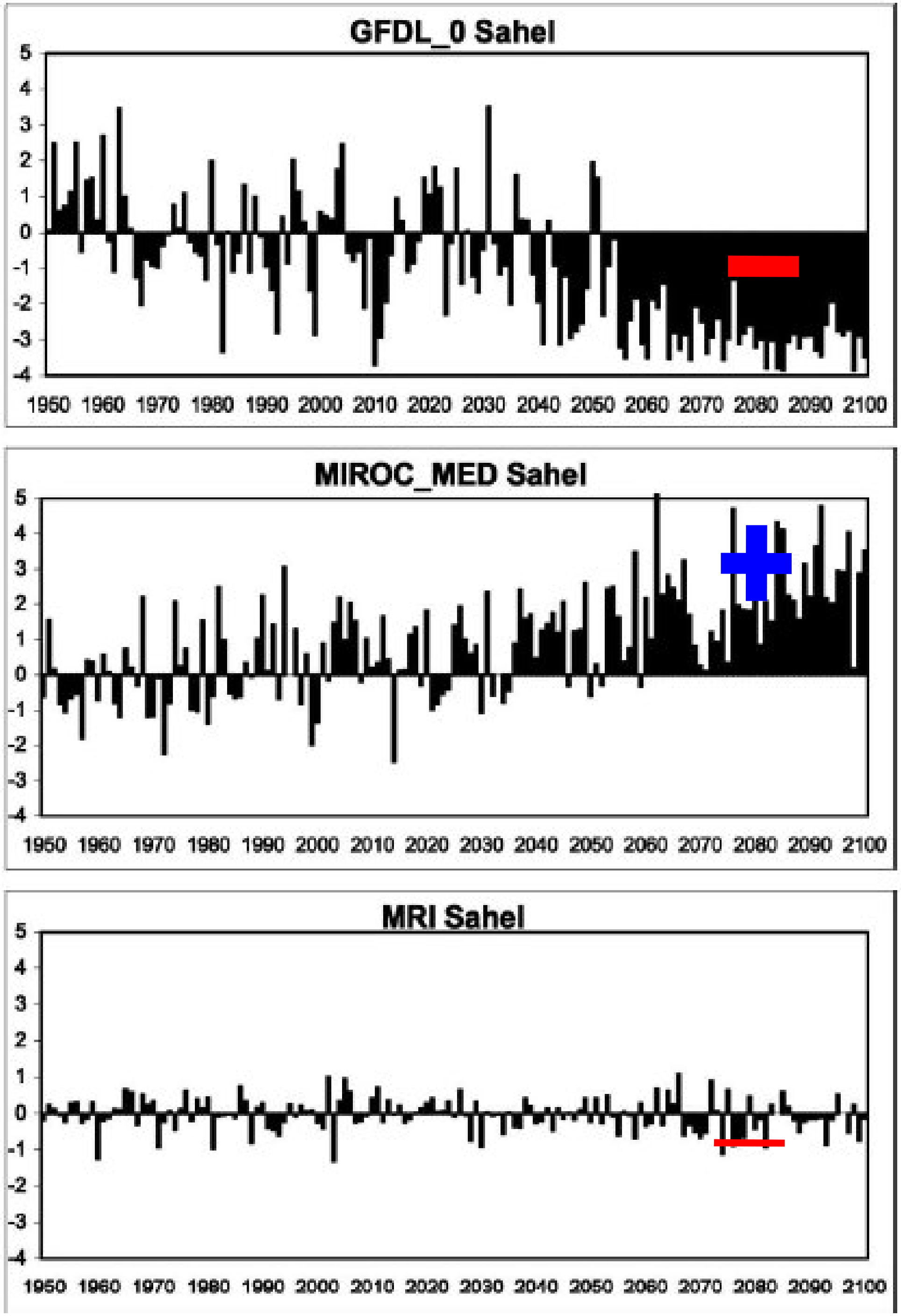


Cook and Vizi (2006)

projections for XXI century

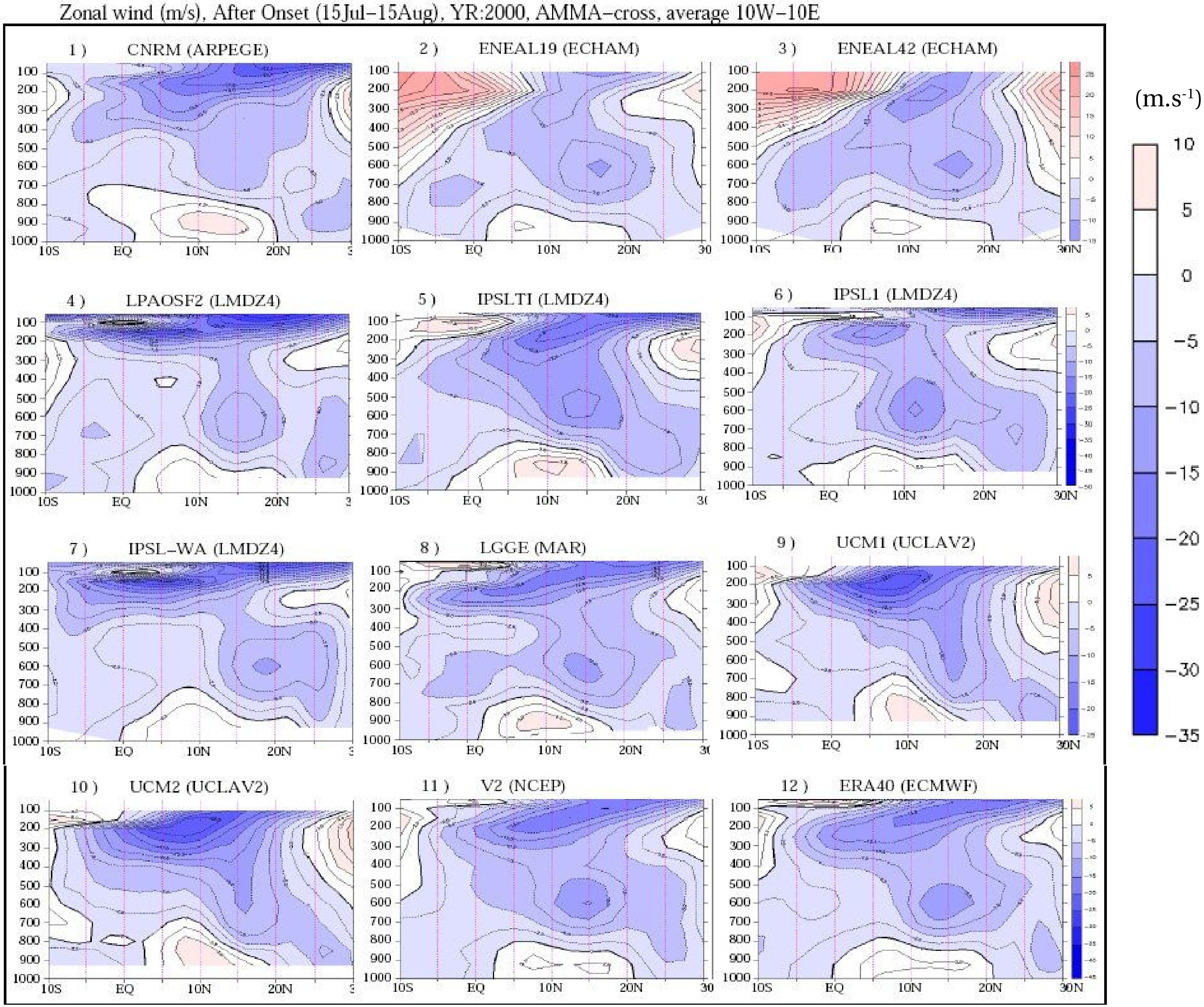
with the 3 “more satisfying” GCMs

(i.e. able to reproduce some specific features of the West African monsoon system)



AMMA-CROSS
Hourdin *et al.* (2008)

zonal wind fct(latitude , height)



GCMs/RCMs with prescribed SST

5 models, some with ≠ configs.

monsoon flow & AEJ simulated

but with spread in intensity & position

no generic explanation accounting for differences

internal variability with 1 GCM << variability among GCMs
<< sensitivity to parametrization/resolution

sensitivity to parametrizations : convection scheme

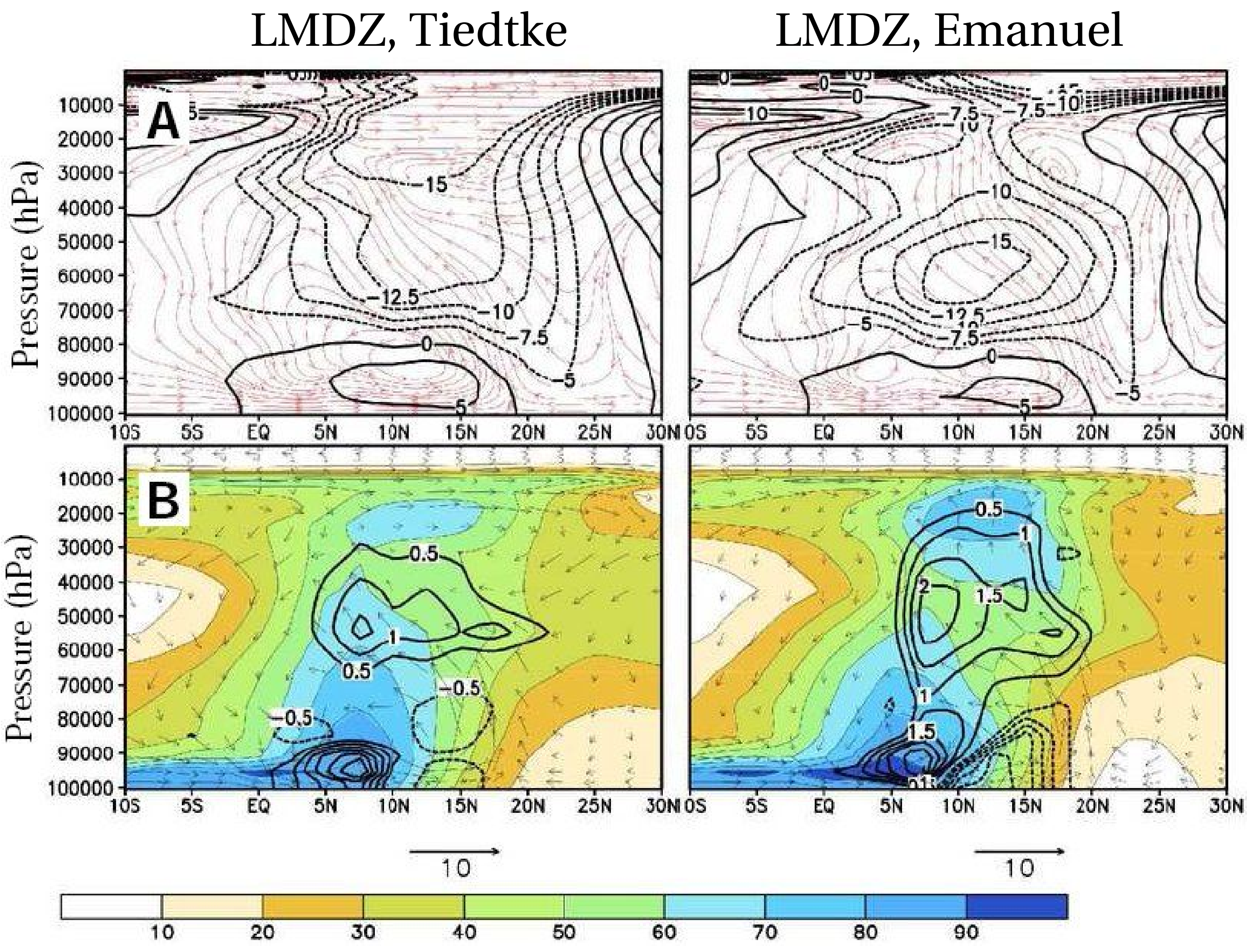
zonal wind

(m.s^{-1})

convective heating rate

(isolines, K.day^{-1})

RH (colors)

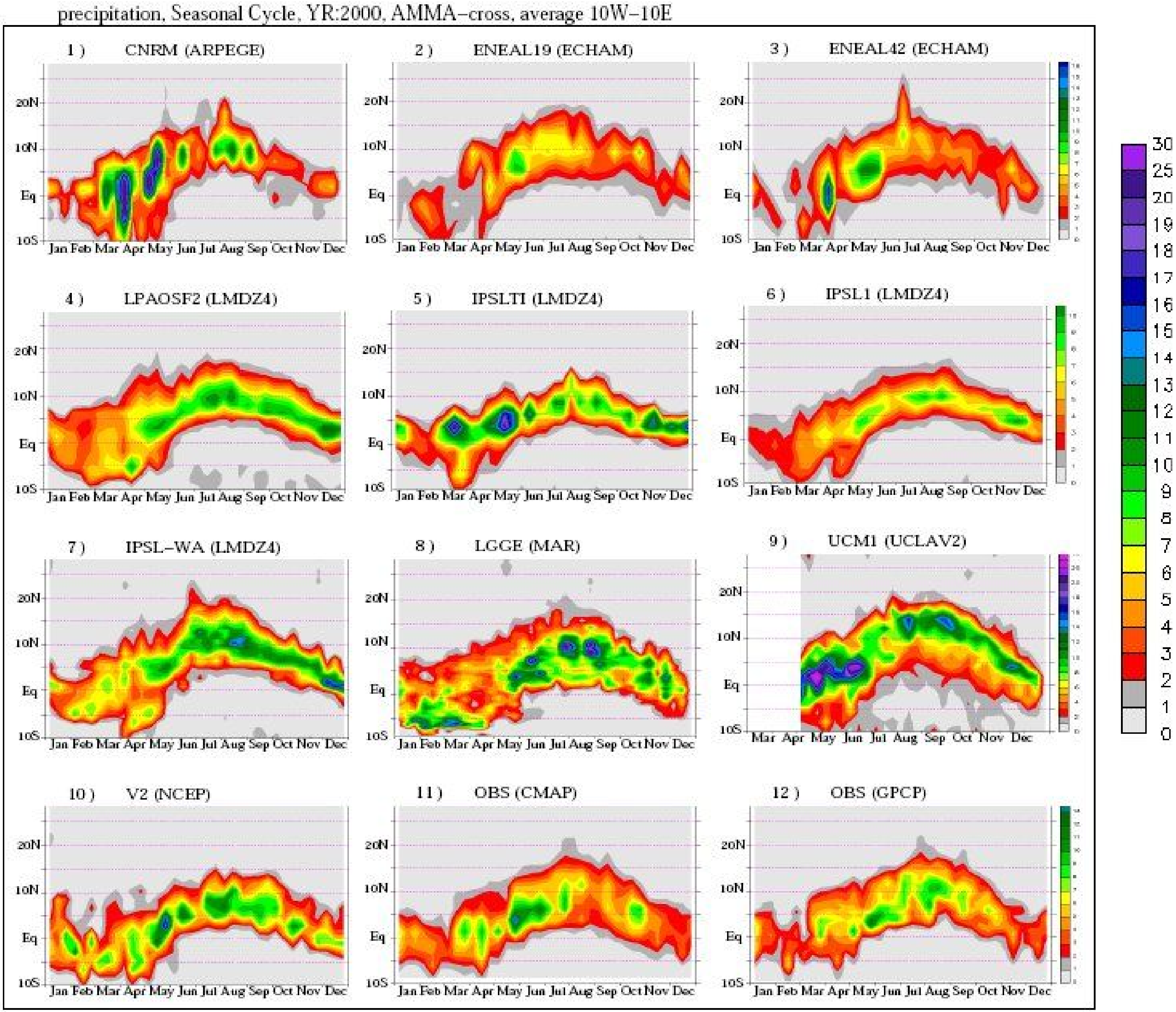


Hourdin et al. (2006)

Precipitation fct(time , latitude)

no simple links between biases in AEJ & rainfall

intraseasonal variability in GCMs : why? good reasons? *to be explored*



Hourdin et al. (2006)

evapotranspiration :
[10°E,10°W]
during monsoon

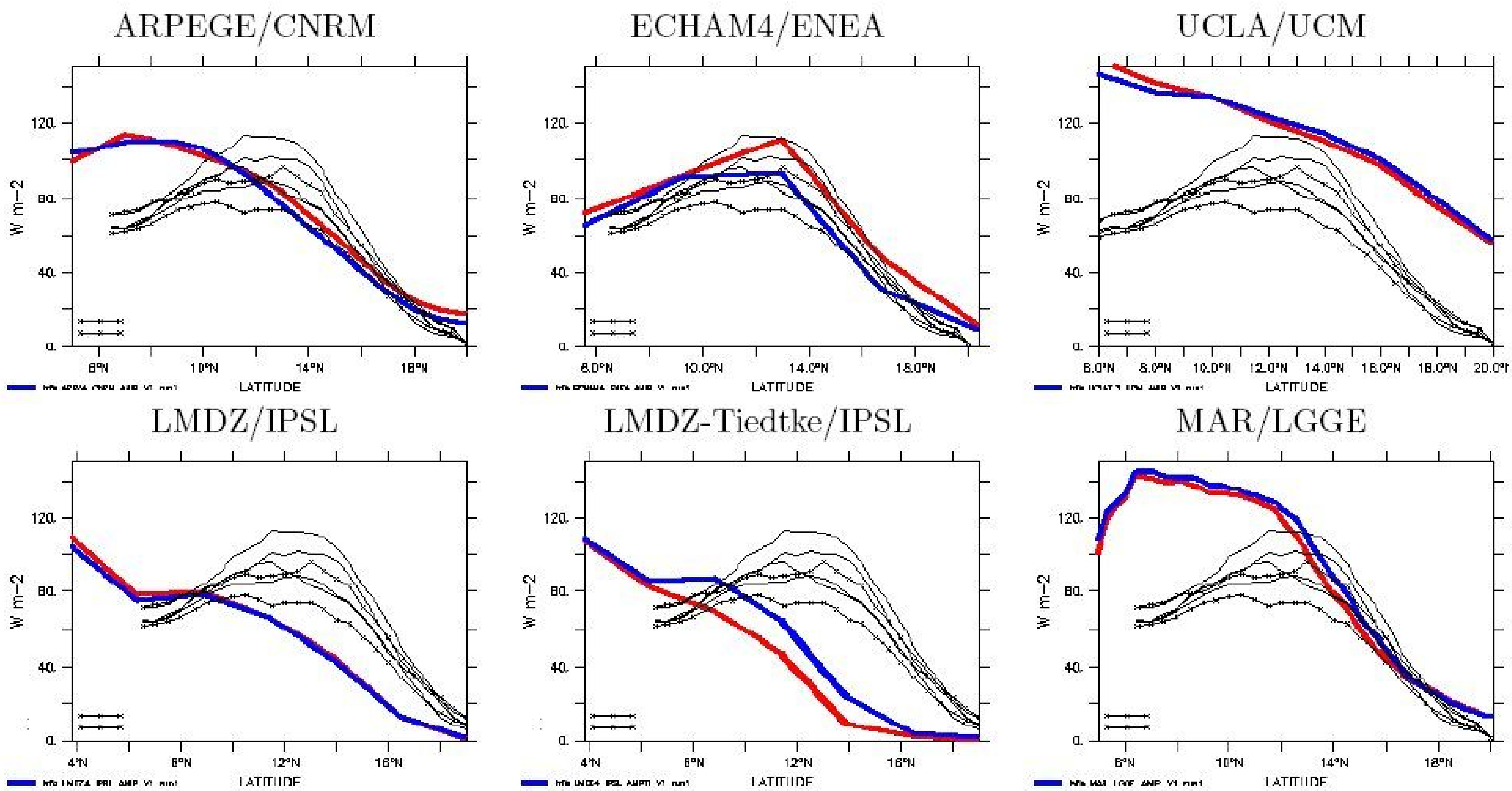
GCMs

1 dry & 1 wet year

&

LSMs offline (ALMIP)

1 line = 1 LSM



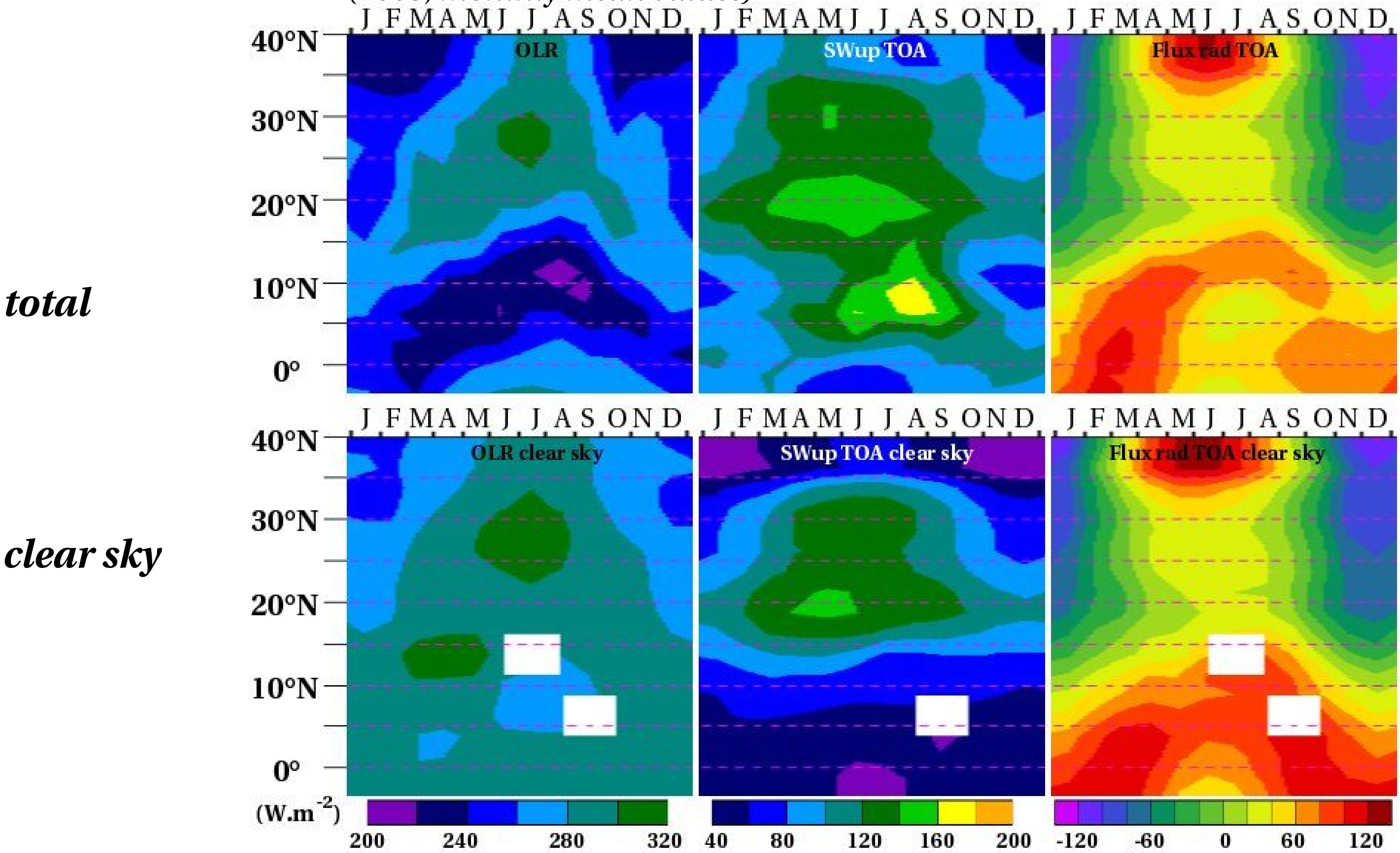
all over the place, significant impact of errors in rainfall likely
LSM outputs are valuable

Hourdin et al. (2006)

CERES-TERRA, TOA radiative flux

"thermodynamic factor" of Chou & Neelin (2003)

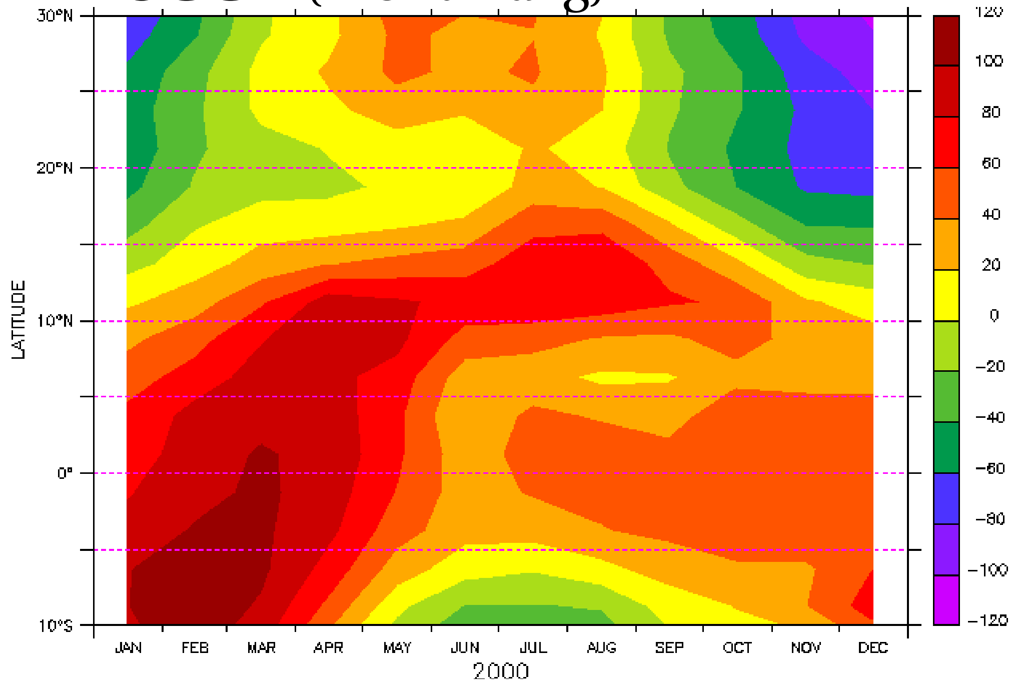
(2003, monthly mean values)



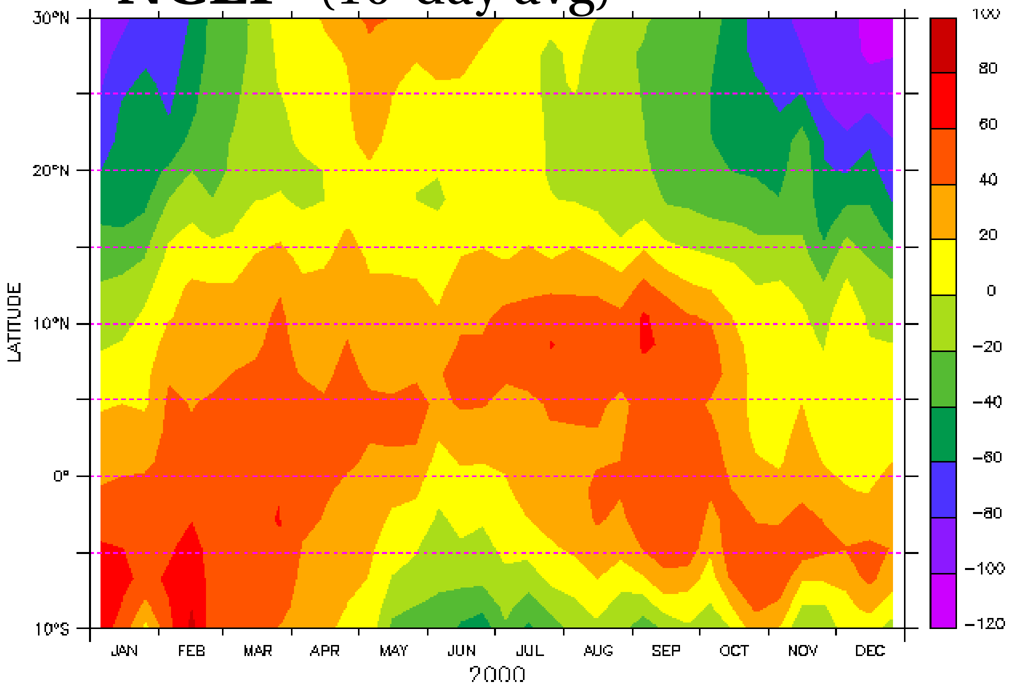
tongue of max incoming net radiation at TOA located over the Sahel in July-August
involves surface albedo & LW & SW cloud radiative forcings
same structure with other satellite products – what about models ? do they care?

TOA net radiative flux

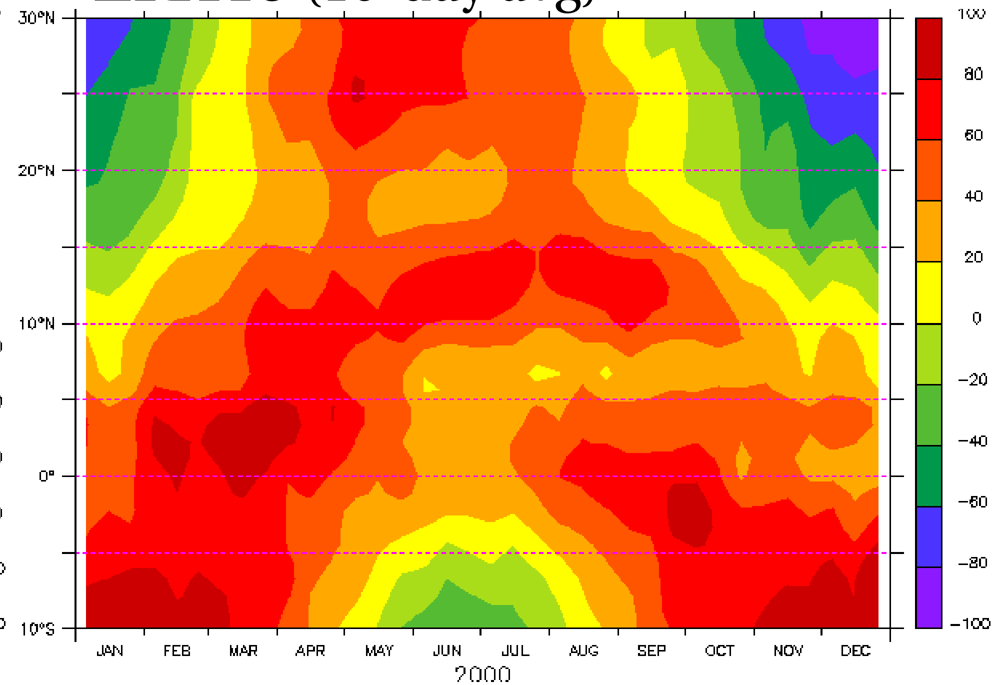
ISCCP (month-avg)



NCEP (10-day avg)



ERA40 (10-day avg)



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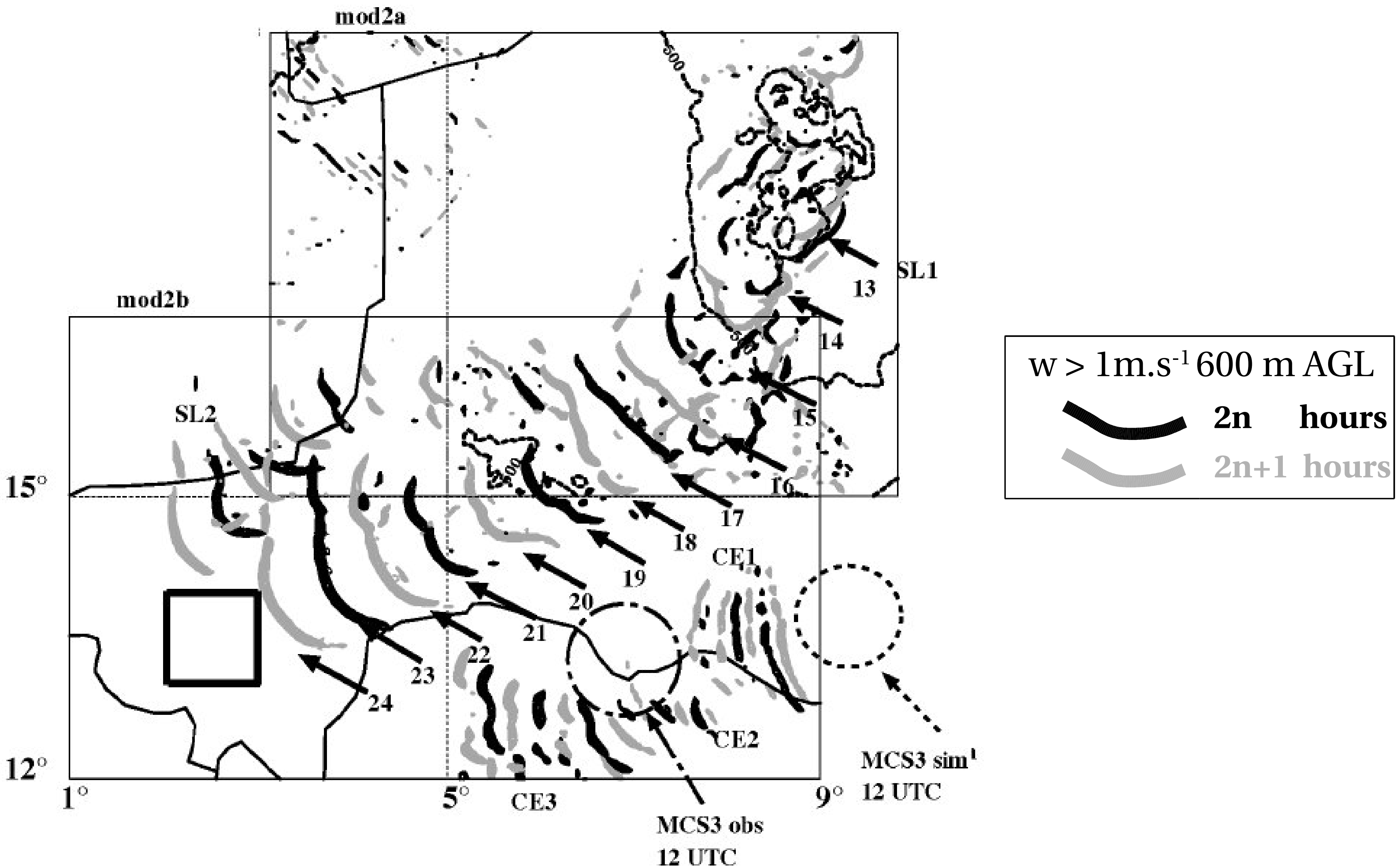
mesoscale modelling

until the 90's, much focus was on the simulation of the mature phase of squall lines with CRMs, academic framework, warm/cold bubbles, introduction of ice-phase & radiative processes

Diongue *et al.* (2002) : explicit simulation of an observed Sahelian squall line

method : mesoscale model with grid nesting , inner domain dx=5 km
objective : convection-wave interactions in a less academic frame

Diongue *et al.* (2002)



« quasi-stationary » behaviour during several hours
cover 1000 km in 15 hours, propagation speed of 17 $m.s^{-1}$

Diongue *et al.* (2002)

IR temperature

observed simulated

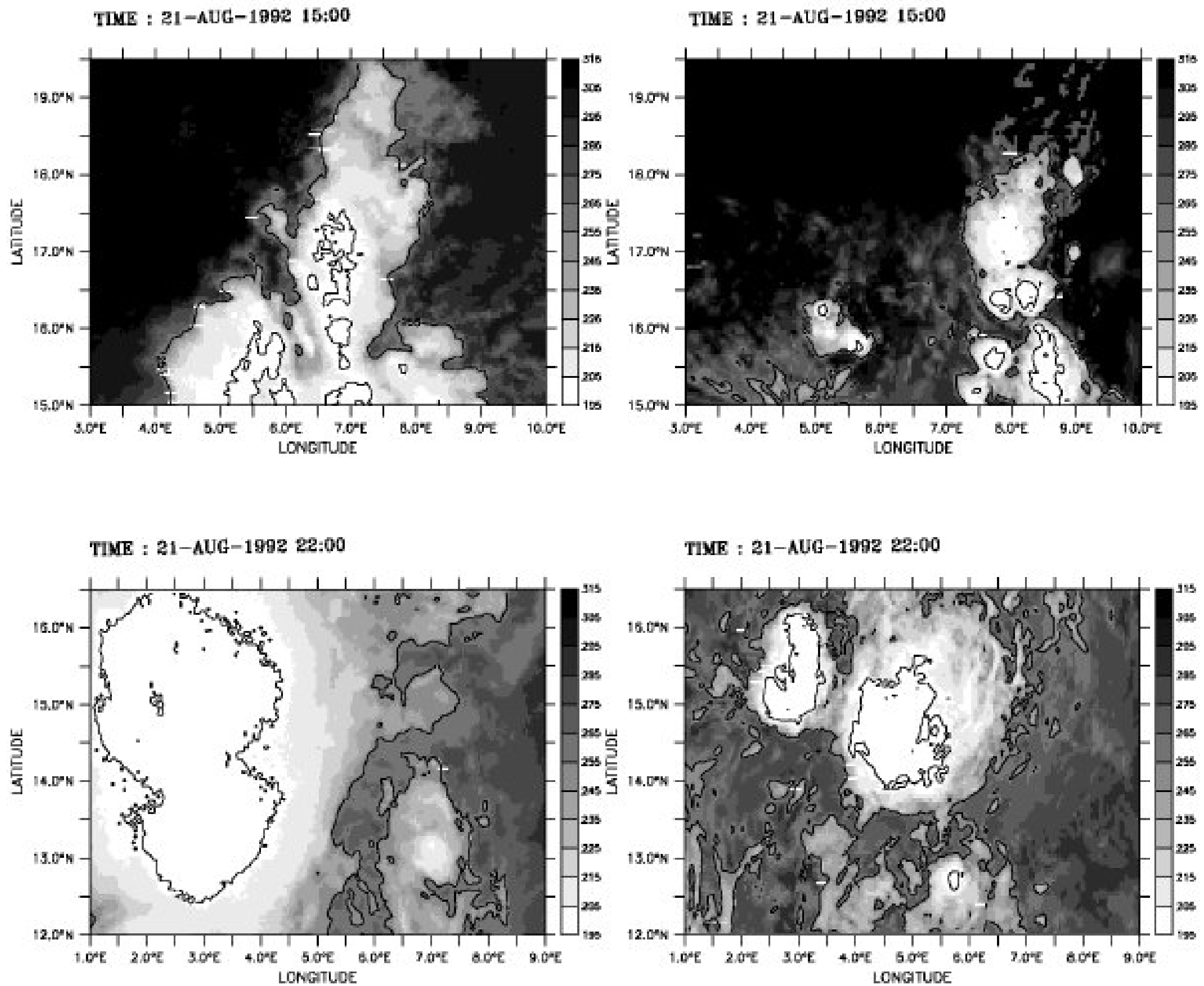


Figure 9. Comparison of the observed brightness temperature (left column) with synthetic Meteosat brightness temperature images computed from the simulated fields (right column) for the infrared (IR) channel at 15 UTC and 22 UTC 21 August 1992 over domains 2a and 2b respectively (see text). Areas with IR temperature lower than 195 K (higher than 315 K) are in white (black). Isolines for 200 and 255 K have been added.

comparison of mesoscale simulations of an MCS

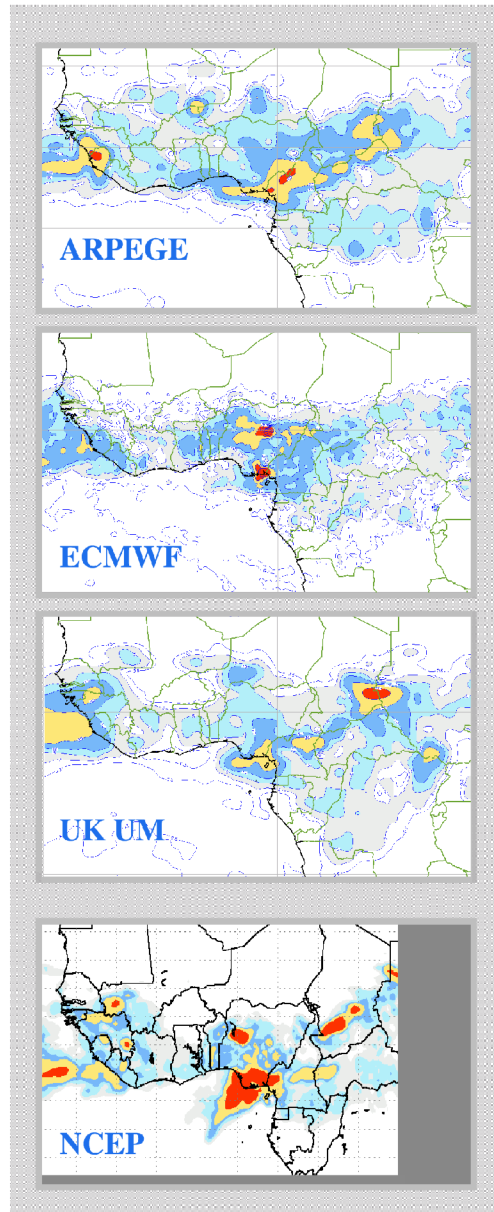
focus on rainfall & evapotranspiration (difficult fields !)
object: precising uncertainties in water budget

Guichard F.[1], C. Peugeot[2] , Asencio N.[1], O. Bock [3], J.-L Redelsperger[1], Cui X.[4], Garvert M.[5], Lamptey B.[6], Orlandi E.[7], Sanders J.[8], Boone, A.[1] , Buzzi A.[7], Fierli F.[7], Gaertner M-A.[5], Jones S.[8], Lafore J.-P.[1], Nuret M.[1], Morse A.[8], Seity Y.[1], Zampieri M. [7], Chopin, F. [9]

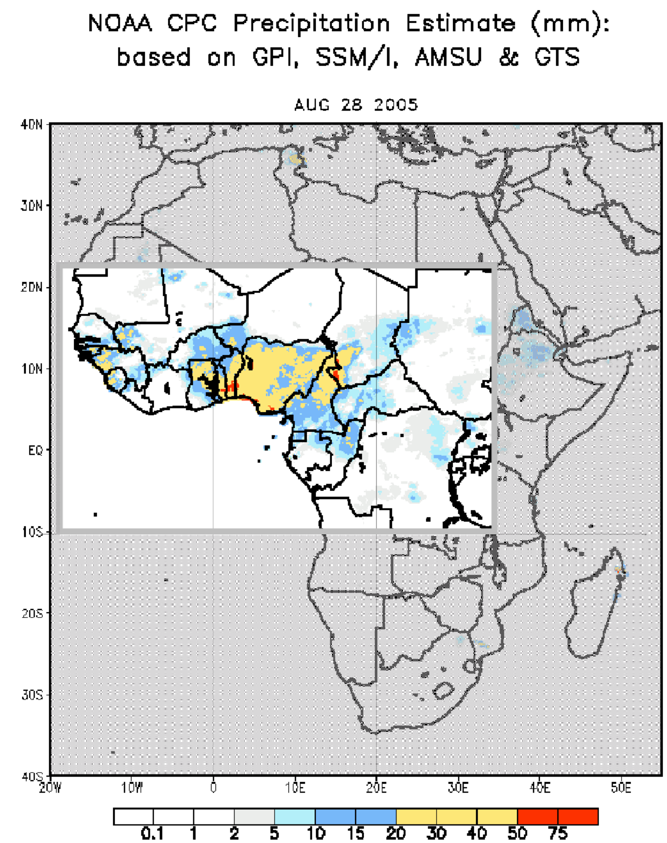
1 : CNRM, Toulouse, France
2 : HSM/IRD & Dir. Génér. de l'Eau, Cotonou, Bénin
3 : LAREG/IGN & SA/CNRS, Paris, France
4 : University of Liverpool, UK
5 : Universiy of Castilla la Mancha (Spain)
6 : NCAR, Boulder CO, USA
7 : ISAC-CNR, Bologne, Italy
8 : University of Karlsruhe, Germany
9 : LMD, Ecole Polytechnique, Palaiseau, France

- 5 mesoscale models
- resolution Δx from 4 to 20 km

operational forecasts



satellite product



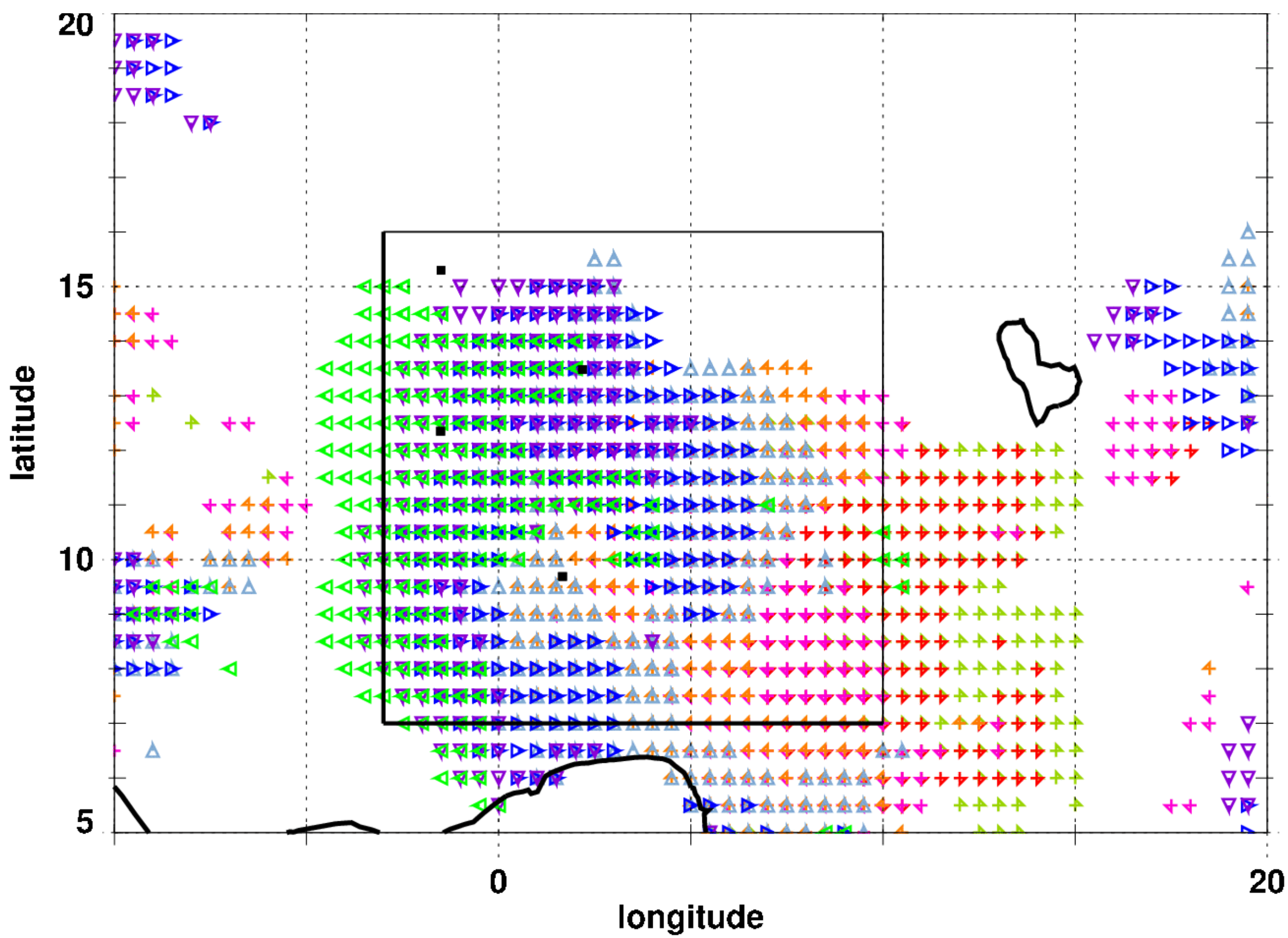
2006 28/8 6Z - 29/8 6Z cumul rainfall adapted from figs available on the 2005 dry run web page http://www.cnrm.meteo.fr/amma-moana/dryrun2005/

case study

a westward (& also slightly northward) propagating rainfall feature

“ad-hoc” rainfall index

24-h sequence from 3-hourly satellite rainfall product



(pixel drawn for P > 2*Pavg in rectangle)

3–h interval ending at	9h	12h	15h	18h	21h	24h	27h	30h
rectangle avg PPT (mm)	0.4	1.1	1.8	2.1	2.1	2.2	1.9	1.3
pixels in rect ... (mm)	4.2	5.4	5.0	4.9	4.5	4.5	4.8	3.9

main “lessons”

♦ important control of initial and lateral boundary conditions on the location of precipitating convection at synoptic scale (within a period of AEW activity)

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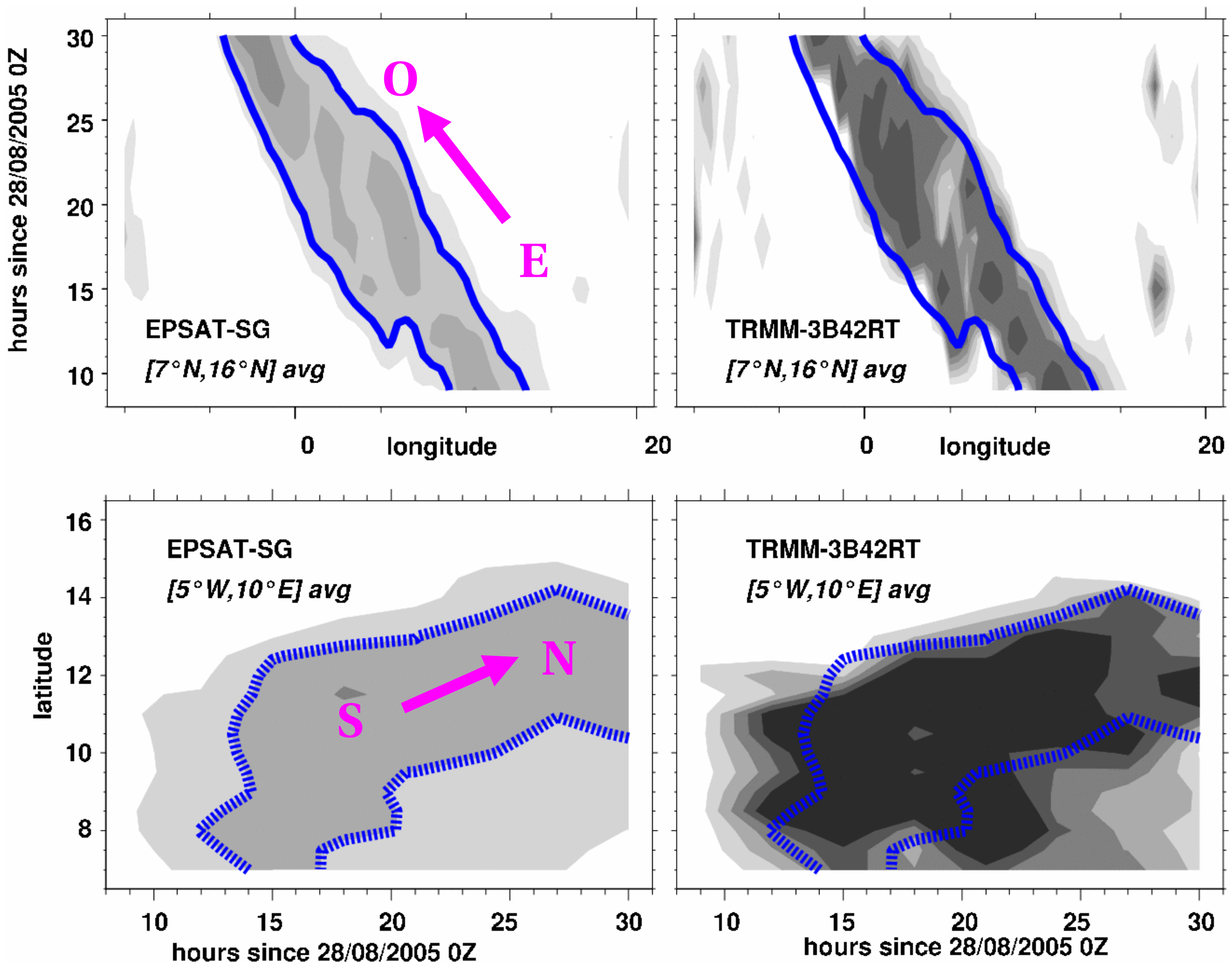
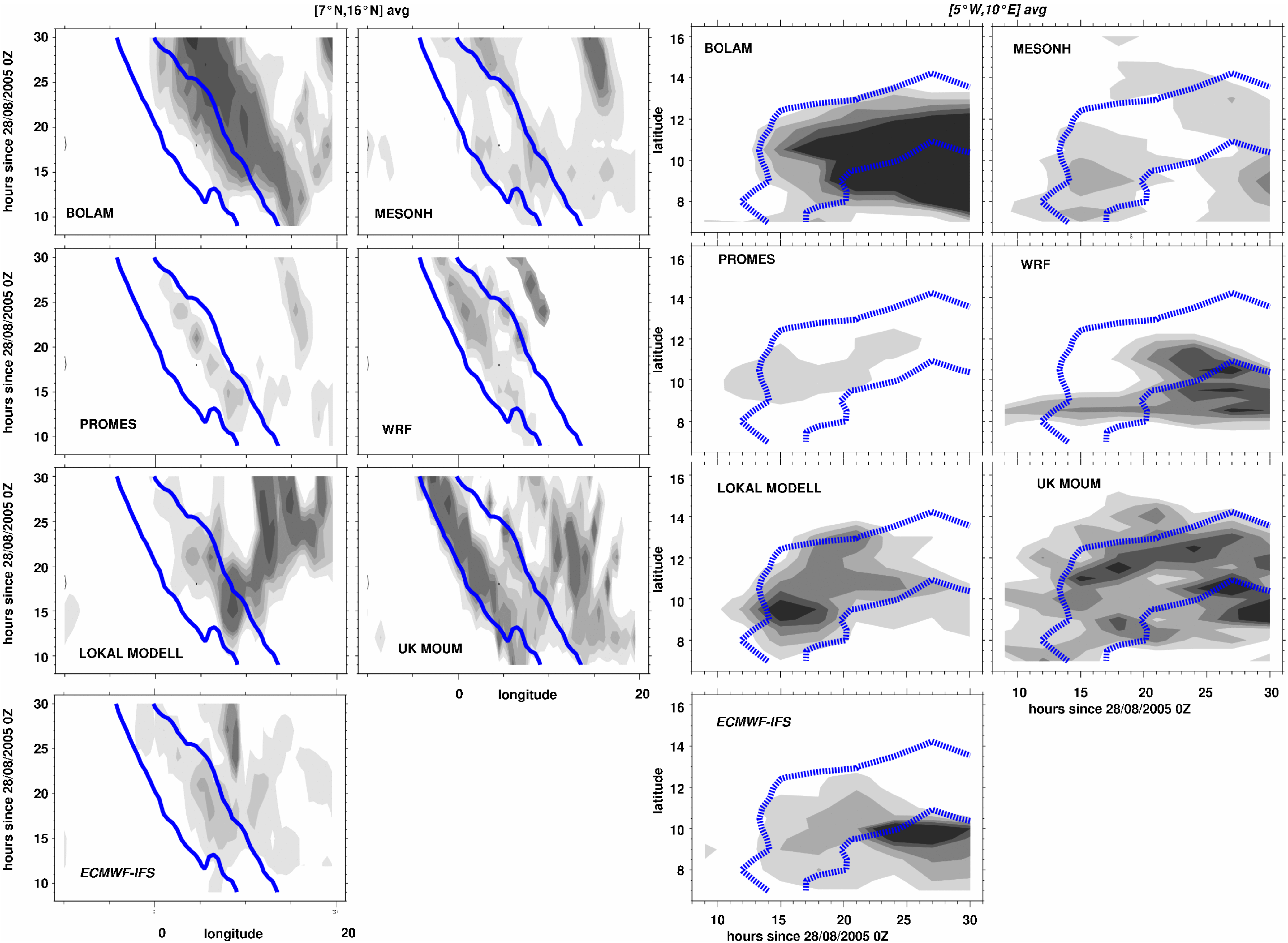
but rainfall is simulated elsewhere also, with large spread in terms of latitudinal gradients and amounts

surface rainfall from 2 satellite products



grey shadings for values from 1, 2, 3, 4, 5, 10, 15, 20 mm and above
the blue thick lines delineate the areas where the EPSAT-SG rainfall estimate is greater than 2mm



[7°N,16°N] avg
[5°W,10°E] avg
hours since 28/08/2005 0Z
longitude
latitude
BOLAM
MESONH
PROMES
WRF
LOKAL MODELL
UK MOUM
ECMWF-IFS
0
20
10
15
20
25
30
8
10
12
14
16

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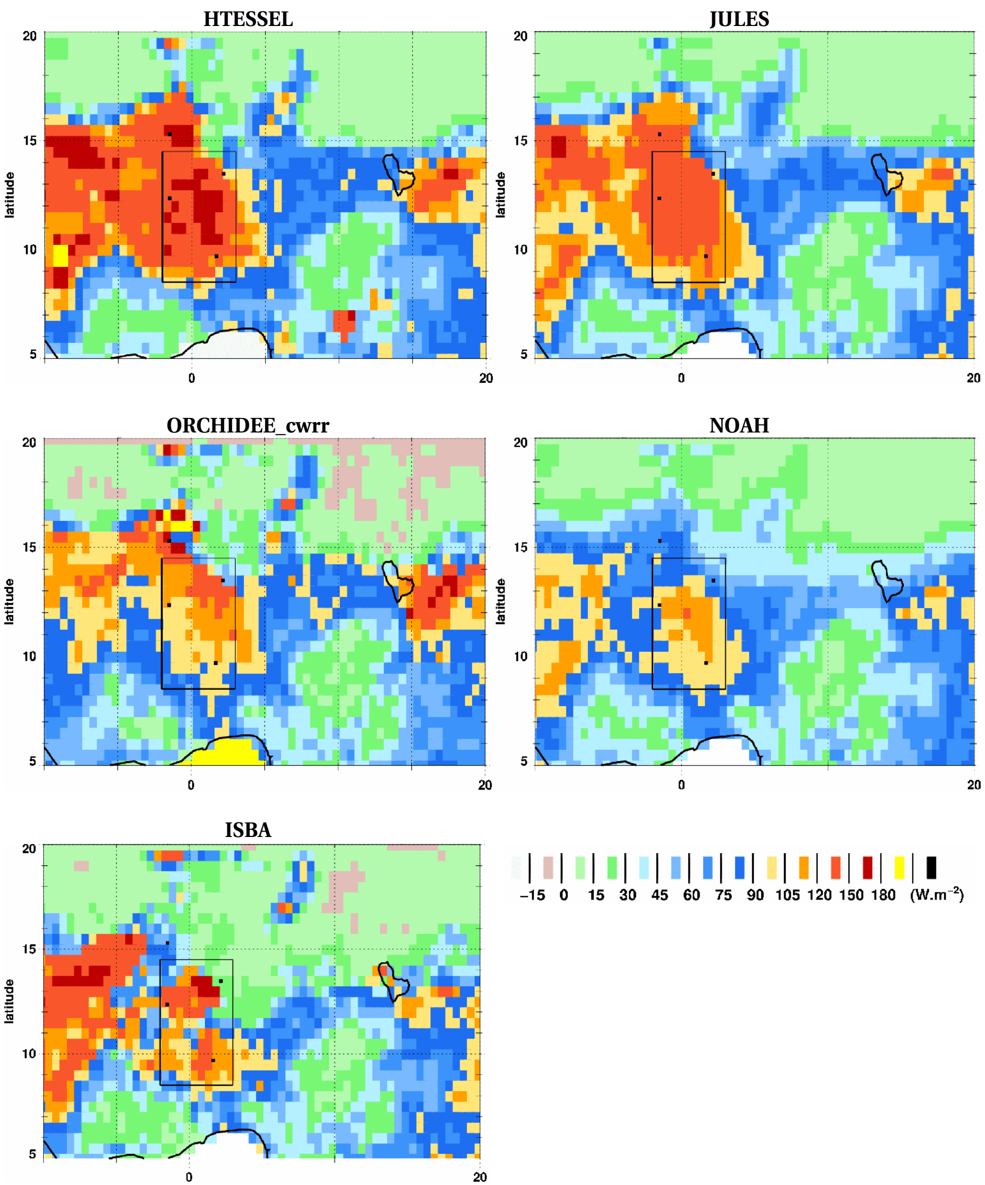
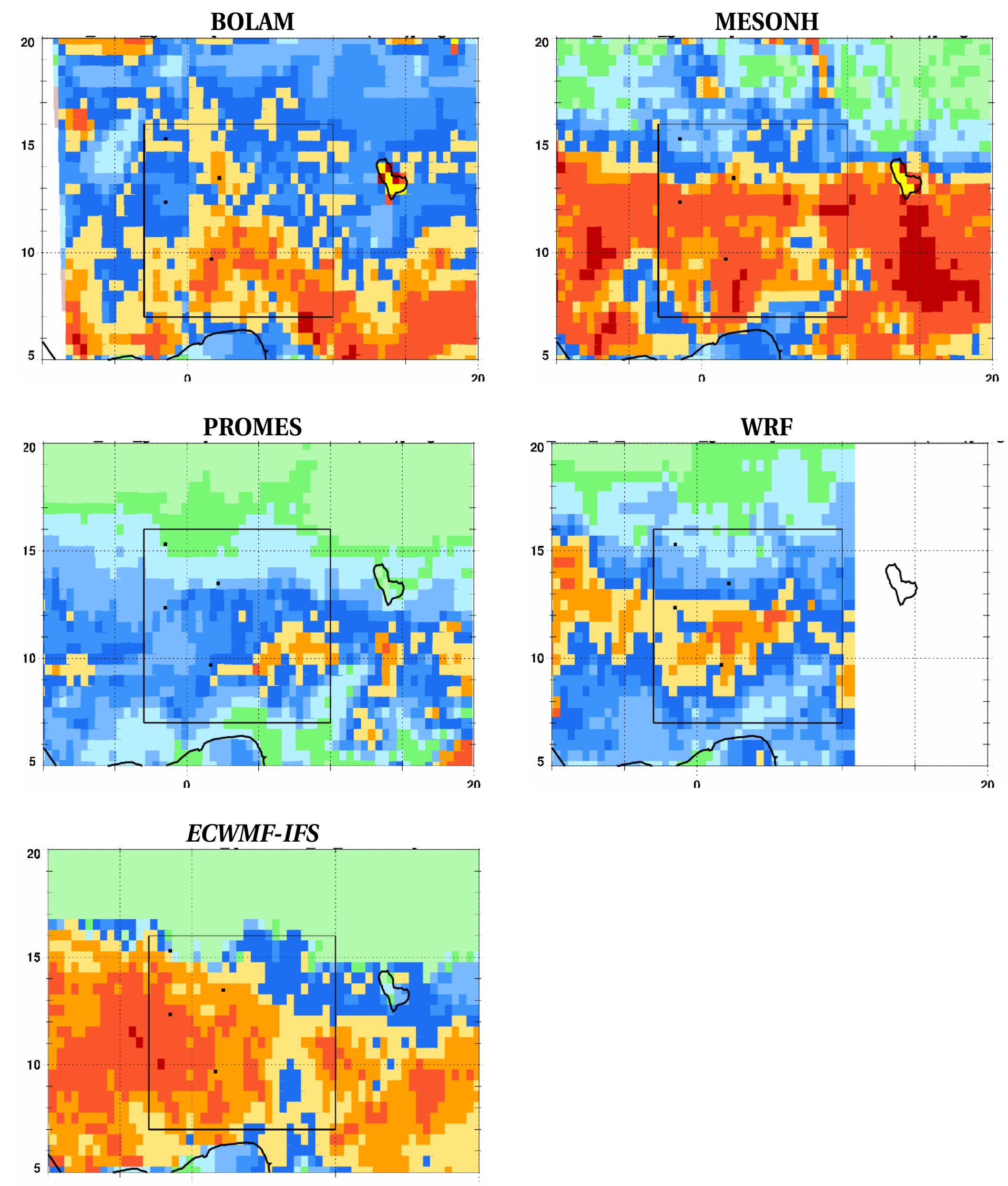
but in most simulations structures too zonally symetric / LSM outputs (ALMIP)

evapotranspiration E 24-h mean (start 2005/8/28 6Z)

land surface models LSMs
(ALMIP, Boone et al.)



mesoscale simulations



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♦ the overestimation of E by MesoNH (& ECMWF-IFS) is related to an overestimation of R^{net}, not to an evaporative fraction that would be too high, differences in SW^{in} point to a lack of clouds

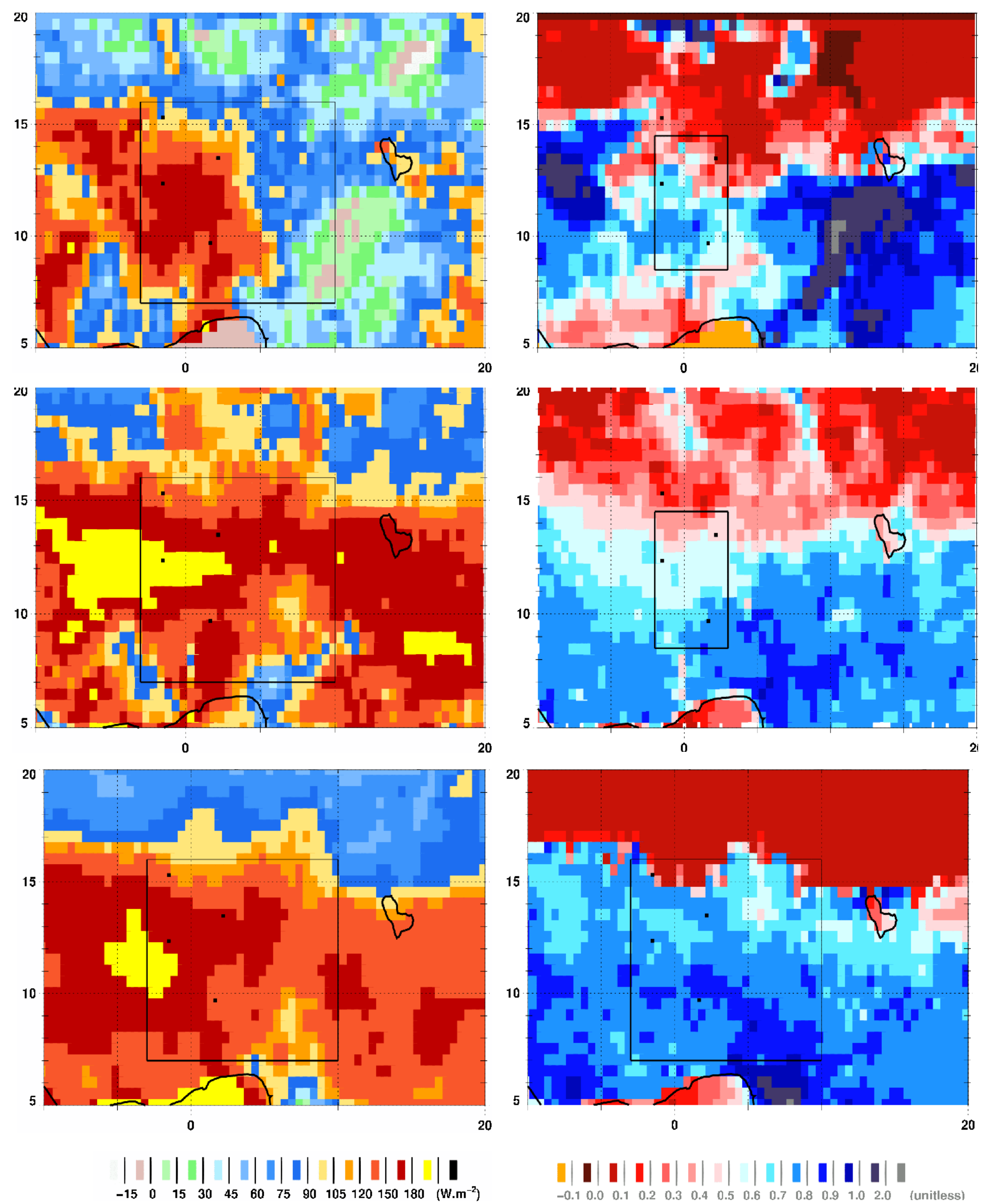
surface R^{net} | **evaporative fraction**

LSM

ISBA
ALMIP
Exp-2

MésoNH

ECMWF-IFS



24-h avg , EF estimated by (24-h LE / 24-h R^{net})

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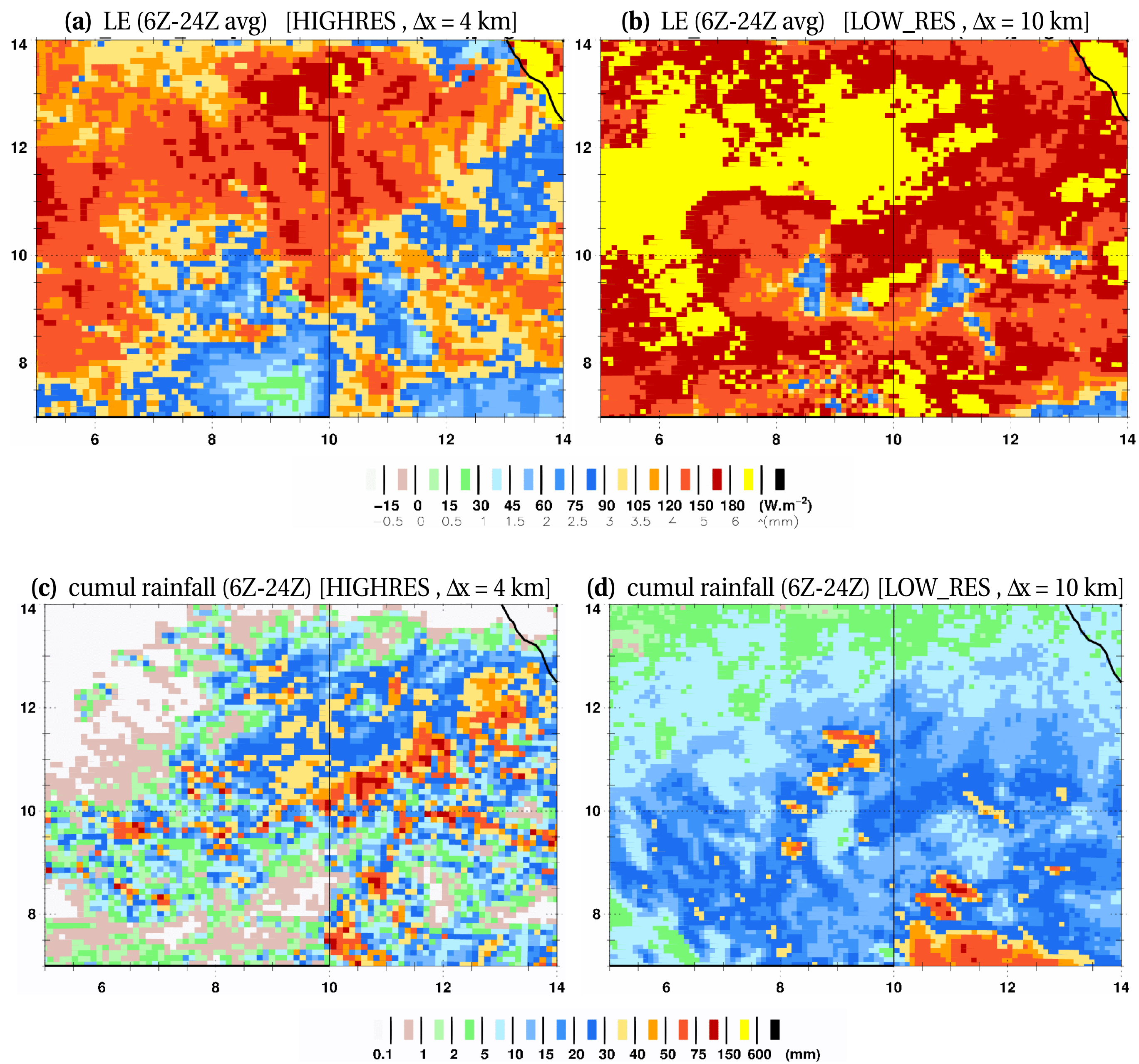
♦ at higher resolution, the partition H , LE is modified (explicit v param convection) scales of variability & distribution of rainfall along latitude as well, and propagation is faster high-resolution low-resolution

LE

rainfall



epilogue

the objective here was to assess what the models were currently doing with a minimum set of requirements

in the mean time, improvements / bugs corrected, case studies from the field campaign started, method tested to initialize better surface fields (with ALMIP)

same differences noted between simulations of new cases using fine & coarse resolution (with explicit versus parametrized representation of precipitating moist convection)

Beyond that, cloud cover can remain a problem, even if care is taken not to start a simulation at times when an MCS is present, this is sometimes critical for studies of surface-atmosphere interactions at mesoscale

Such features can be sensitive to the boundary conditions (i.e. analysis) that is used to drive the mesoscale model (differences among surface & low levels in analyses)

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surface radiative budget & thermodynamics in the Sahel

♦ data for guiding modelling, testing the realism of proposed mechanisms & coupling , precise quantification in time and space

- *which factors control surface radiative fluxes and their variations?*
- *which relationships between θe , fluxes & precipitation?*

- *precising magnitude & nature of interannual variability*

- *characterizing differences with more Southern sites (meridional gradient)*

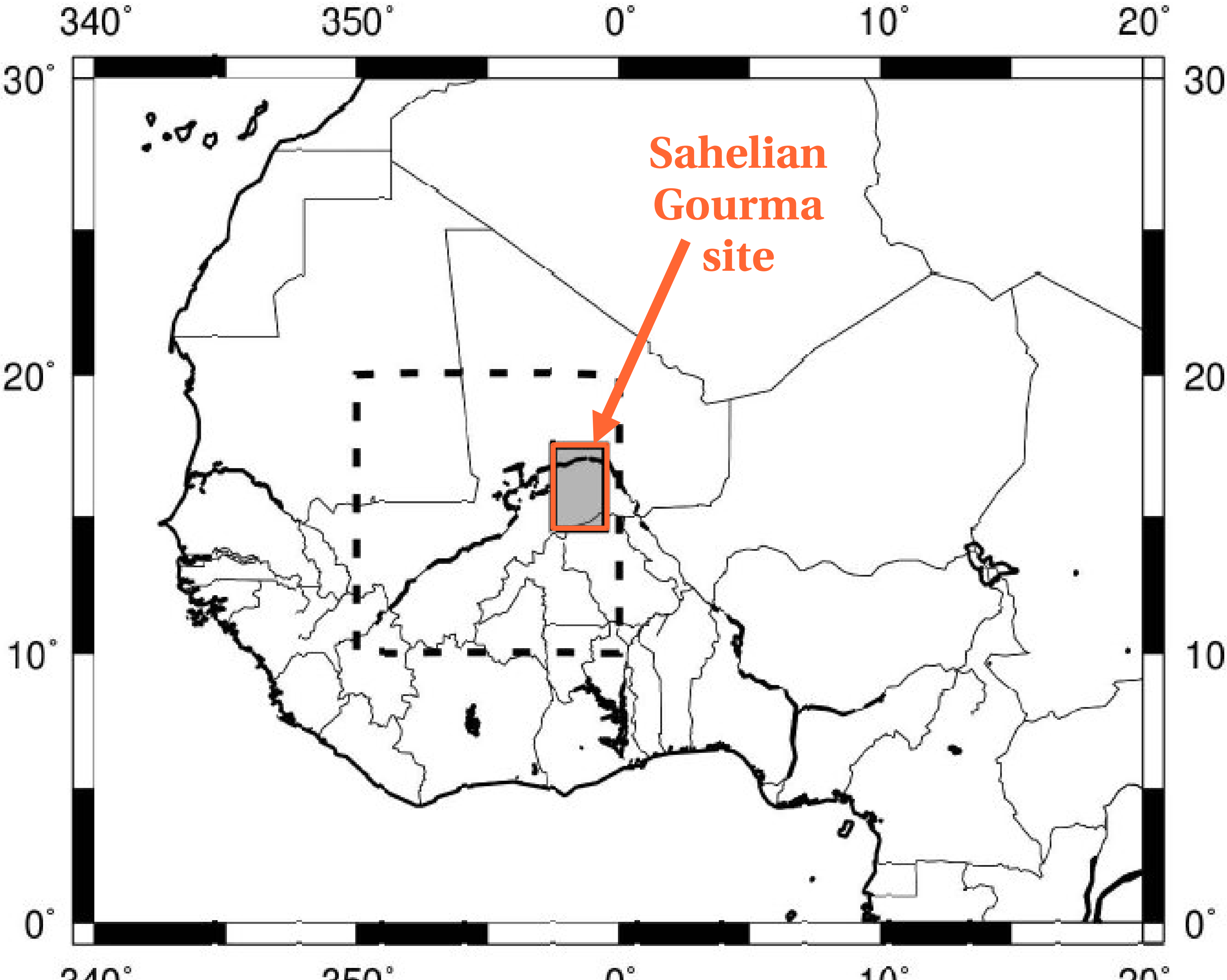
♦ such types of analyses: conducted over other land regions (e.g. Betts & Ball 1998)

♦ data types & sources :

- *automatic weather station, T, RH, wind, radiative fluxes, pressure*
- *sunphotometer Aeronet : aerosol optical thickness , precipitable water*

  Mougin, Timouk et al. (Sahelian zone, Gourma, 15°N to 17°N)
  Galle, Lloyd et al. (Soudanian zone, Oueme basin, ~10°N)

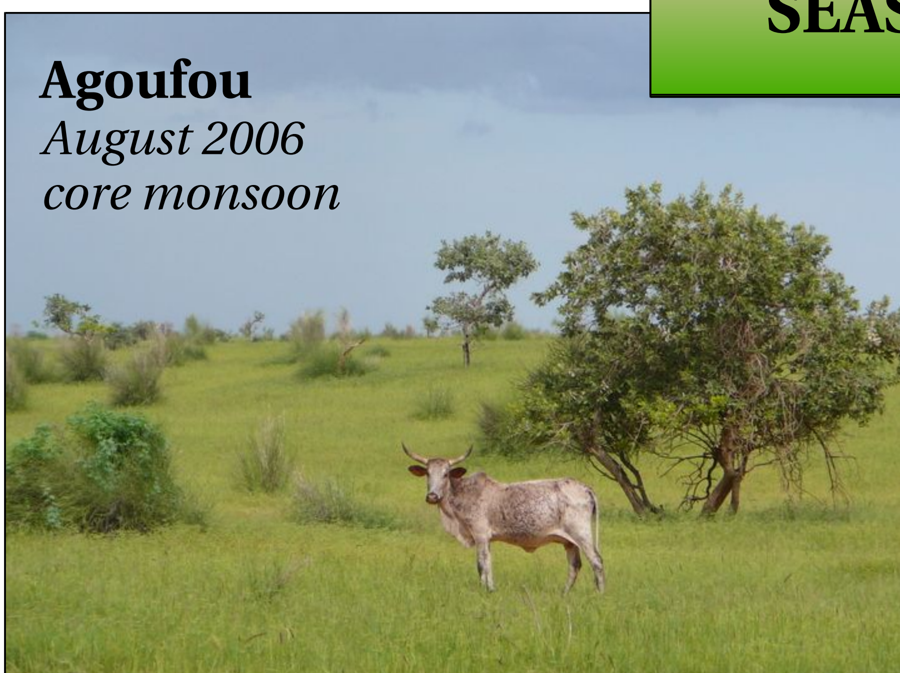
- *high-resolution soundings (Niamey 13°N, AMMA SOP, Parker et al. (2008))*



340°
350°
0°
10°
20°
30°
20°
10°
0°
Sahelian
Gourma
site

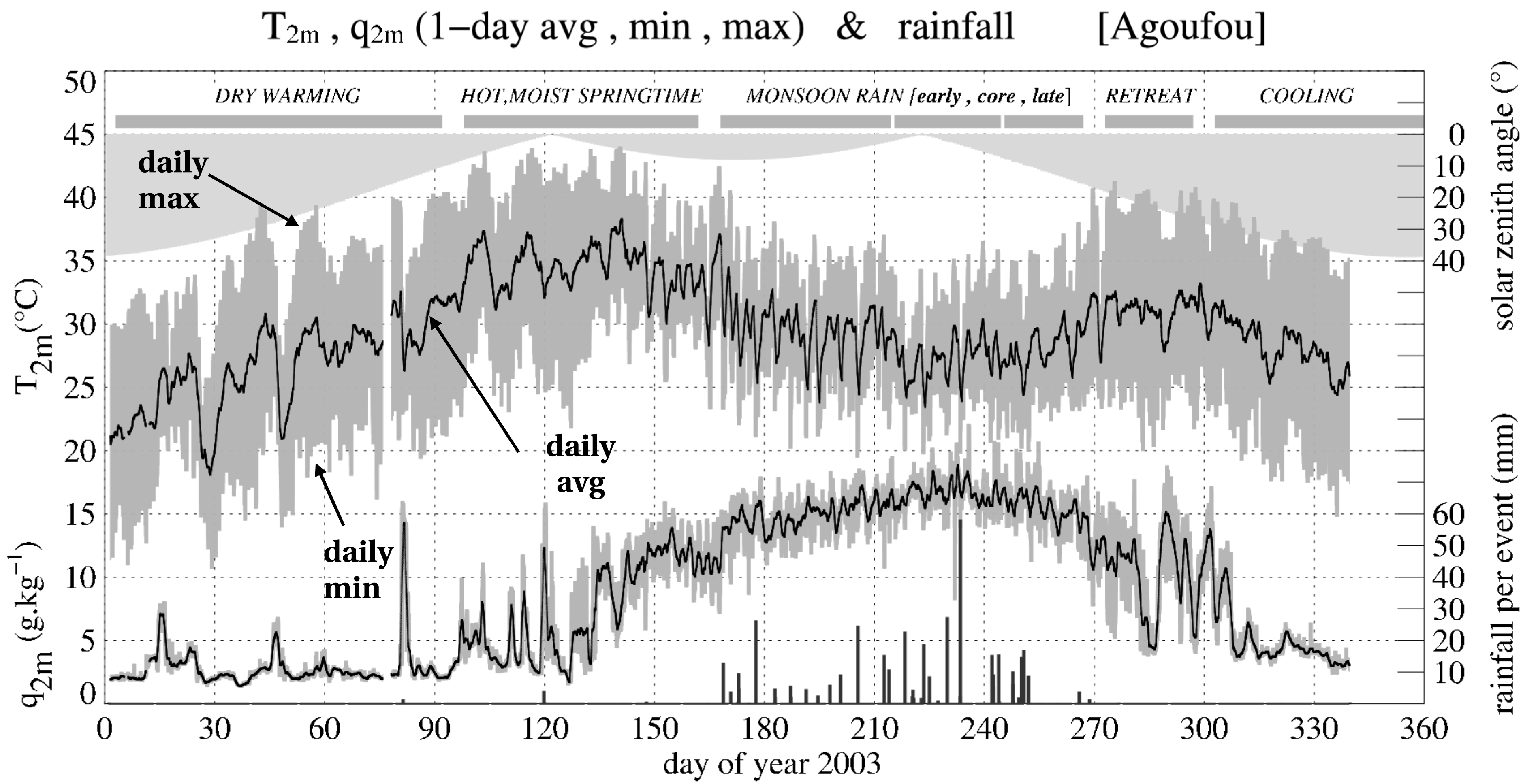
Sahelian Gourma site, Mougin, Hiernaux et al.

SEASONAL CYCLE



photos accacia site & dry season V. Le Dantec

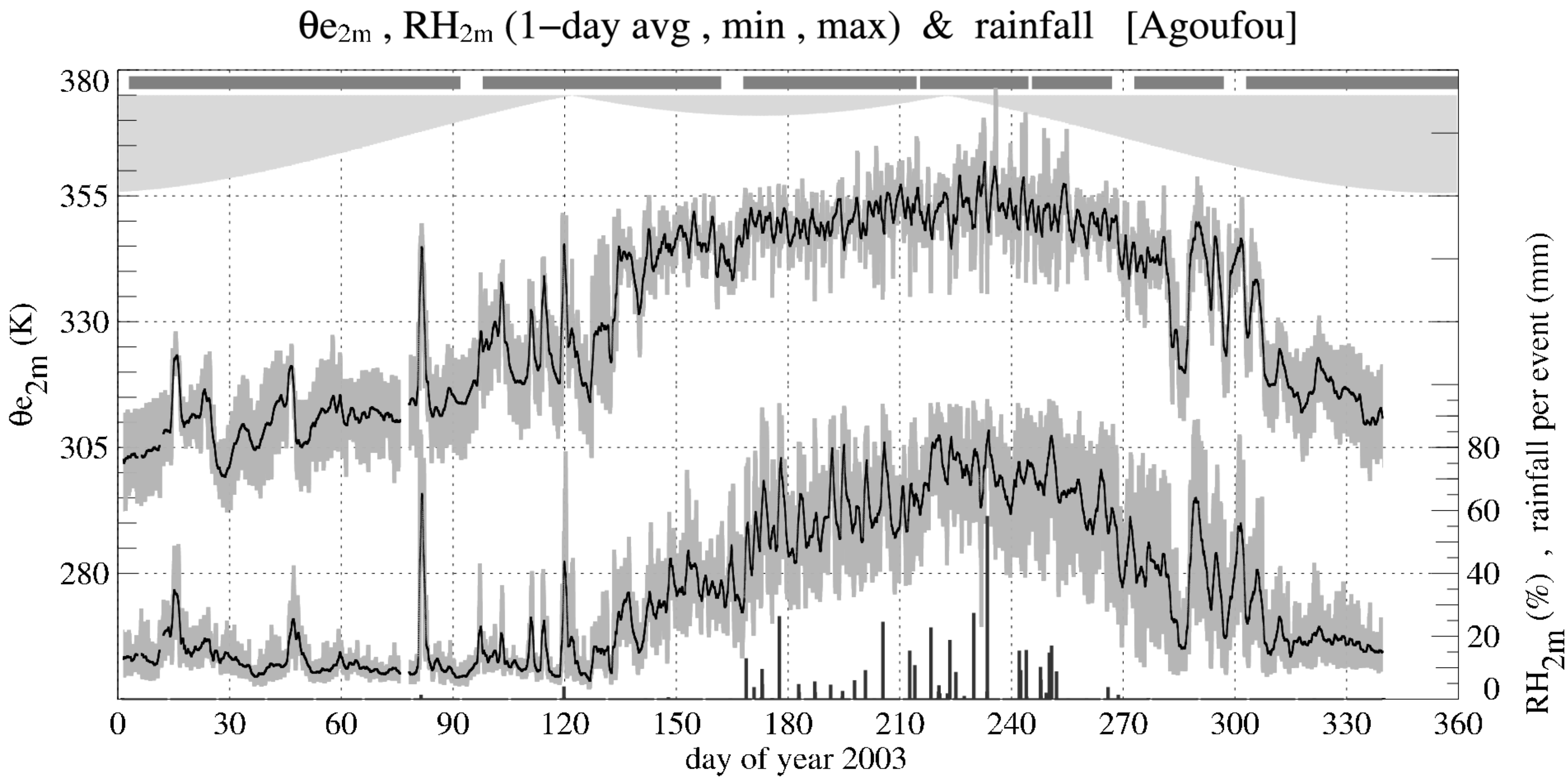
seasonal cycle *(with data from 2003, wet monsoon)*



- moist from May until October, with rainfall from June to September
- large (q_{max}-q_{min}) early & late in the monsoon season

- T_{max} in May, following the arrival of the monsoon flow, coupled to decrease of (T_{max}-T_{min})
- warming is slow at time of maximum TOA insolation (advection) – node in the year
- T_{min} in August, around the 2nd min of solar zenith angle
- sharp drops of T associated with rainfall events

seasonal cycle

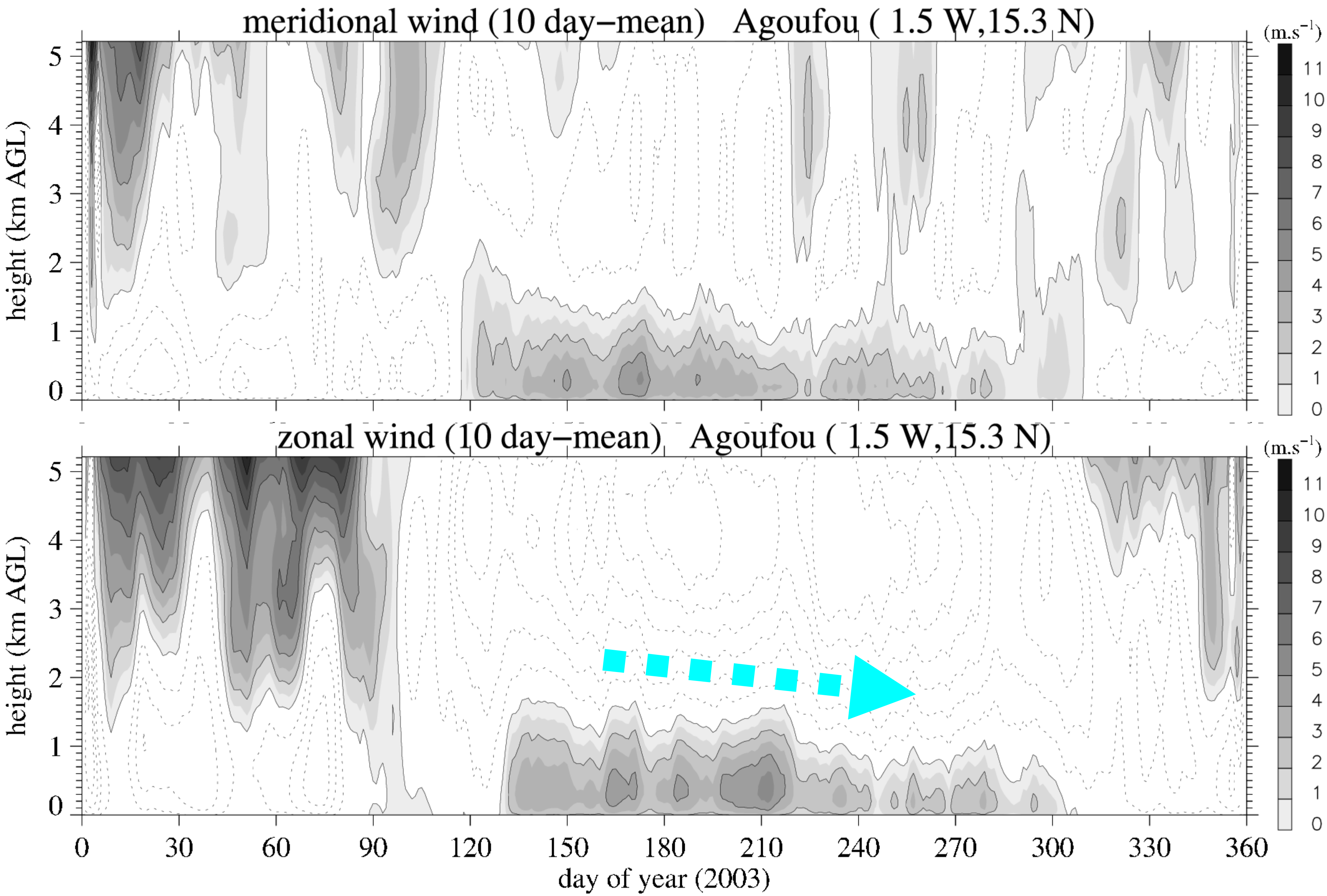


• seasonal variations of T & q [T+,q-], [T-,q+] lead to more steadiness of θe during the monsoon & jump of θe at the beginning of the monsoon season

• spikes of RH in response to rainfall events, until late July

• (θe_{max} - θe_{min}) increases from June to August

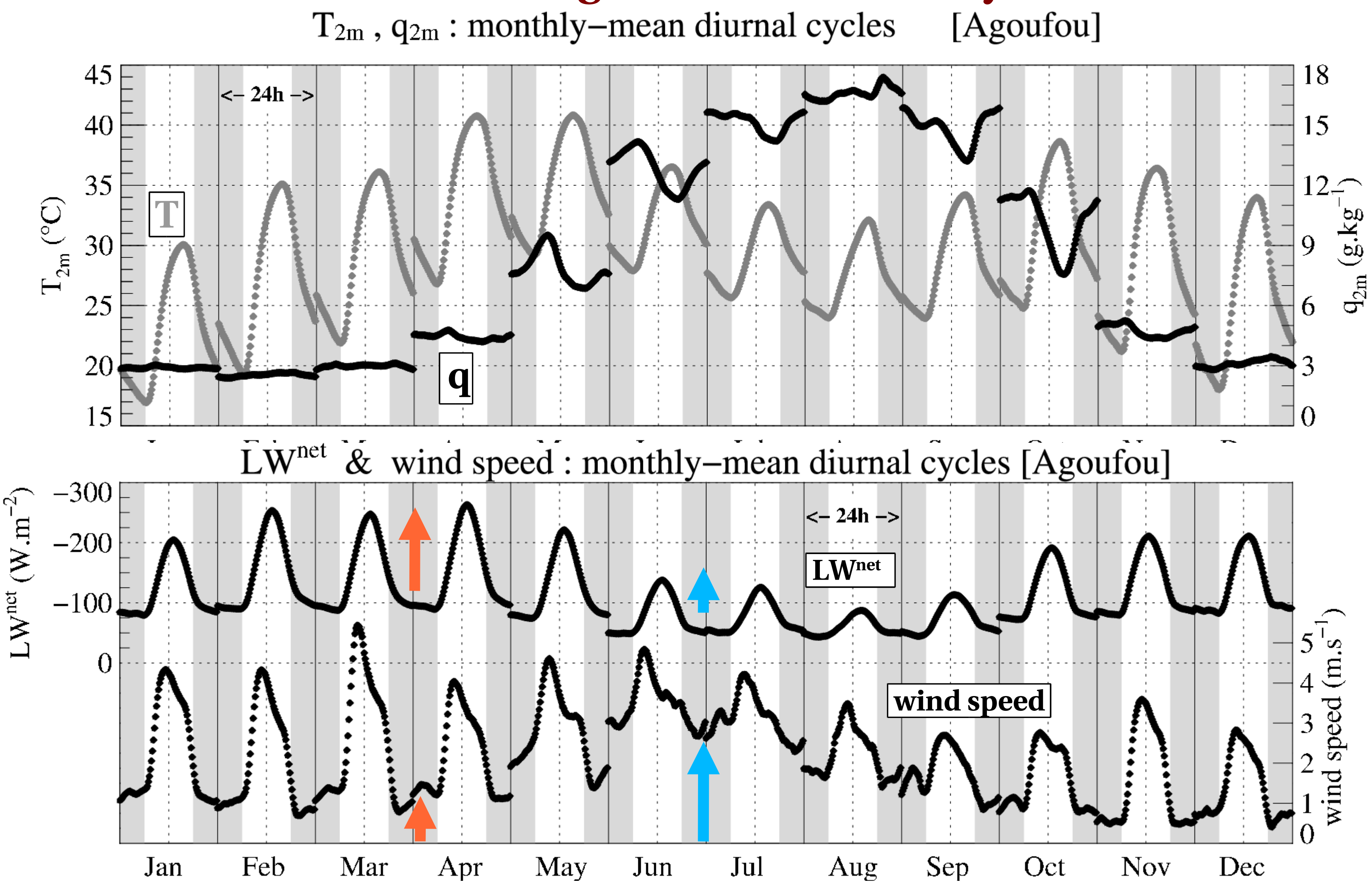
seasonal cycle



weakening & thinning of the monsoon flux from May to October

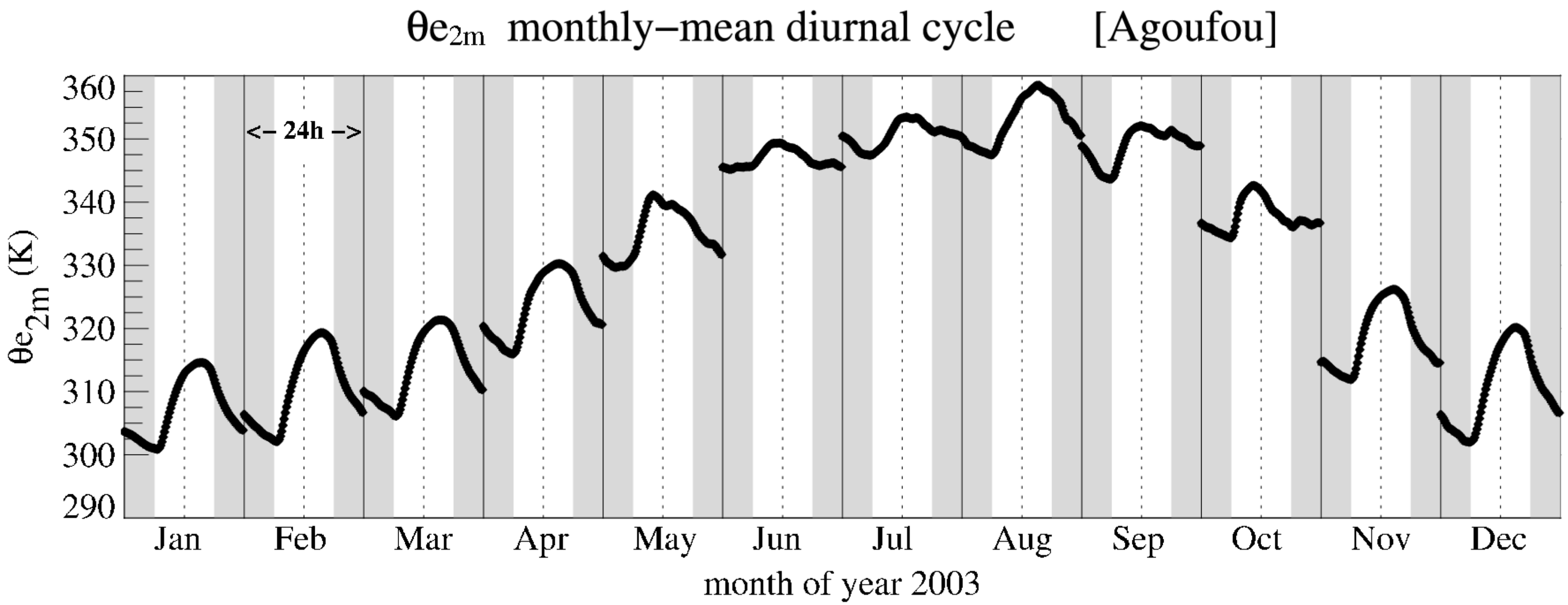
(related to the seasonal cycle of the heat low possibly)

seasonal changes of the diurnal cycles



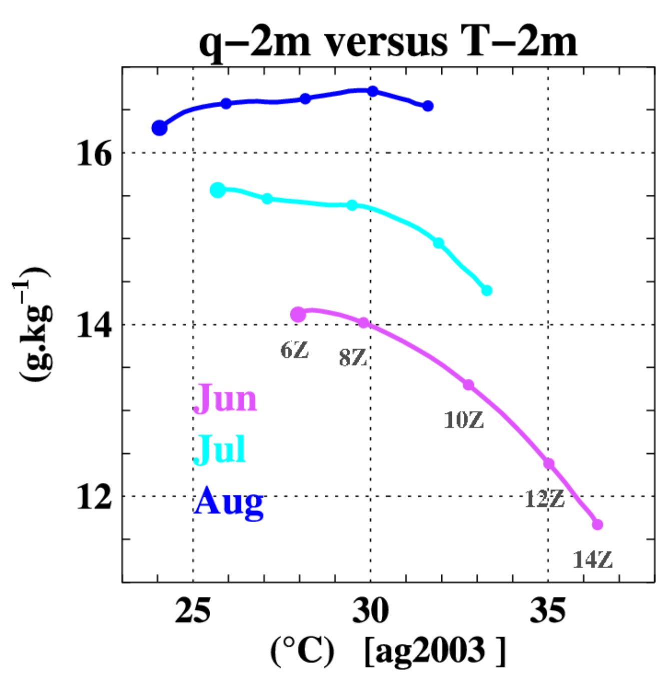
- decreases of the amplitude of the diurnal cycle of T from May to September
- radiative decoupling of the surface (LW^{net}) weakens & nighttime wind speed increases
- transition from a flat q cycle in March to morning peak in May, daytime decrease in June, afternoon decrease in July & finally flat again in Aug – conv BL growth & entrainment (dry air)

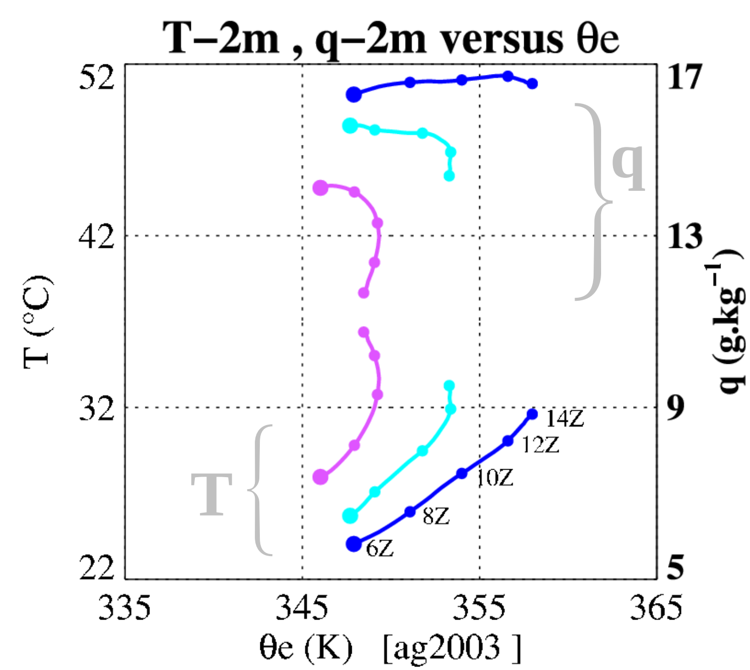
seasonal changes of the diurnal cycles

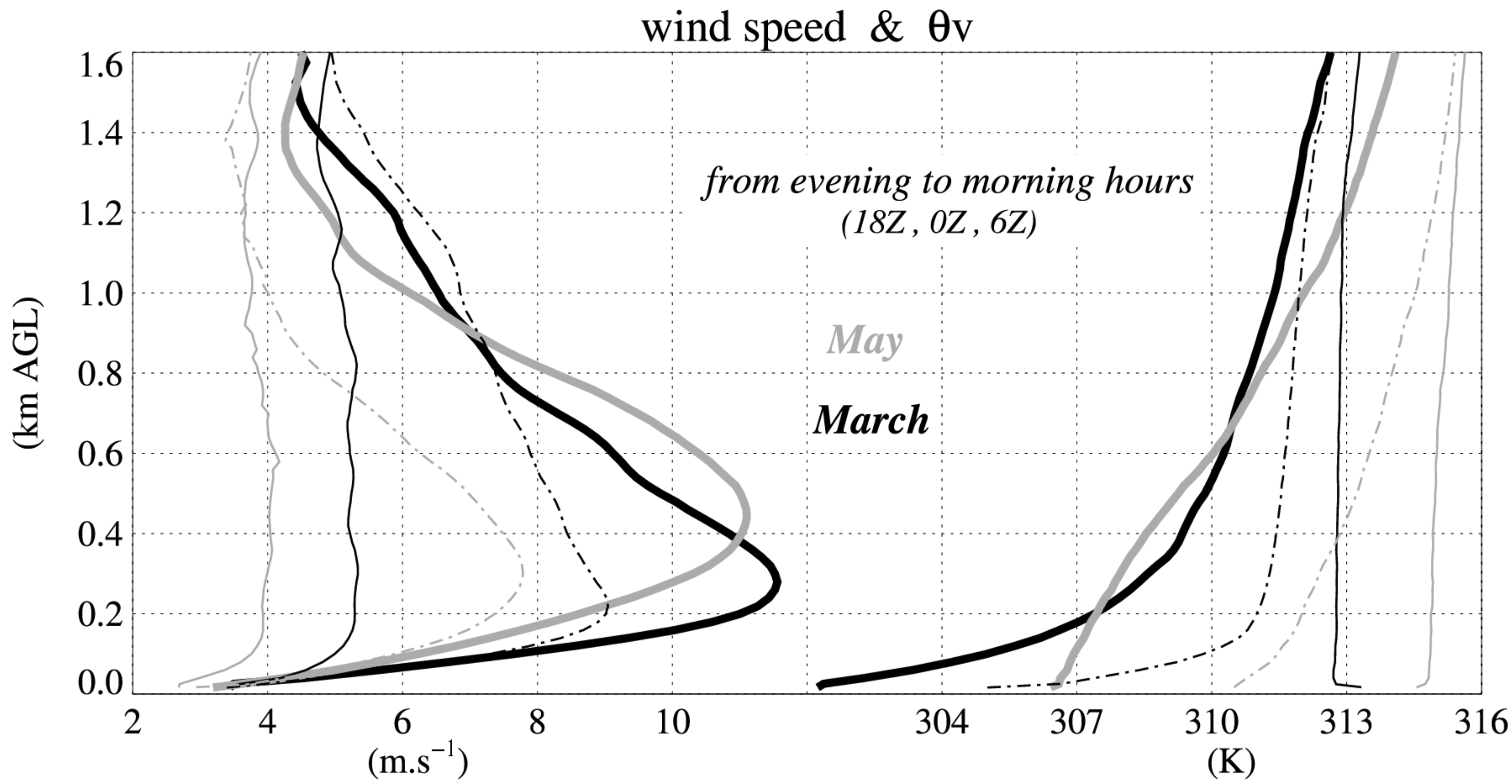


daytime drying:
strong impact on the diurnal cycle of θe

during the monsoon, significant diurnal cycle of θe in August only (flatter in Jun, Jul, Sep)







(Niamey soundings)

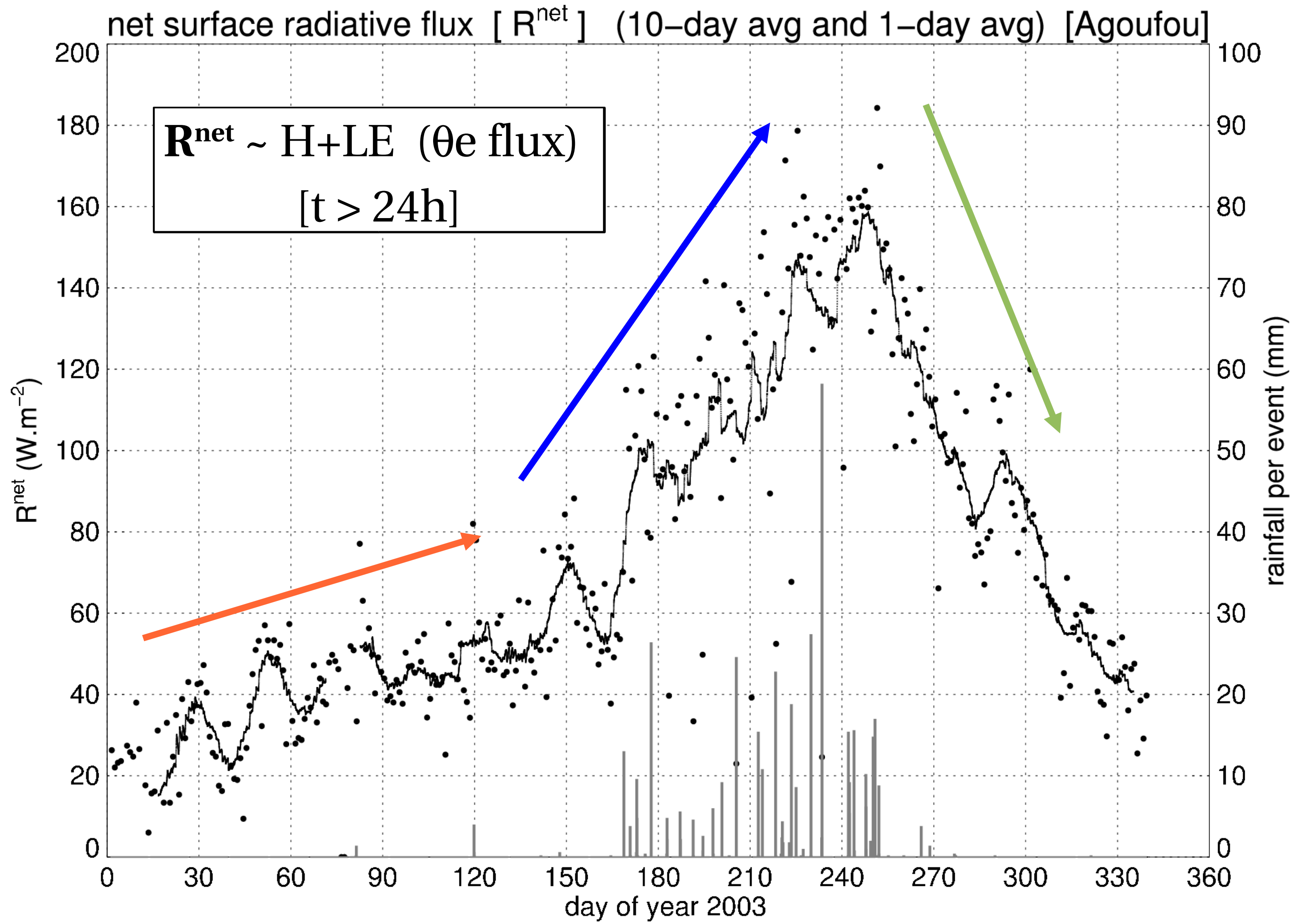
~ 30 soundings per monthly-hourly mean profile

For same magnitudes of wind speed (as in this case/example)

- when <u>dry</u> *(March)*, stronger surface decoupling: <u>lower nocturnal jet & stable layer</u>
- when <u>moist</u> *(May)*, lower surface decoupling: <u>more mixing & stable layer higher</u>

→ *implies changes on subsequent daytime BL growth*

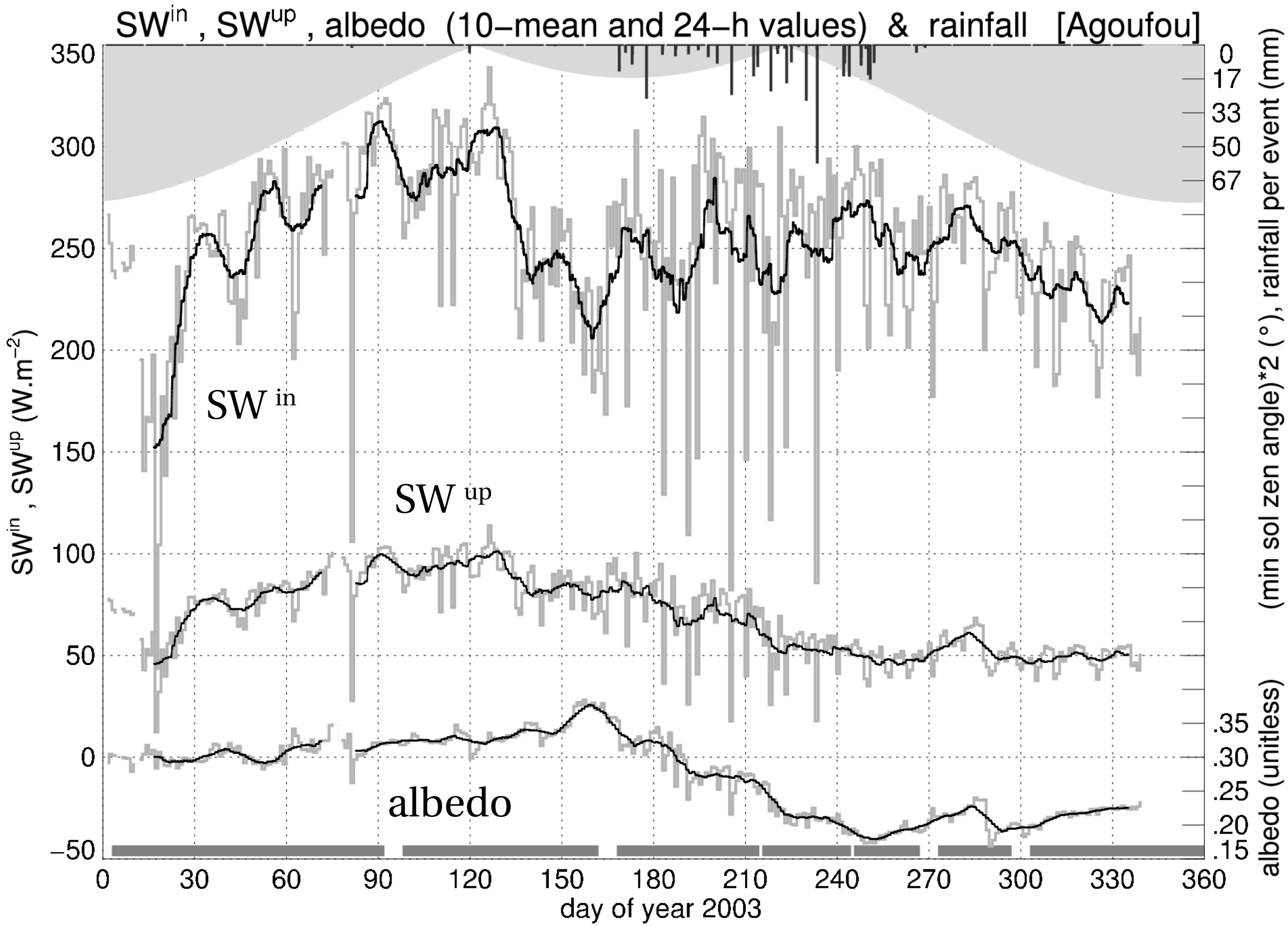
seasonal cycle of surface radiative fluxes



strong seasonal fluctuations
how, why?

$\longrightarrow$ $\mathbf{R^{net}} = LW^{in} - LW^{up} + SW^{in} - SW^{up}$

seasonal cycle of surface radiative fluxes

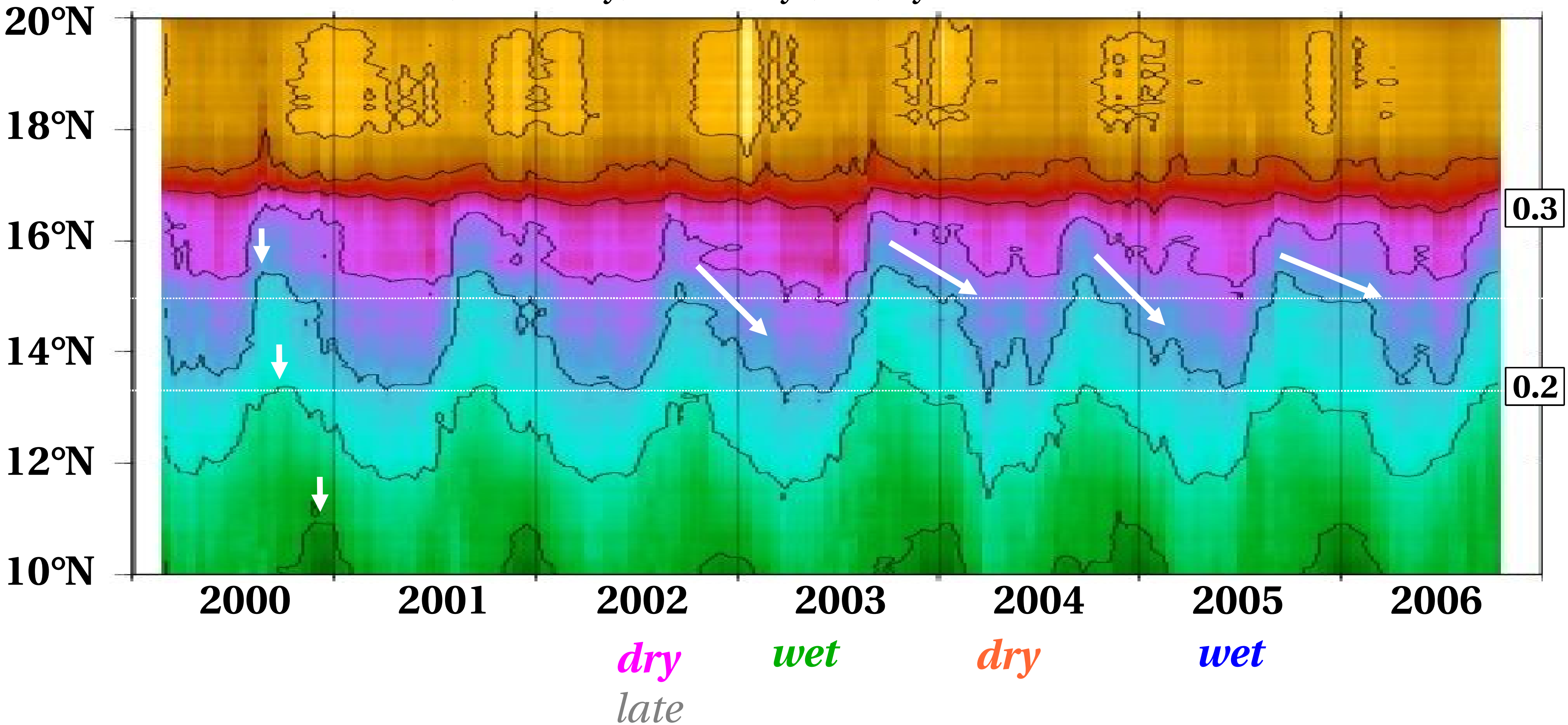


- strong fluctuations of SW ^{in} not mirroring those of R^{net}, min in June prior to rainfall
- SW ^{up} does not follow the same evolution as SW ^{in}
  - *drop of the albedo during the monsoon (0.35 to 0.2) [linked to vegetation]*
  - *fluctuations of albedo fct(spectral composition of Sw ^{in}) - aerosols & water vapour*

albedo satellite MODIS moyenne [10°W,0°]

(shortwave, white sky, Δt=16 days, Δx , Δy = 1 km)

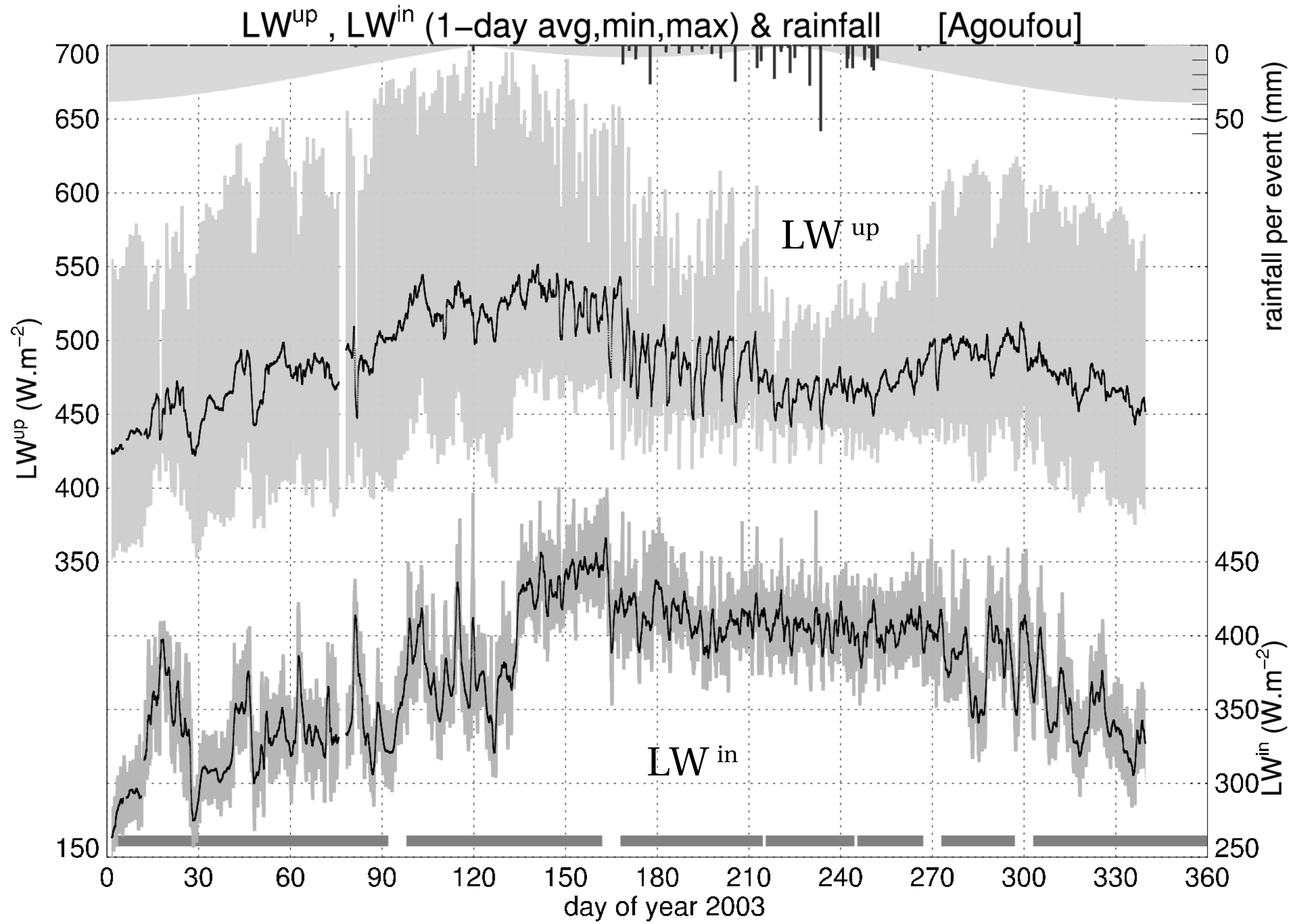
adapted from ***Samain et al. (2008)***



Δt = 16 days, so no precise determination of extrema, thus variability can be somewhat damped

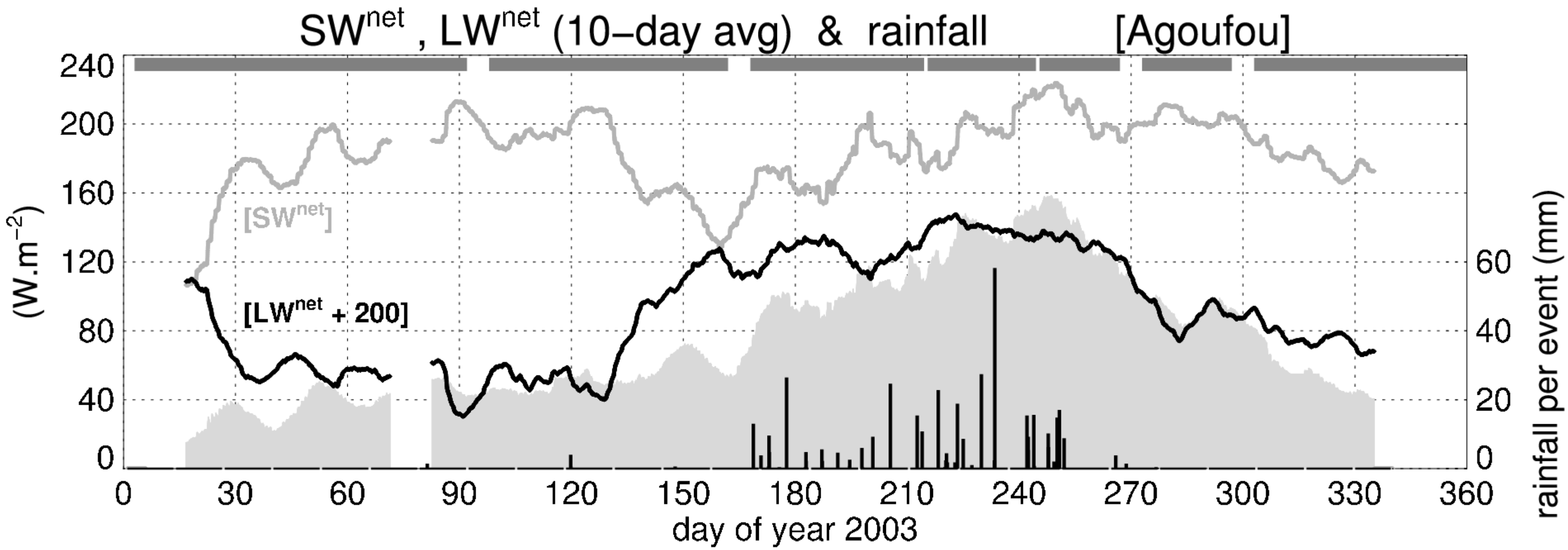
- meridional gradient : 0.02-0.03 / ° latitude (Sahel)
- ≠ of seasonal cycles: min later Southwards, sharper jumps North of 12-13°N
- albedo interannual fluctuations not limited to the monsoon season *(litter?)*

seasonal cycle of surface radiative fluxes



- close evolutions of LW^{up} and 2m-temperature T
- in June, max of LW^{in}, when SW^{in} is min (atmosphere warmer and more opaque)
- LW^{in} decreases from June to Sept while qv, RH, PW increases & clouds are more numerous *(not so intuitive, implies an atmospheric cooling)*

seasonal cycle of surface radiative fluxes



$R^{net} = LW^{net} + SW^{net}$

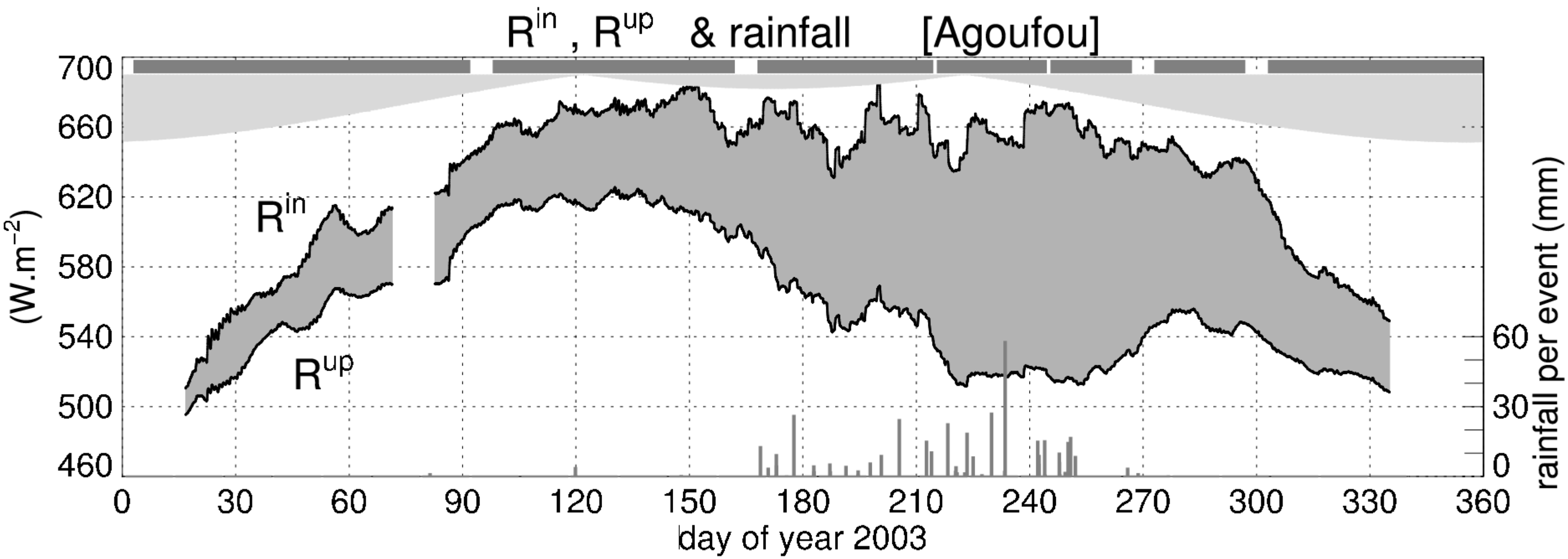
partial balance between net LW & SW fluctuations

dry season: warm surface & low opacity of the atmosphere
opposite situation during the monsoon

SW^{net} increases from June to mid-Sep (albedo, rad forcing of aerosols/water)

LW^{net} fluctuations mirror those of water vapour

seasonal cycle of surface radiative fluxes



$$\mathbf{R^{net}} = (LW^{in} + SW^{in}) - (LW^{up} + SW^{up}) = R^{in} - R^{up}$$

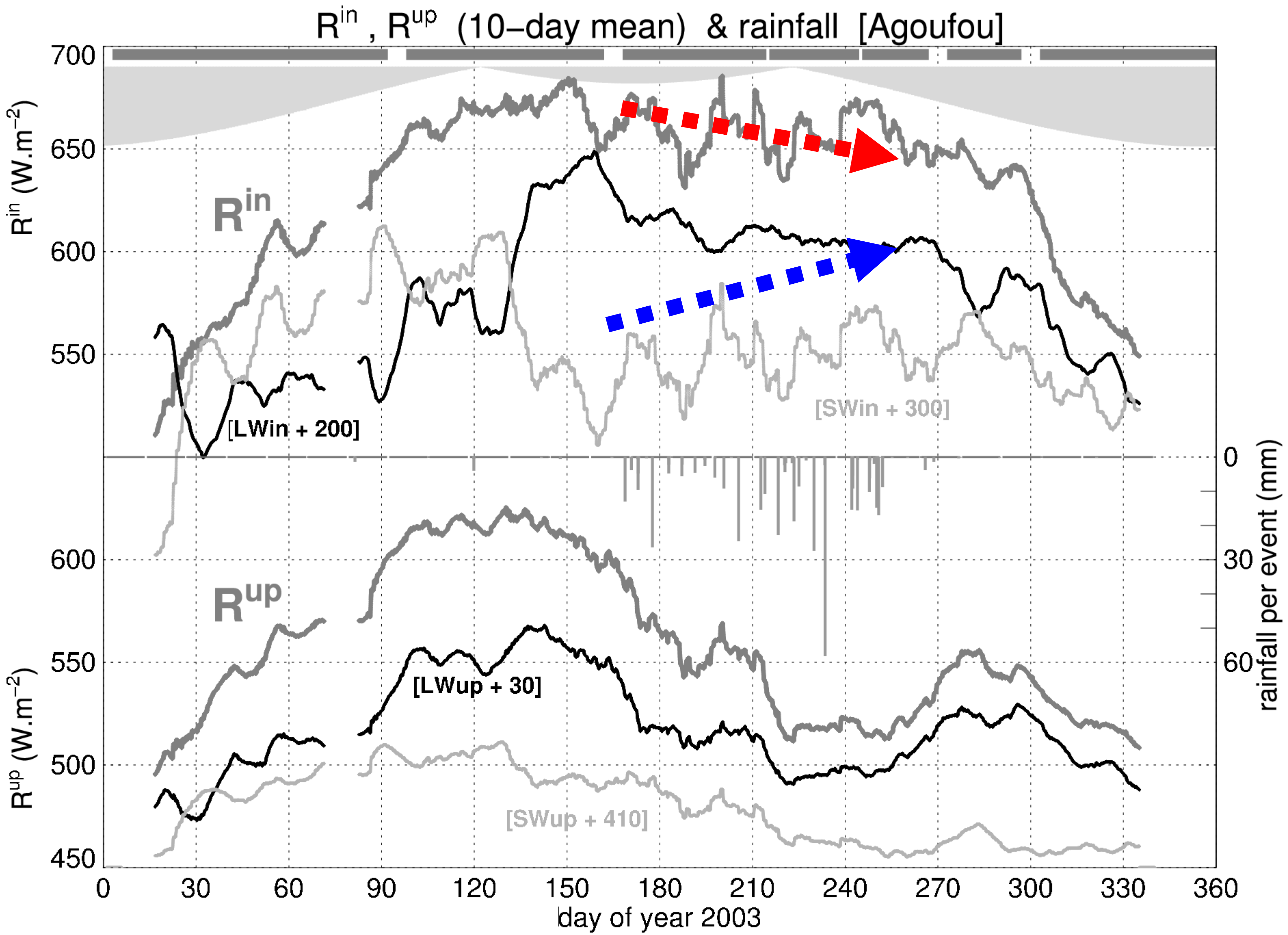
R^{net} changes mainly driven by the decrease of R^{up} from June to mid-Sep

does not mean than aerosols & clouds do not matter!

e.g. reduction of SW^{in} by clouds and aerosols ~ 25% in July-August

seasonal cycle of surface radiative fluxes

$R^{net} = (LW^{in} + SW^{in}) - (LW^{up} + SW^{up}) = R^{in} - R^{up}$, details



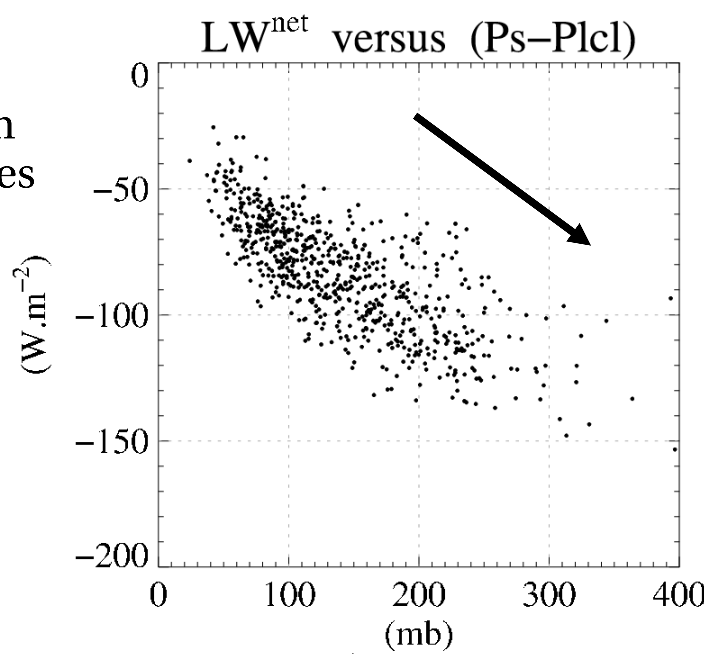
thermodynamic-radiative coupling during the monsoon

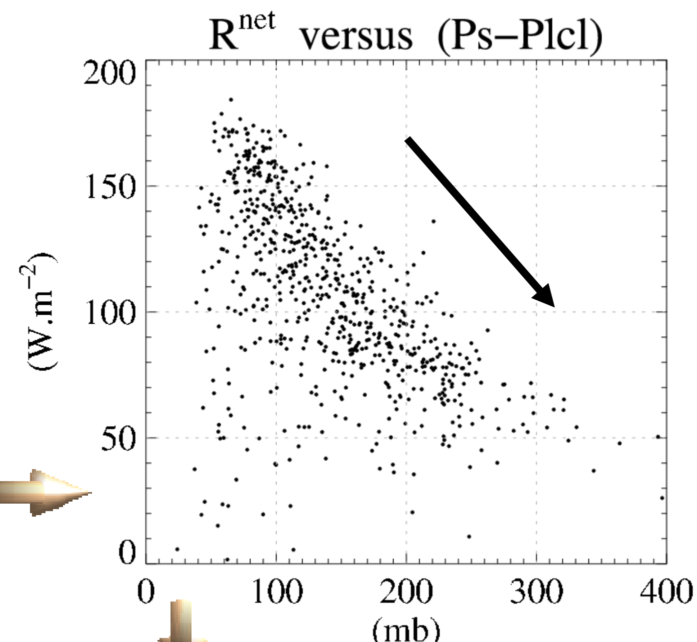
daily values, JJAS 2002 à 2007

(1)

consistent with previous studies (Betts 2004, Schär *et al.* 1999)

range of the relationship extended

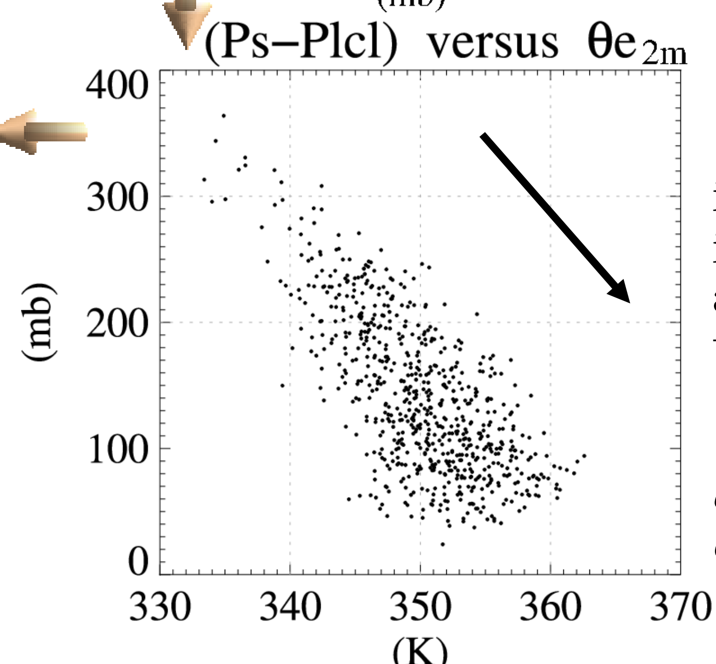




(2)

R^{net} increases even more than LW^{net} with Plcl because SW^{net} does not decreases at lower Plcl

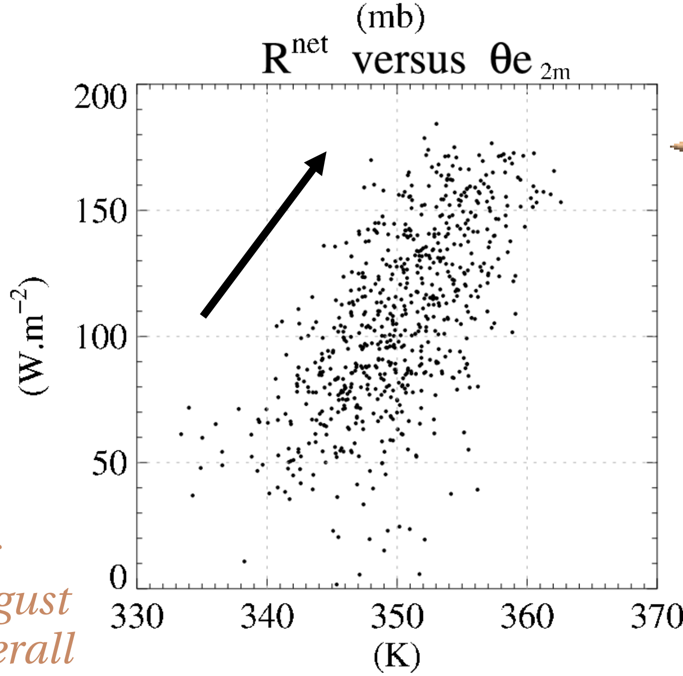
semi-arid zone cloud impact is not dominating over other factors



(3)

increase of θe is coupled to a lowering of the lcl

increase of T associated with decrease of q

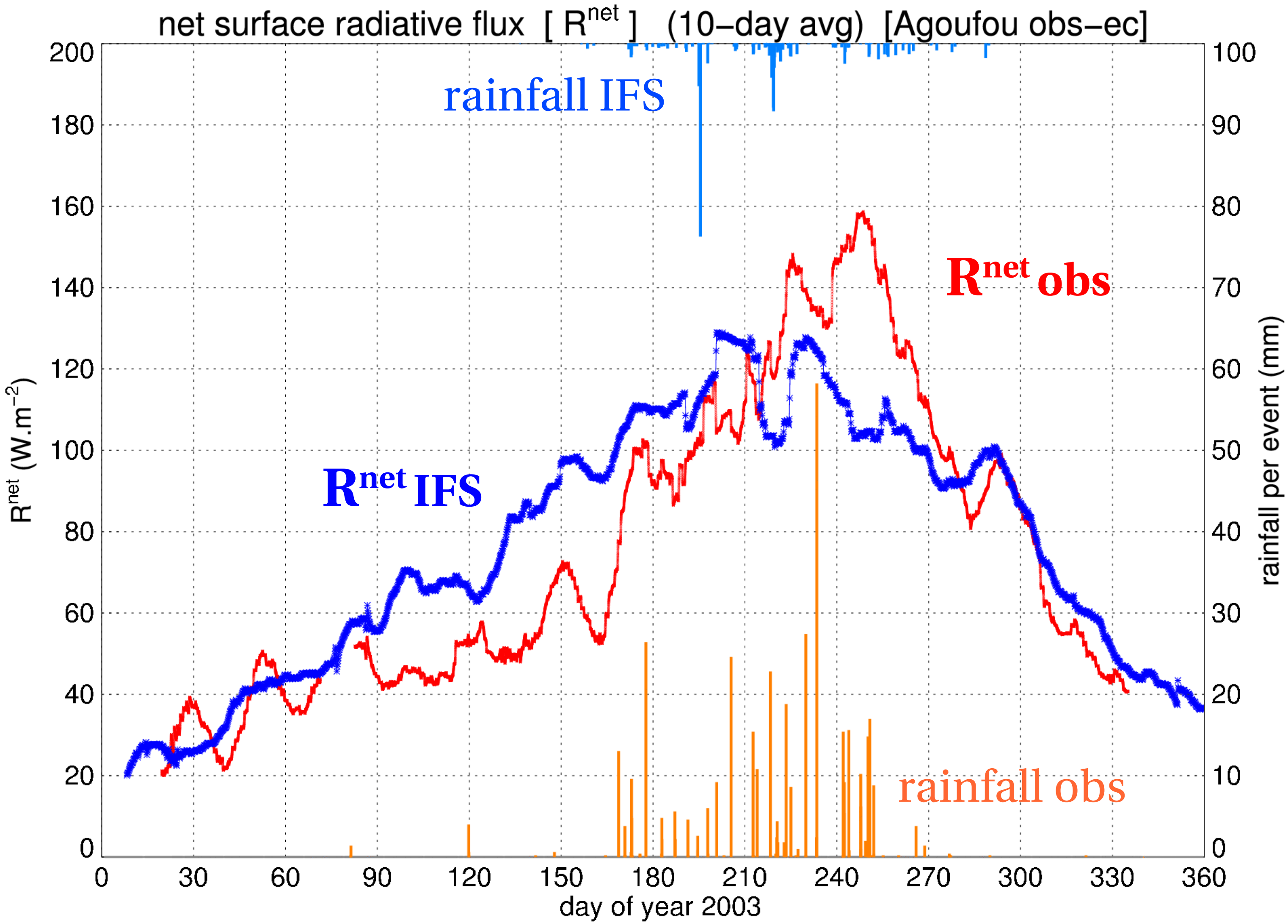


(4)

R^{net} and θe positively related

relationship involves transformations from June to August & implies an overall > 0 feedback between soil moisture & rainfall at this local spatial scale

a glance at the ECMWF-IFS

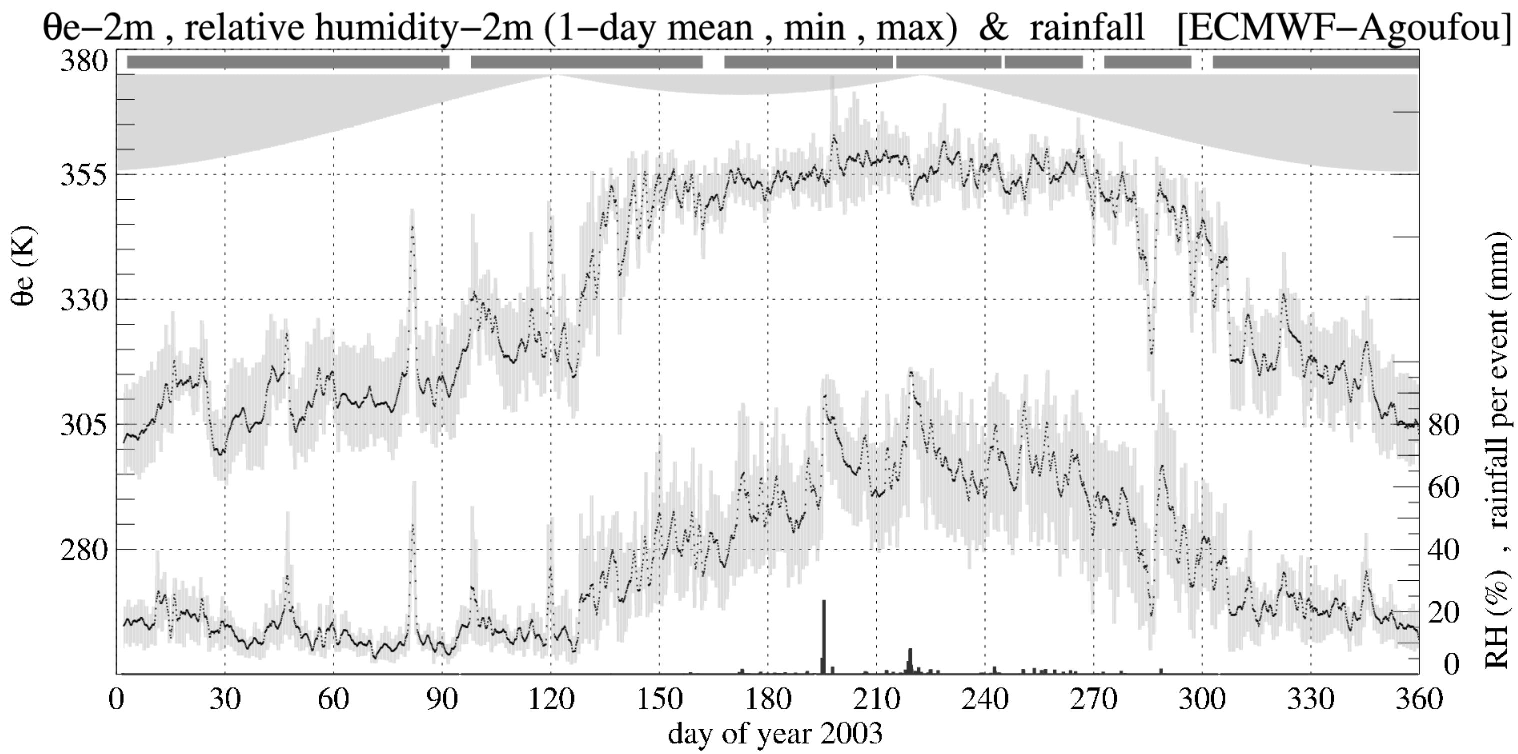


more symetric, less dynamic, too strong in spring, early Summer

response to rainfall events too long (& strong)

year 2003: old aerosol climatology, more opaque atmosphere at that time

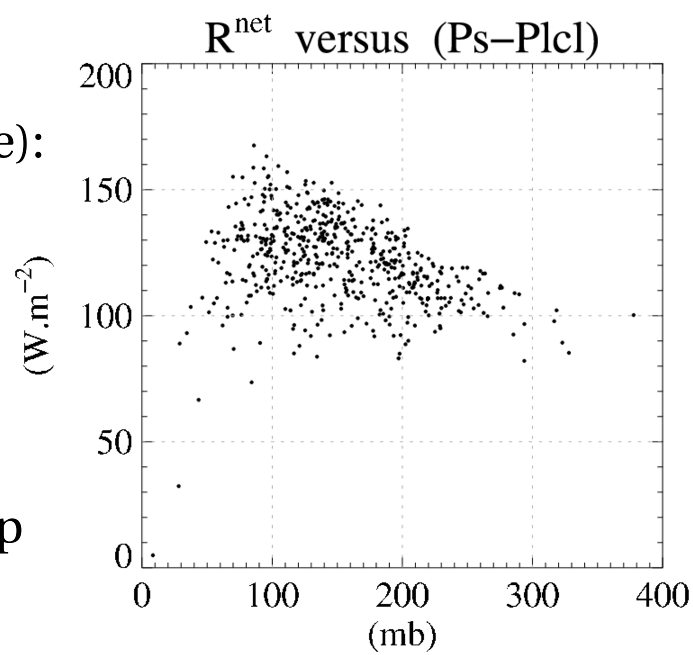
a glance at the ECMWF-IFS

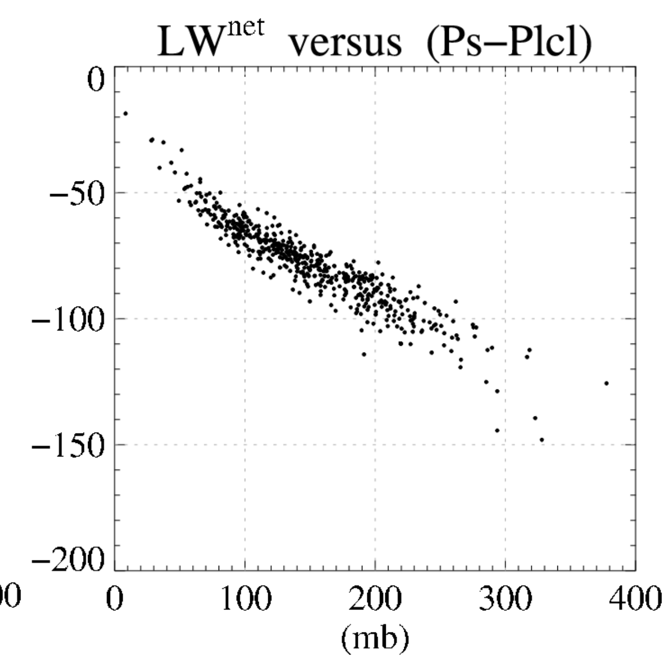


from 3-h dataset

<u>seasonal cycle</u>, year 2003 (above):
good daily thermodynamics
except for response to rainfall
events

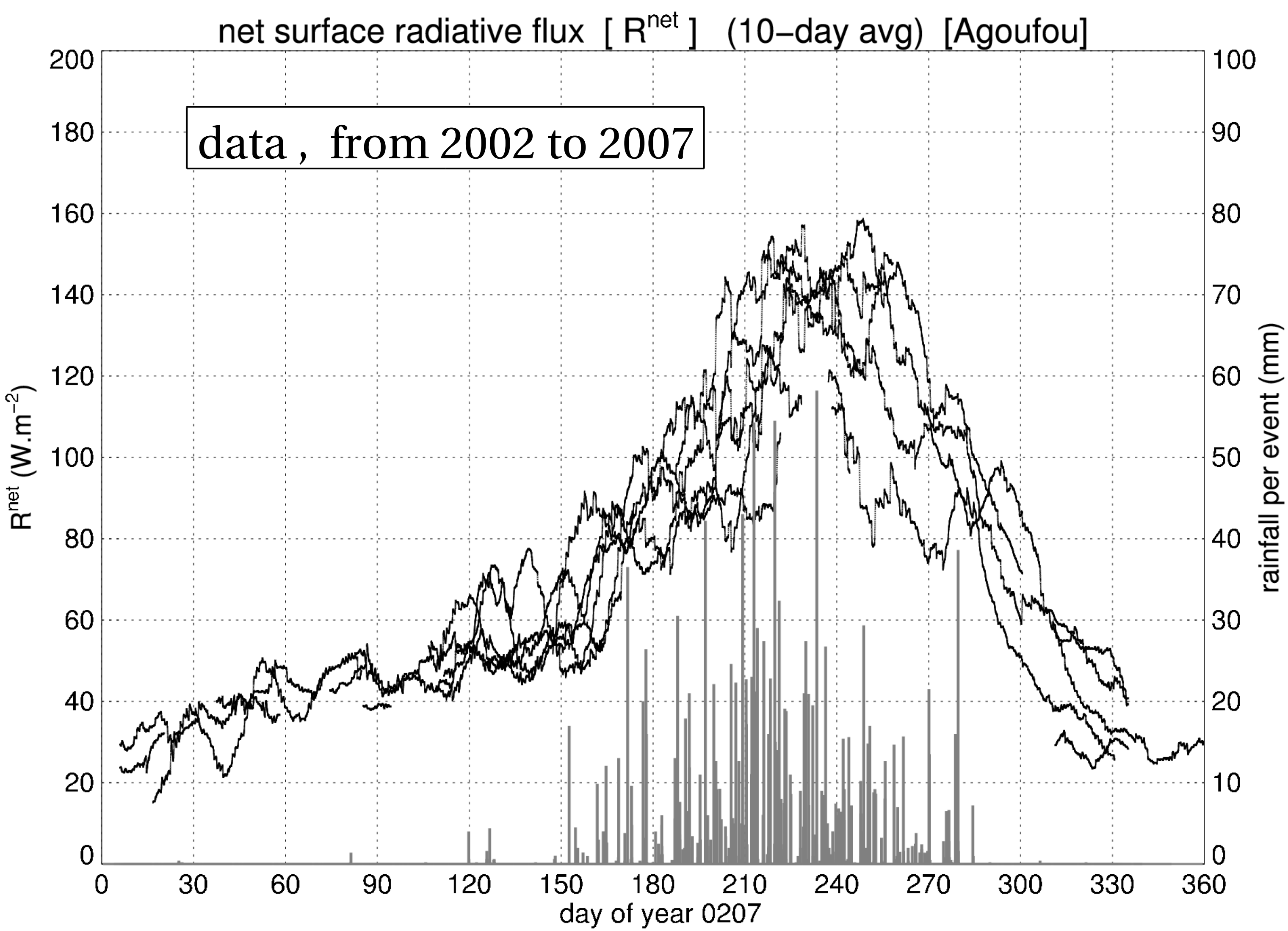
<u>scatter plots</u> (right) :
IFS 2003-2007, JJAS
similar (LWnet,Plcl) relationship
more pb with SW fluxes





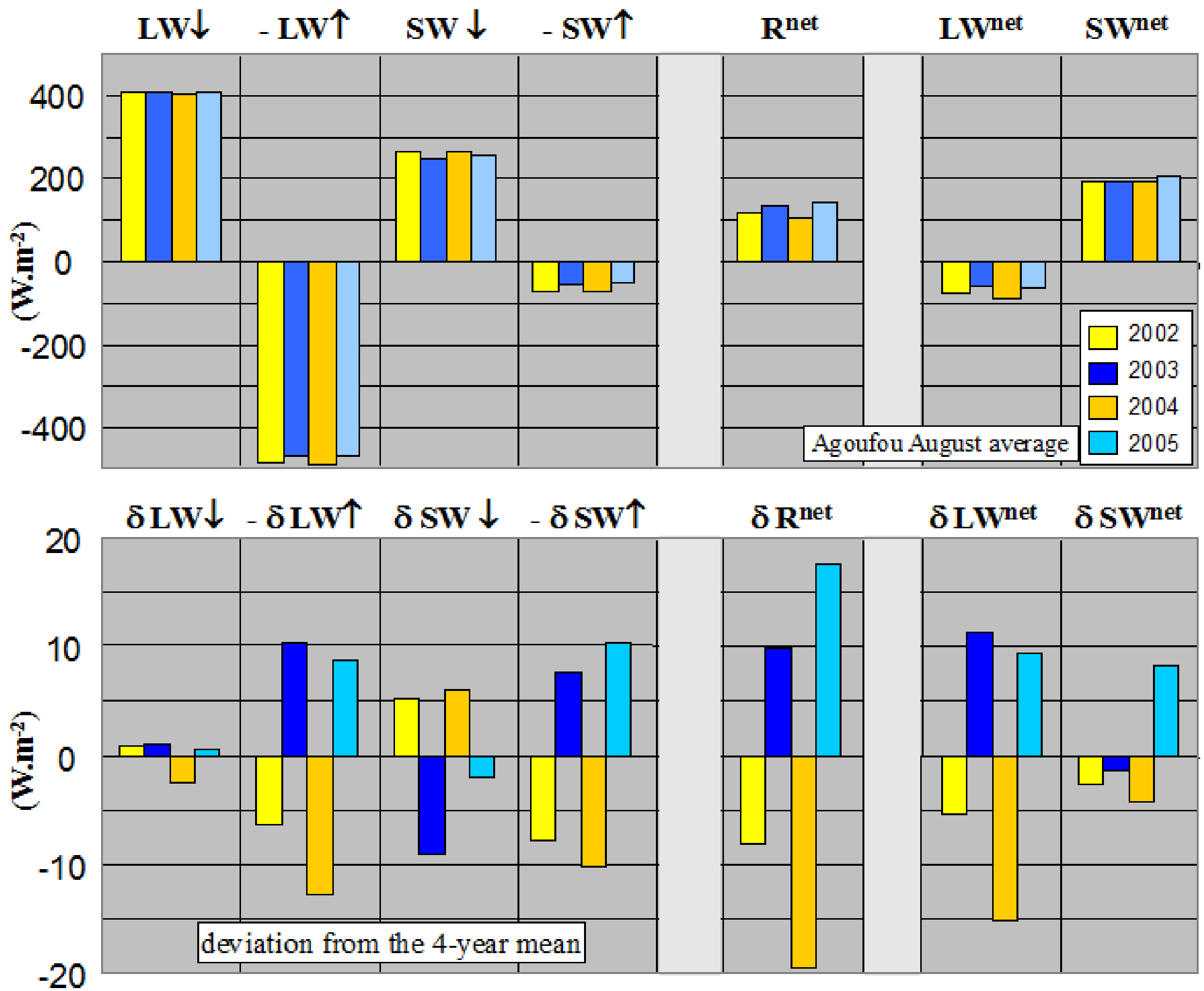
INTERANNUAL VARIABILITY

interannual variability



large interannual fluctuations , during the monsoon season

interannual variability

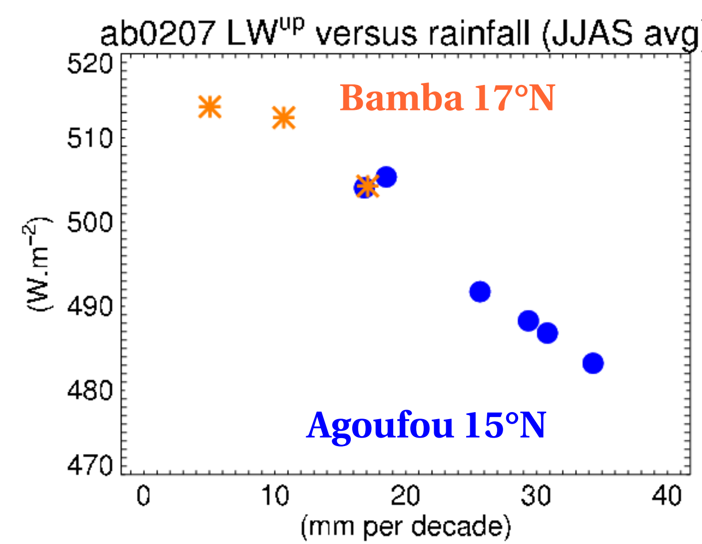


$\Delta(R^{net}) \sim$ 20-35 W.m^{-2}
for R^{net} values~ 120 W.m^{-2}

weaker albedo in
[2003 & 2005] / [2002 &2004]
more that compensates
lower SW^{in}

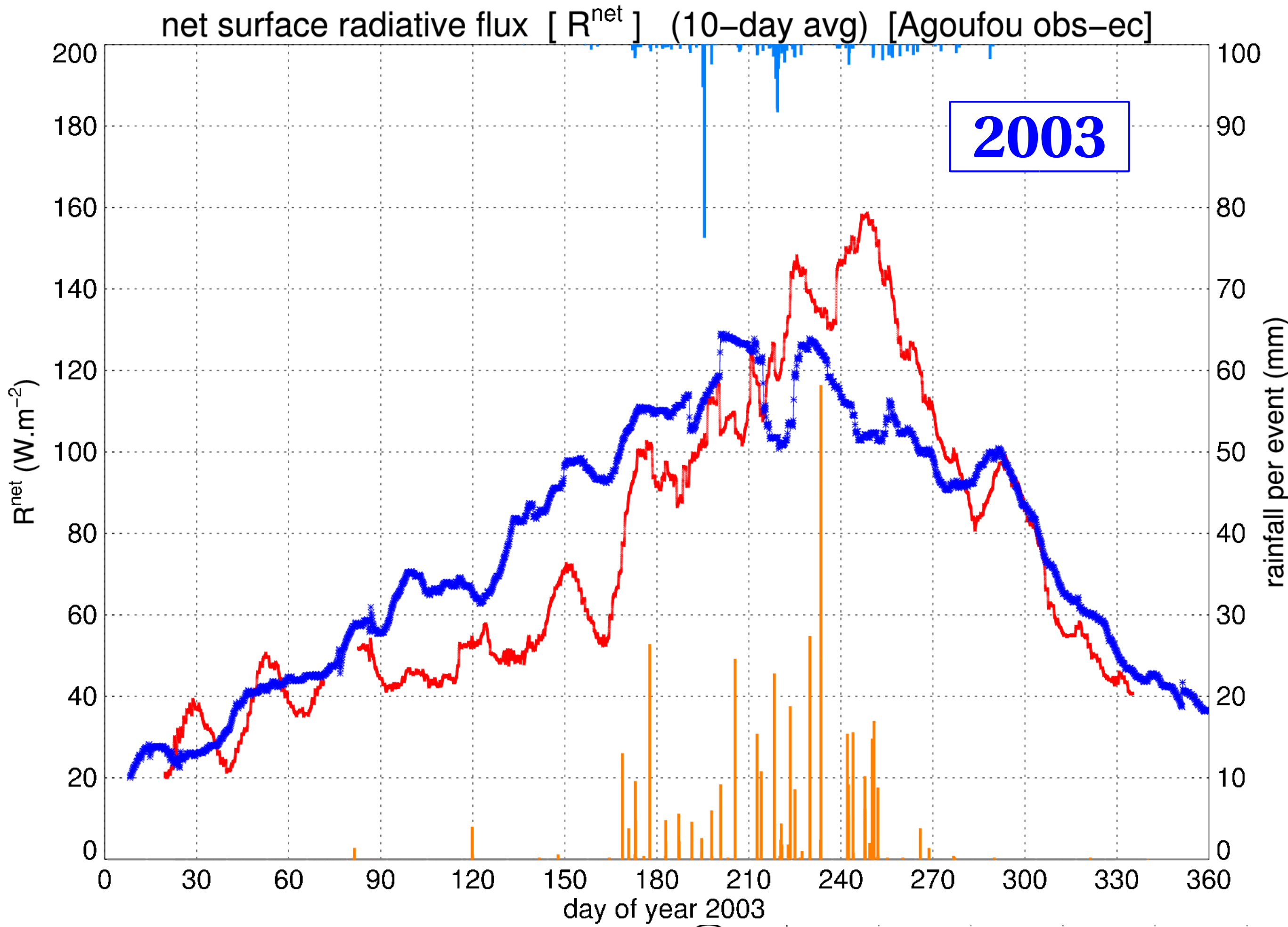
consistent with a more cloudy atmosphere for rainier years

variations of LW^{up} dominate

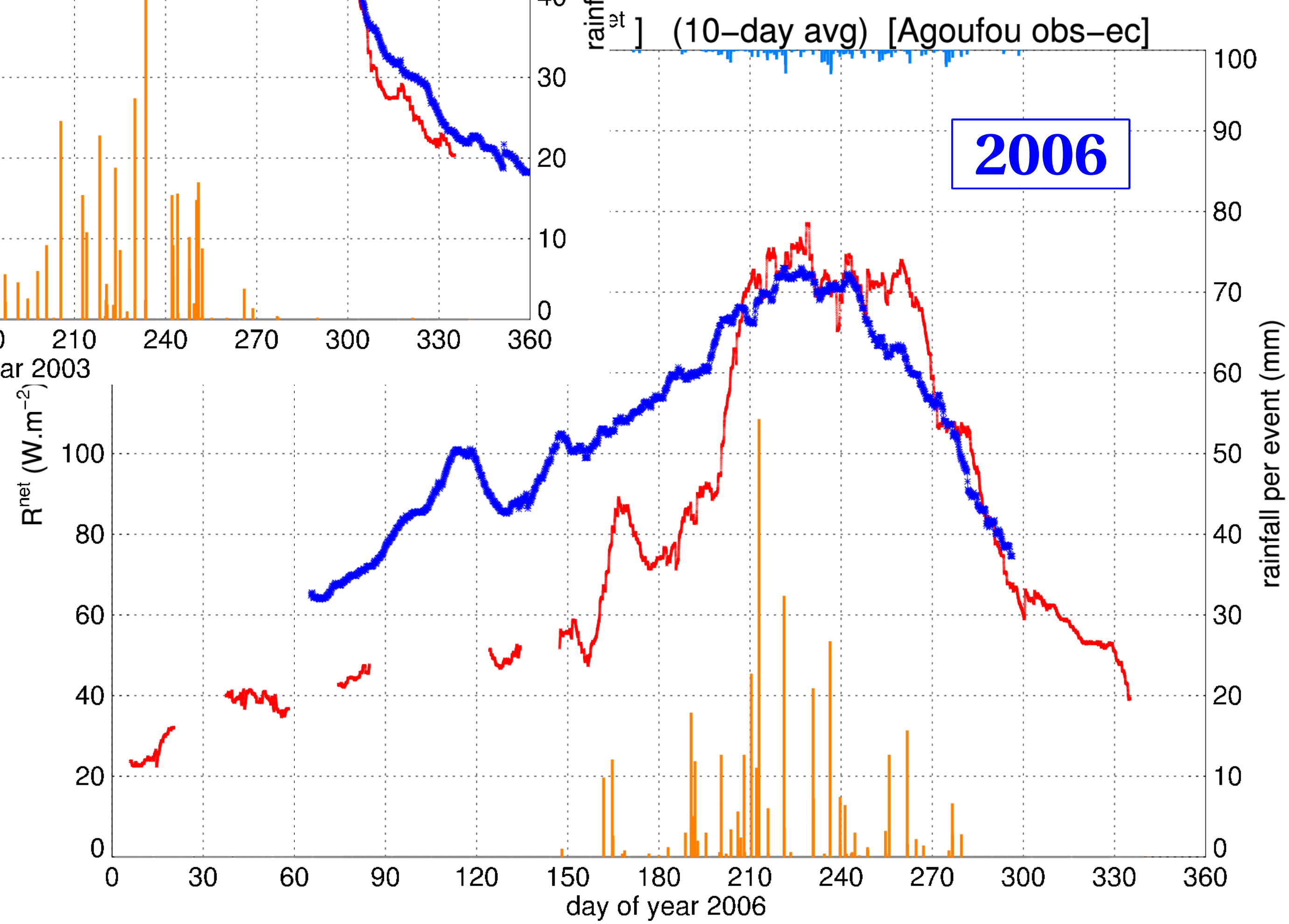


strong link with rainfall →
coupling of water & energy cycles

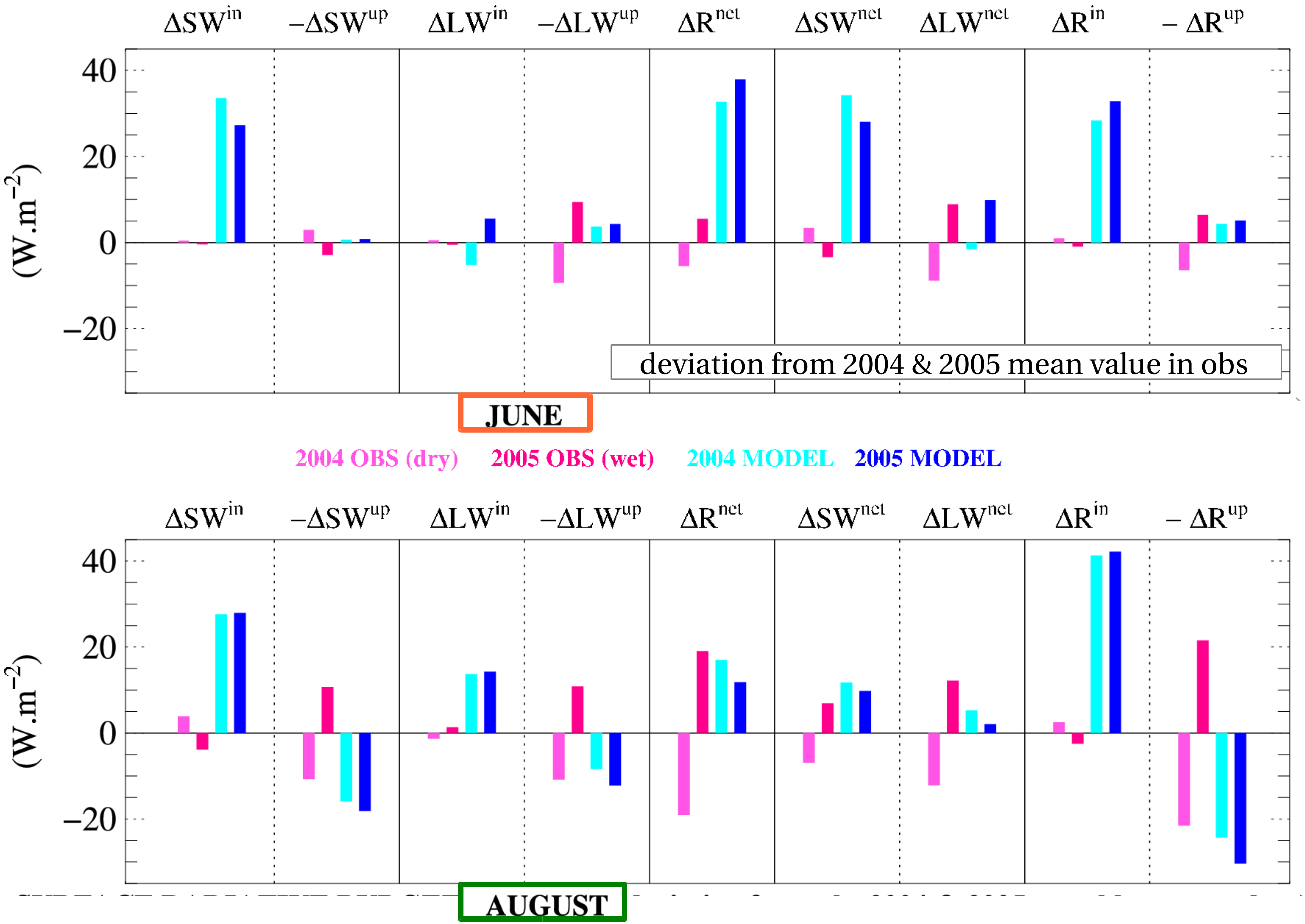
ECMWF-IFS



from 2003 to 2006 change in aerosol climatology seems to dominates over other changes in the physics for this location

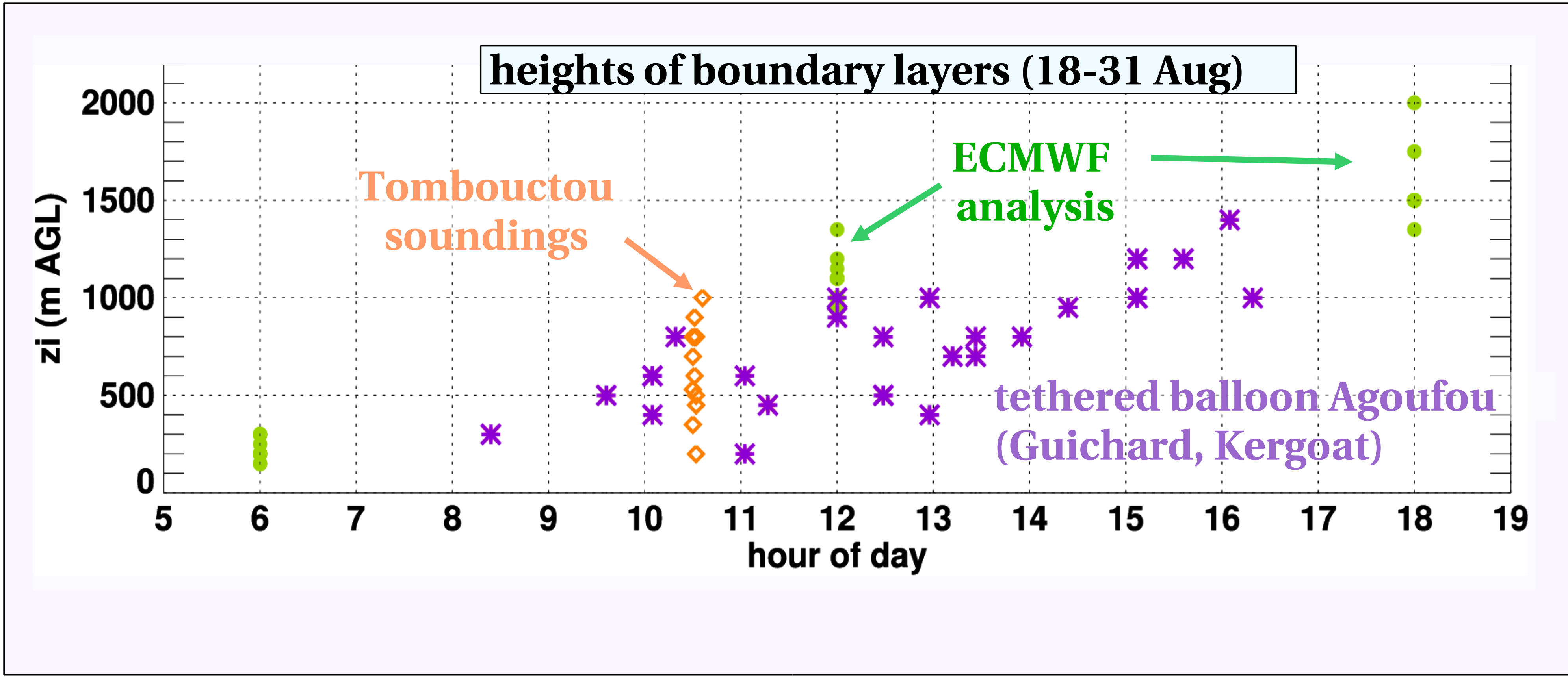


surface radiative budget



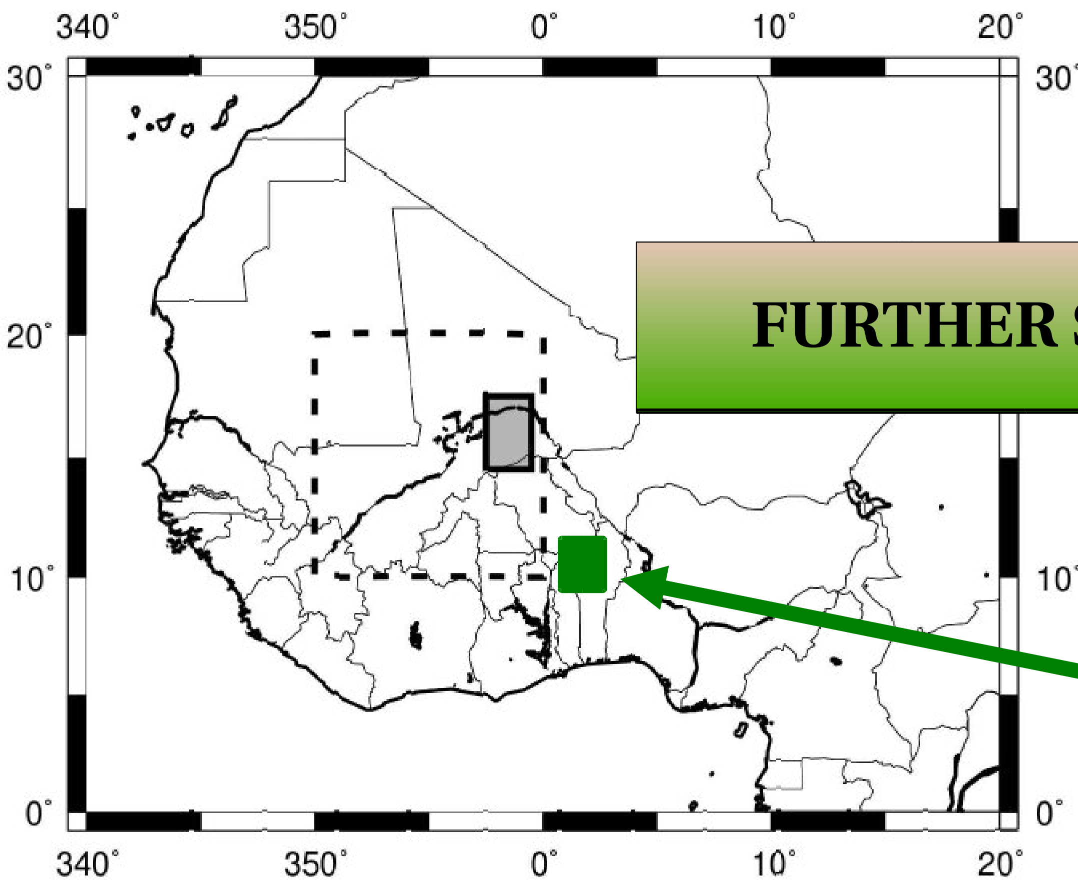
SW^{in} too high in both June & August

no interannual variability in the model (because of processes missing or too approximate)



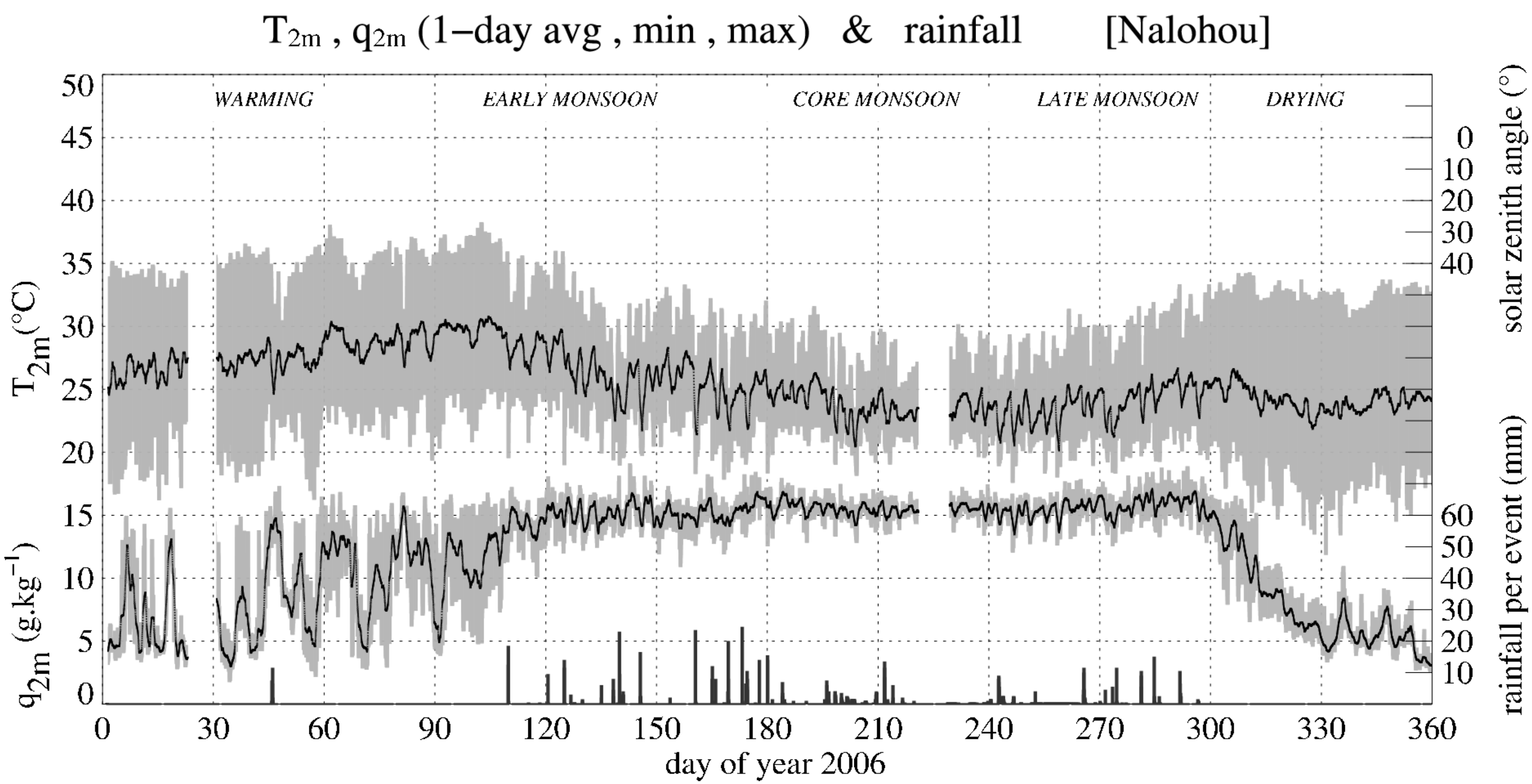
the height of the daytime BL in the Sahel often too large in the model links with too large SW^{in}?

FURTHER SOUTH

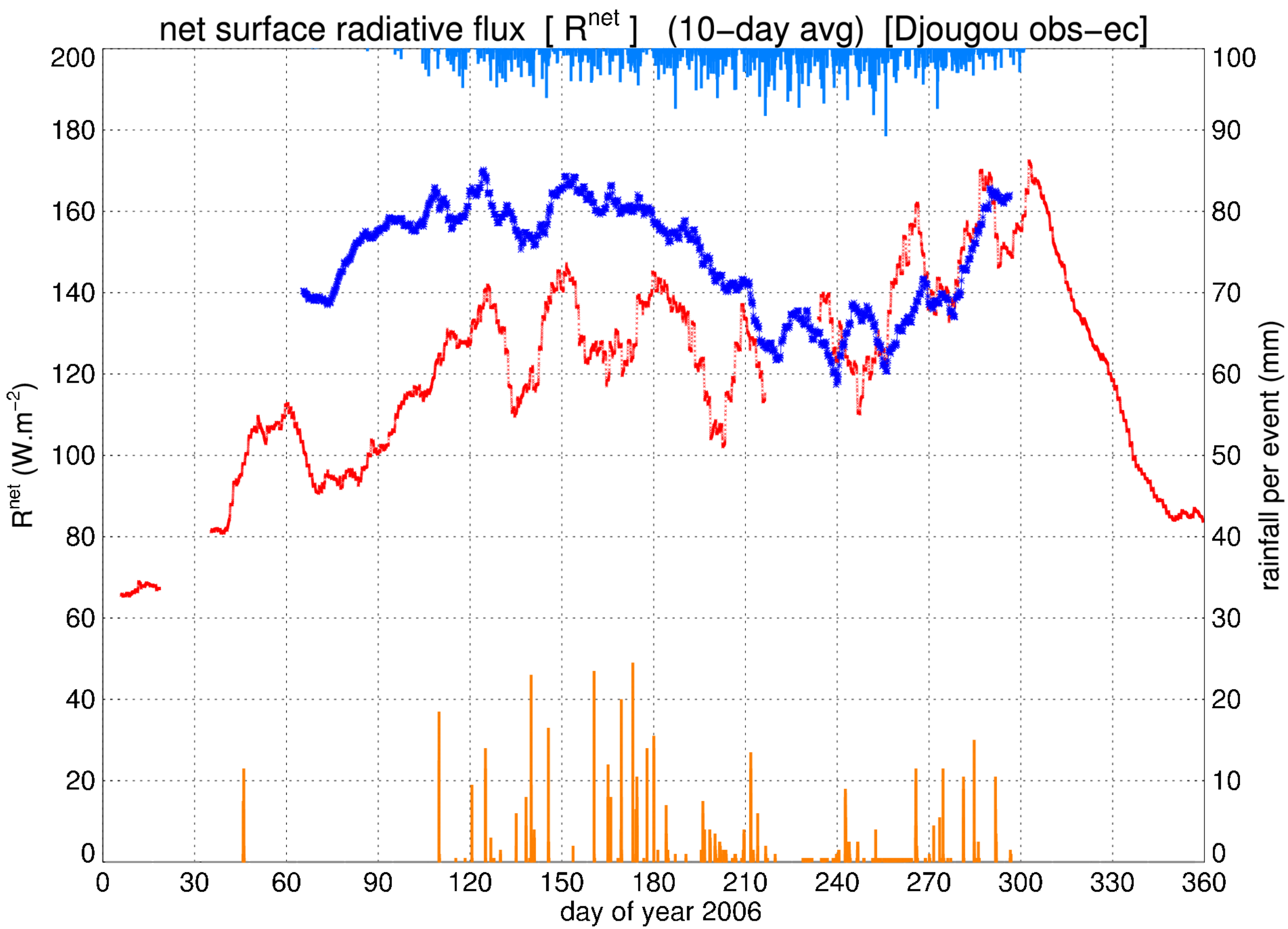


Oueme basin
Soudanian zone

seasonal cycle in Nalohou (Oueme, 10°N)

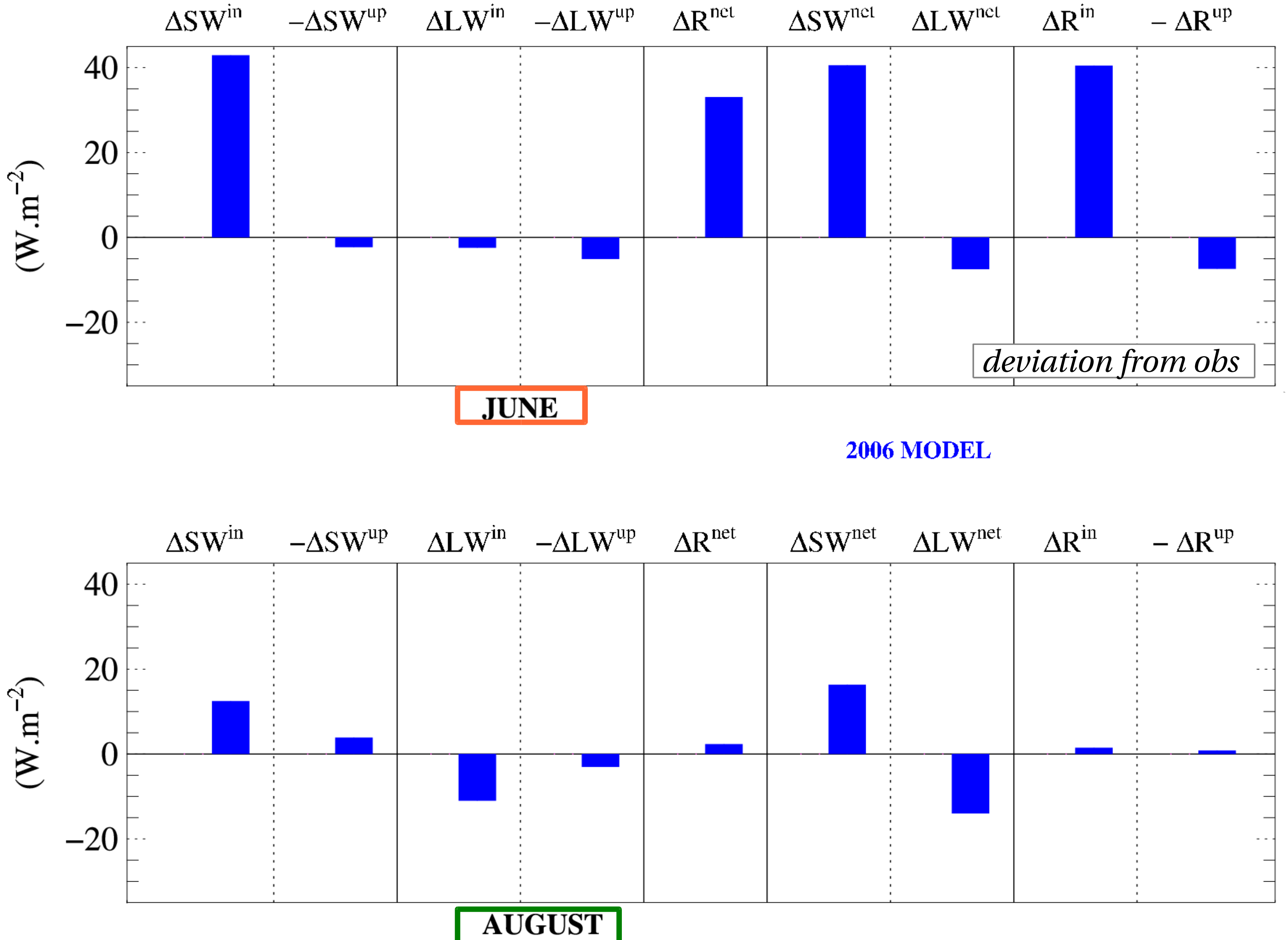


fairly distinct from Sahelian site, [T+,q+]
closer to saturation



As in the Sahel, larger differences between obs & model in Spring, early Summer

surface radiative budget, 10°N Djougou



SW^{in} too high in June

in August, simulation much better, R^{net} close in obs & model

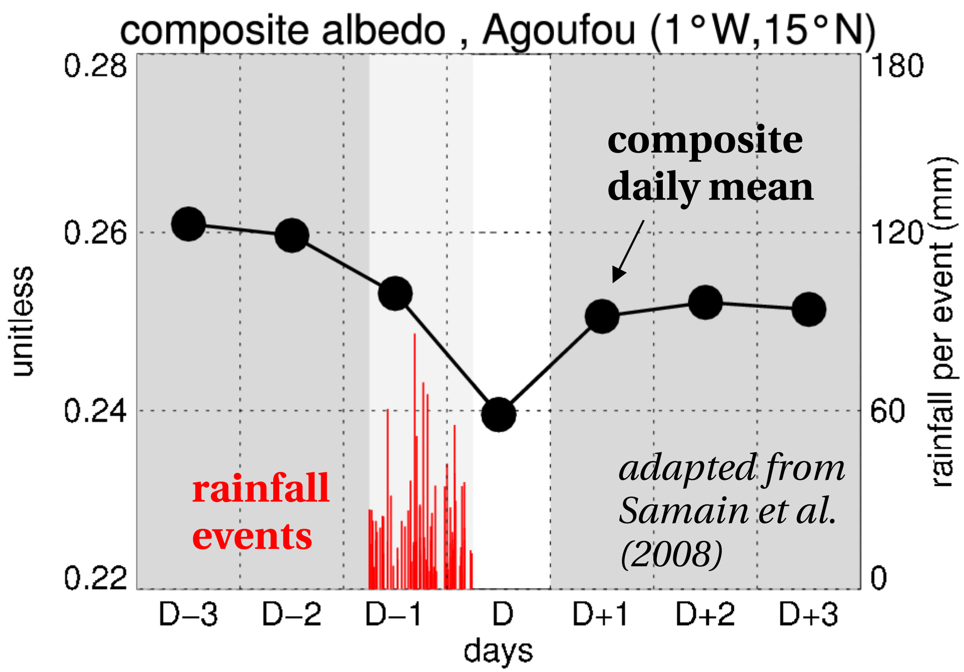
RAINFALL EVENT COMPOSITE

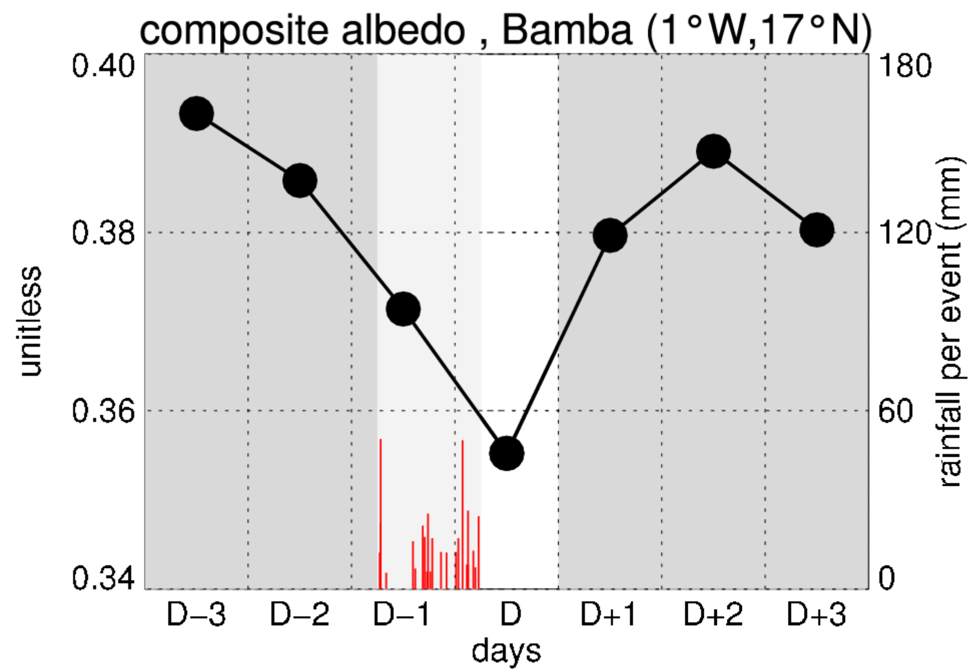
characterization of the surface around a convective event

magnitude of jump, recovery period etc...

composite over all rainfall events > 5mm in JJAS
6Z day D-1 to 6Z day D years 2002 to 2007

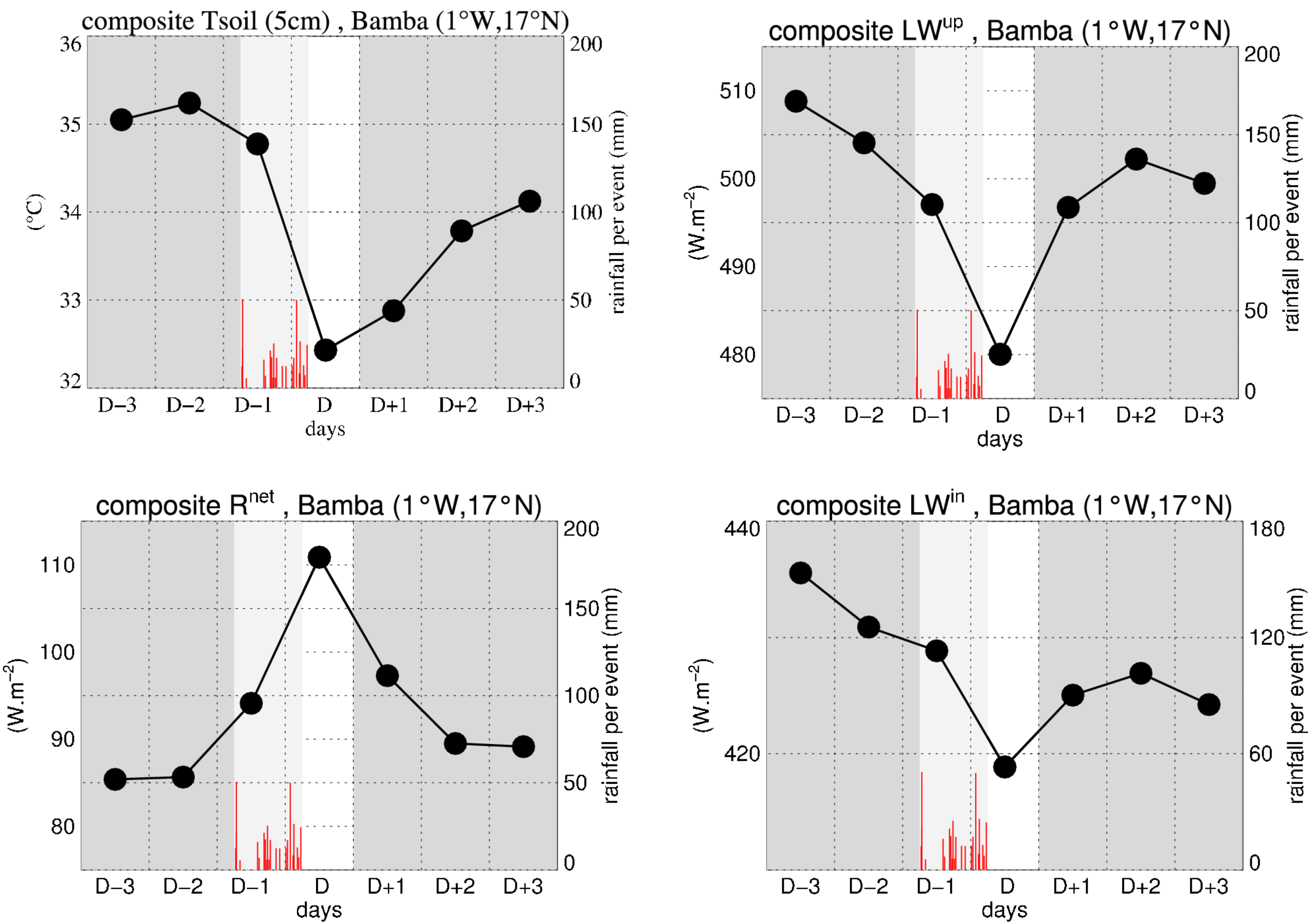
qualifying/quantifying rainfall event, soil moisture induced-albedo change





- *short lived*
- *limited impact on average over JJAS*
- *stronger over bare soil (early monsoon)*
- *larger scale trend: growth of vegetation*

- *stronger impact (less vegetation)*
- *but less rainfall events in Bamba (17°N) than in Agoufou (15°N) [gradient]*


composite Tsoil (5cm) , Bamba (1°W,17°N)
(°C)
rainfall per event (mm)
36
35
34
33
32
200
150
100
50
0
D−3
D−2
D−1
D
D+1
D+2
D+3
days
composite LW^up , Bamba (1°W,17°N)
(W.m^−2)
510
500
490
480
composite R^net , Bamba (1°W,17°N)
110
100
90
80
composite LW^in , Bamba (1°W,17°N)
440
420
180
120
60

Summary

modelling side

at large scale, improved parametrizations critically needed over West Africa
- rainfall, clouds/aerosols, turbulence & vegetation at least
- usefulness of frameworks such as AMMA-MIP (AMMA-CROSS , AMMA-MIP: AEWs)

at mesoscale need of improved methods to initialize simulations (case studies)

process understanding

data provide valuable diagnostics/guidance regarding processes at play
- highlight of the sharp seasonal & interannual fluctuations of Rnet in the Sahel
- shaped by modifications of the surface via rainfall events & vegetation phenology
- importance of LW fluxes (several not so intuitive features)
- transformations of the diurnal cycle during the year (physical/dynamical couplings)
- show that θe & R^{net} positively related
- flatness of θe cycle (consistent with analysis of soundings), parametrizations?

intermediate models needed also, e.g.:
- CRM-LES type case studies (e.g. C. Rio *et al.*, daytime shallow convection early Summer)
- 2D & 1D models (budgets from soundings in next years, cf GATE, COARE, ARM budgets)

re-analysis from ECMWF (Panareda *et al* , 2008)– corrected humidity from soundings

much more left to be to learn in following years…


Thank you