Annual cycle of the surface energy budget in West Africa: radiative-thermodynamic couplings and cloud impact

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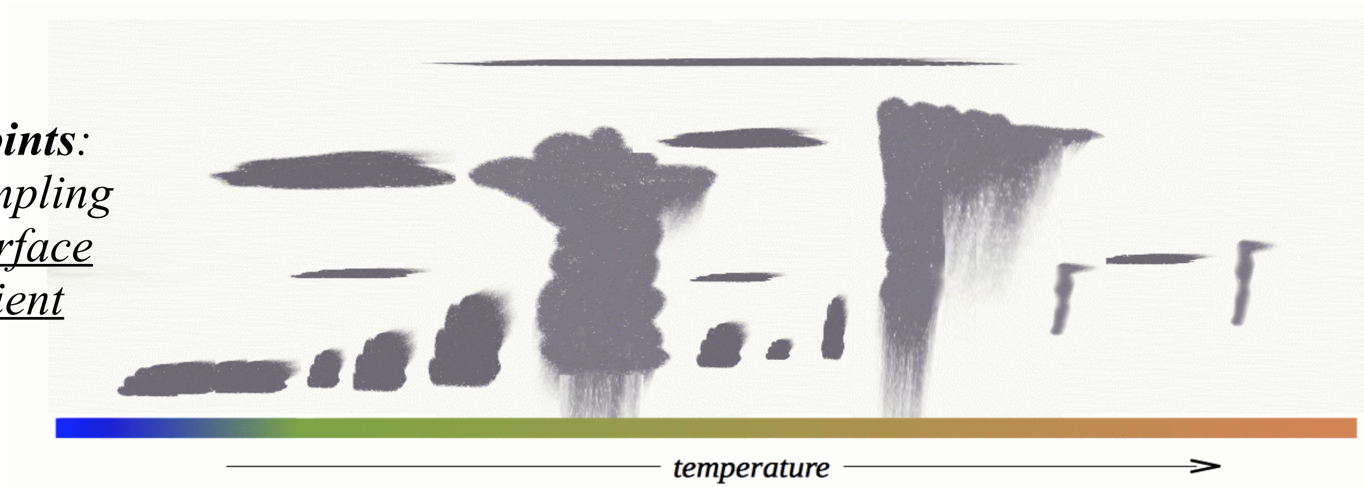
Thanks to H. Douville, F. Favot, S. Tyteca, A. Voldoire & CMIP5

Ground-based observations: AMMA-Catch and CEH, ARM MF in Niamey
Thanks to L. Kergoat, O. Bock, F. Timouk, S. Galle...

***cfSites AMMA points**: a set of points sampling clouds along a surface temperature gradient over land*



West Africa, common perception: importance of the lower troposphere, strong couplings between convective rainfall, surface processes & surface energy budget

However, clouds are also important players in the surface energy budget there, in the wet Tropics (Guinean zone) but also over semi-arid regions such as the Sahel, via a far from negligible cloud radiative impact.

This affects the boundary layer evolution at short time scale – within the diurnal cycle, with potential implications on convection.

A few pieces of information about **datasets** (ground-based only below + partial)

various sets of ground-based observations/measurements, available over periods ranging from ~ a year to several years to a few decades

- automatic weather stations and flux stations
  surface meteo & radiative fluxes and surface energy budget, $\Delta t \sim 30$ min

- ARM Mobile Facility of Niamey [used by Bouniol et al. (2012) for clouds]

- Thousands of high-resolution soundings (Δt = 3 h, 6 h, 12 h, or more)
  [Parker et al. 2008]

- Precipitable water (GPS, Δt = 1h)
  [Bock et al. 2008]

- SYNOP data (Δt = 3h to daily)

- low-resolution GTS soundings

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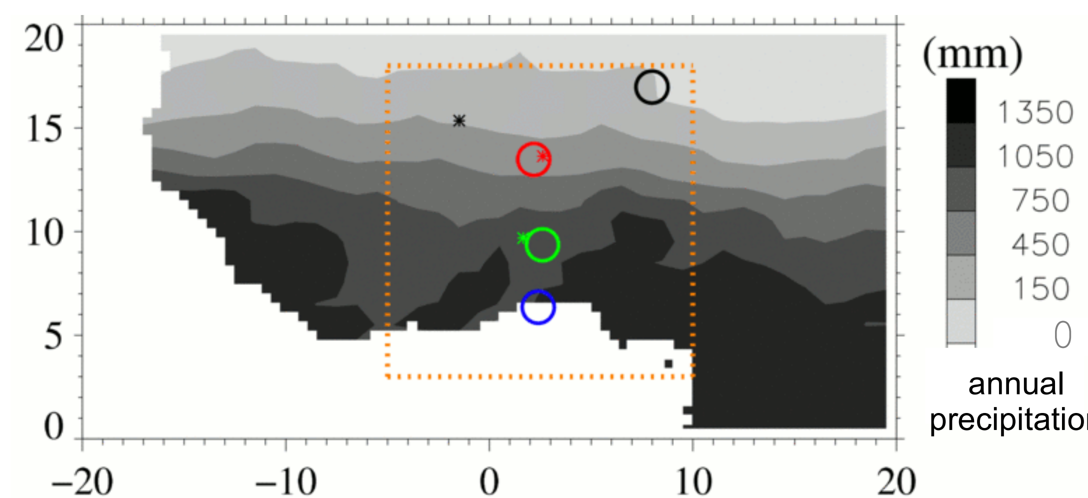


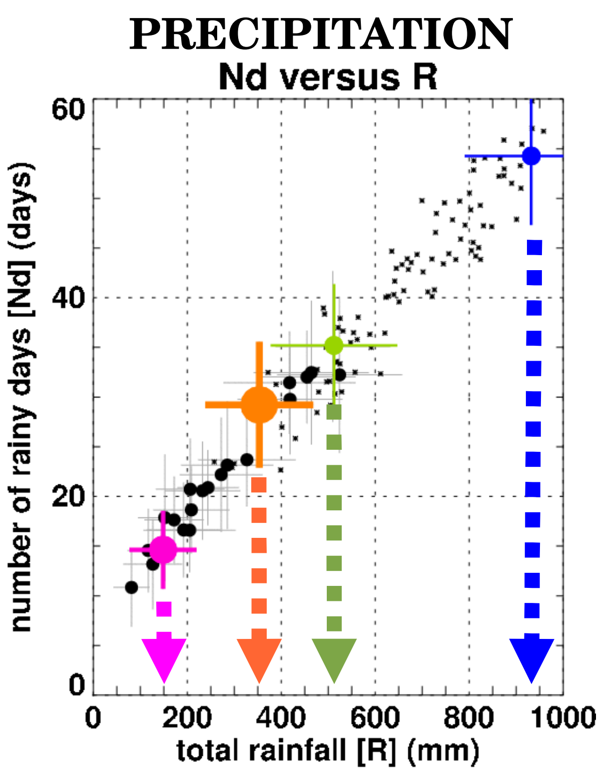
(from Gounou et al. 2012)

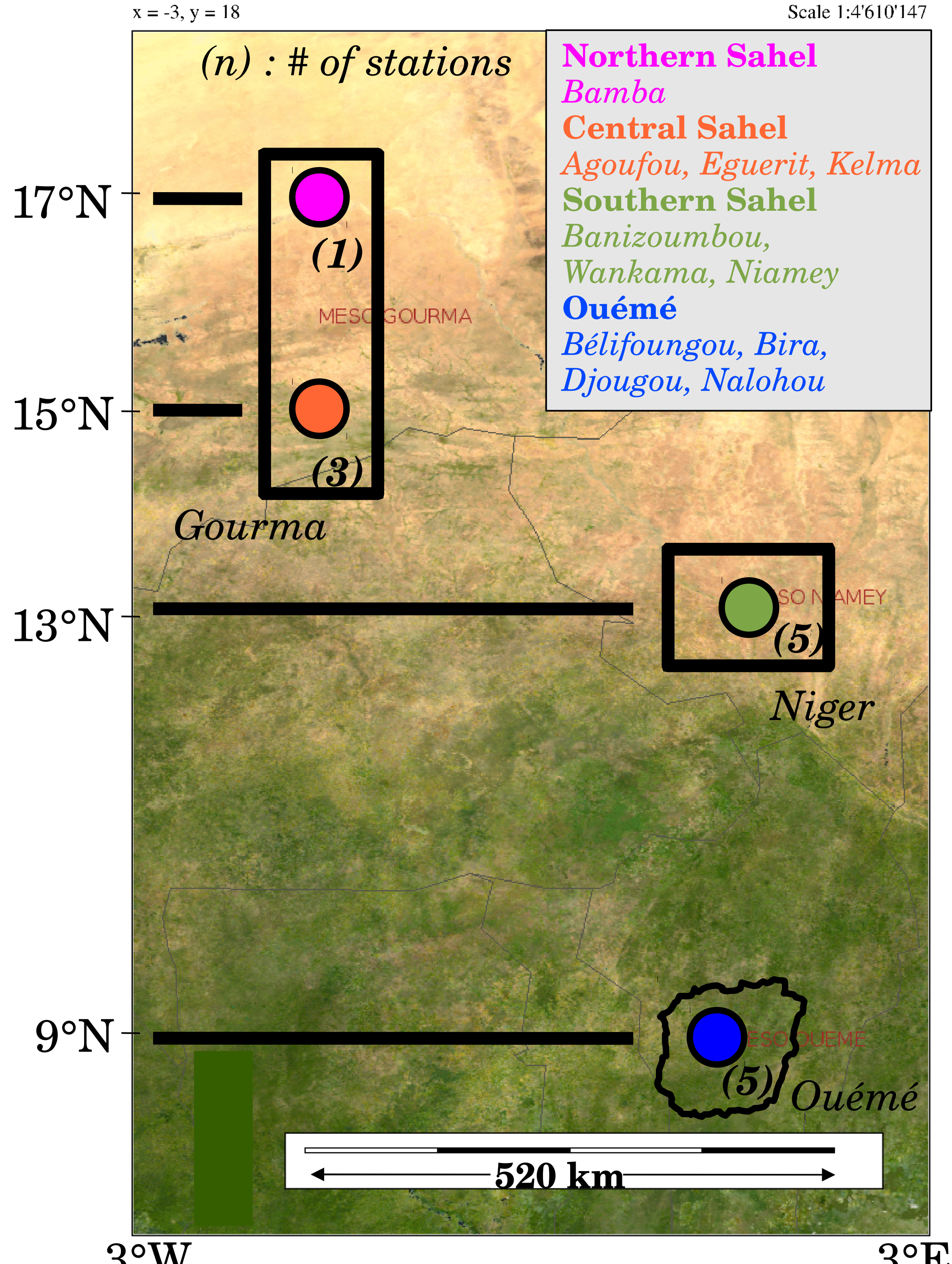
THE MEASUREMENT SITES AMMA-CATCH

Located along a meridional climatological gradient

Over ≠ surface/vegetation types

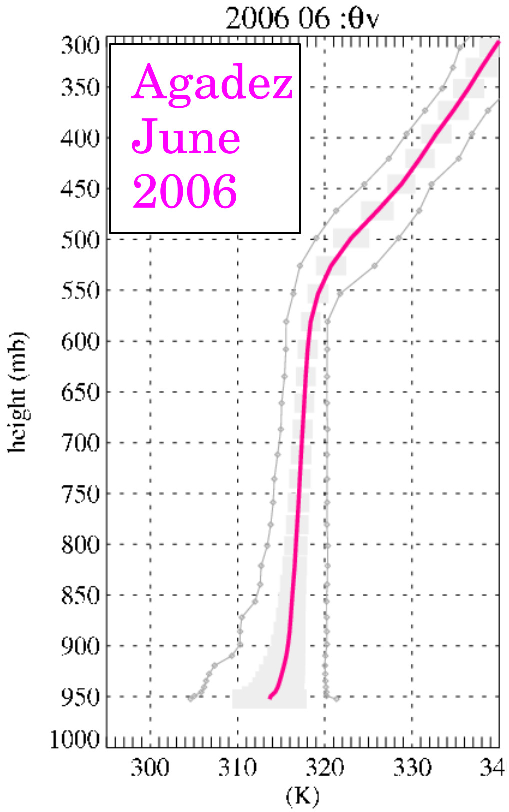
more about these sites in the special issue of Journal of Hydrology (2009)

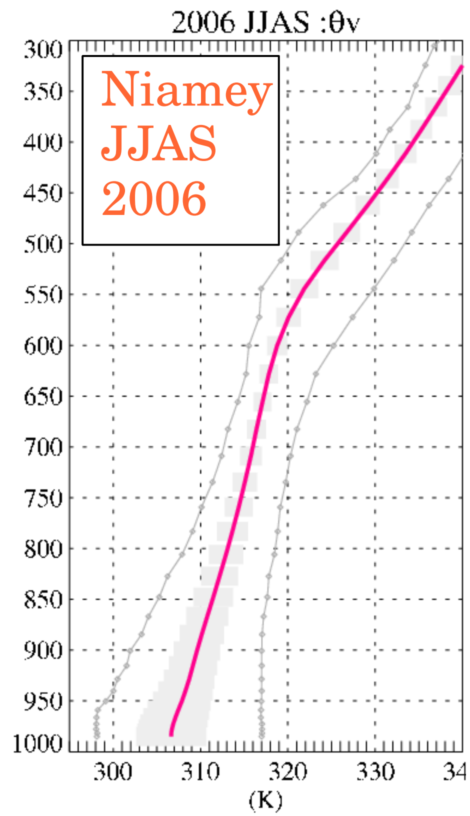


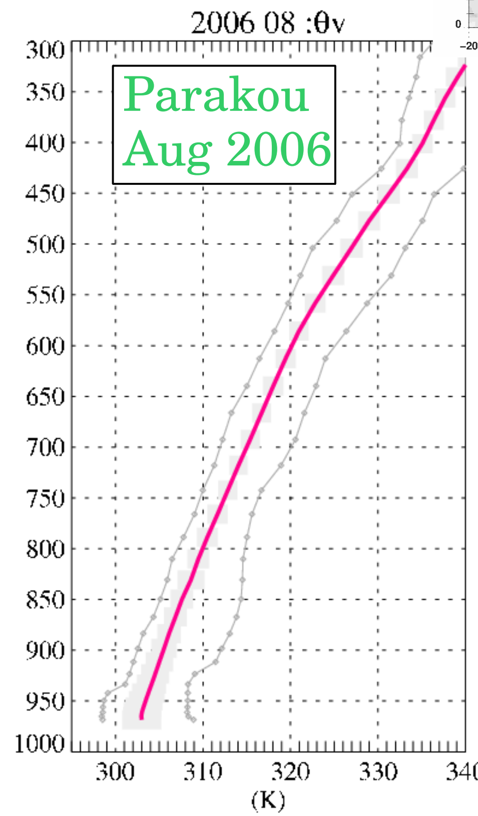


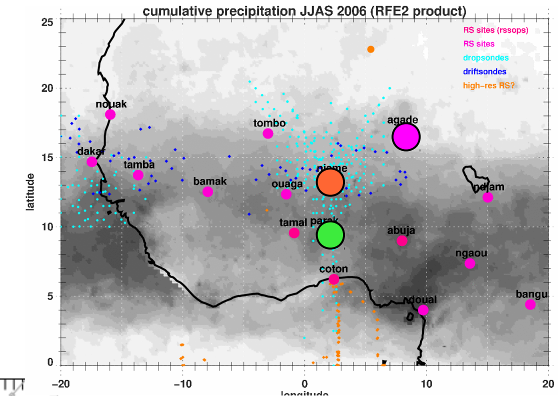
From AMMA-CATCH GIS web mapping

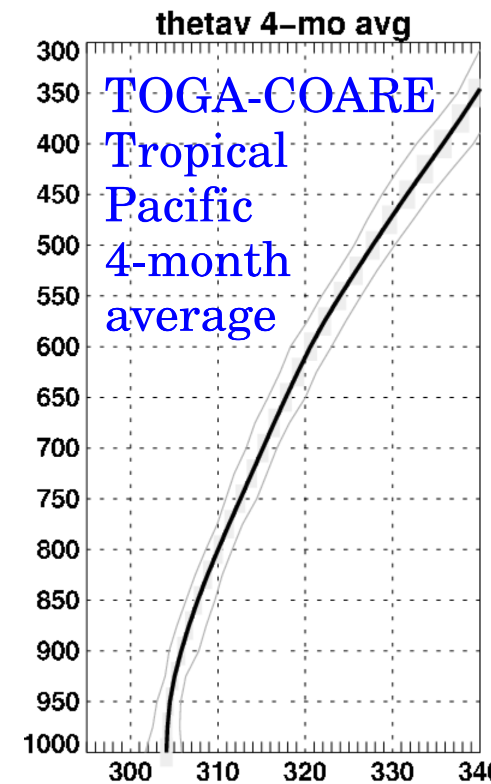
SOUNDINGS











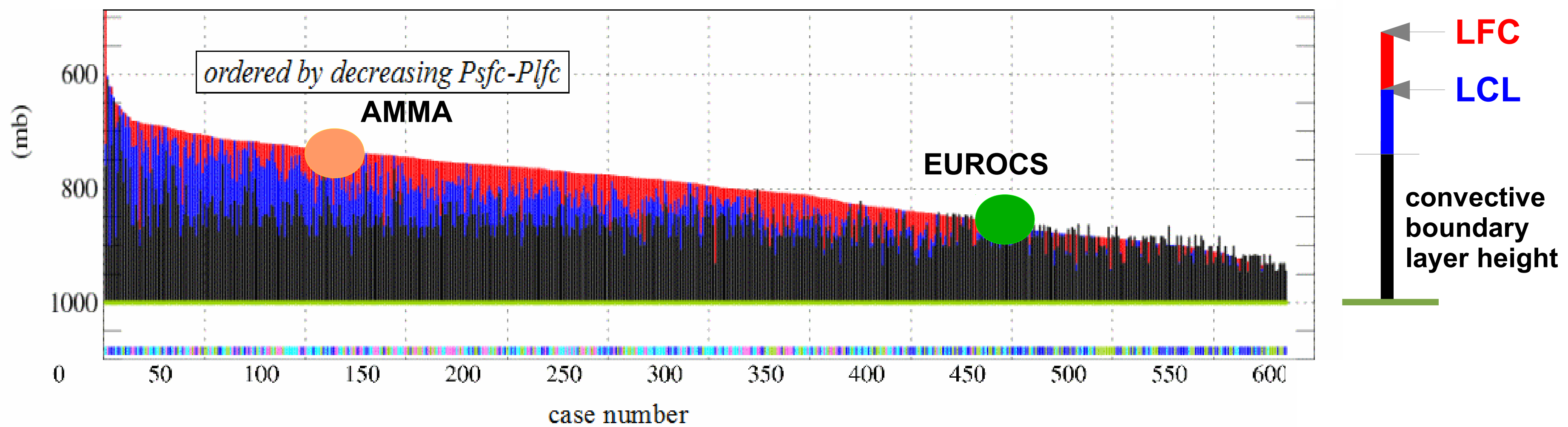
θv at different sites

A wide variety of boundary layers and tropospheric structures in space and time

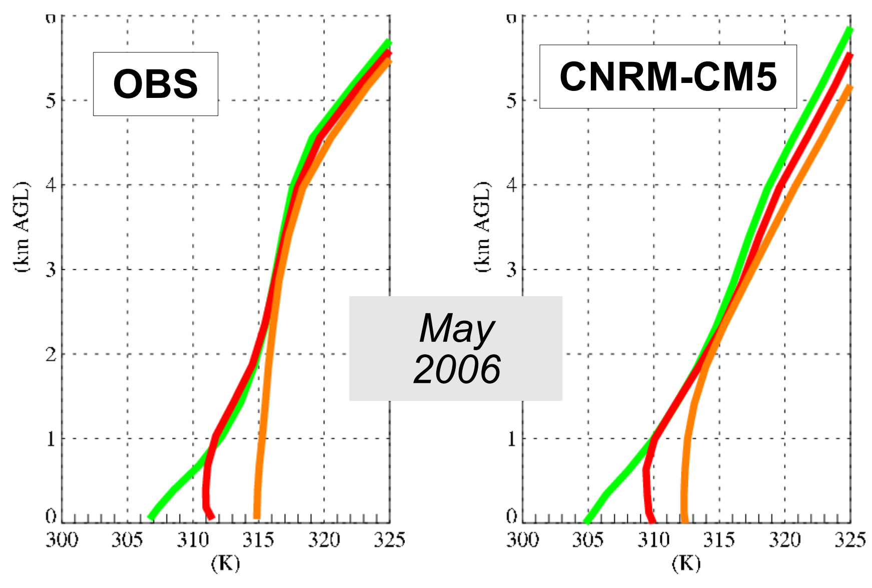
"SOUNDING" DIAGNOSTICS

Simple boundary layer and convective diagnostics from soundings (BLH, LCL, LFC, CAPE, CIN...) that can be used equivalently for simulated profiles

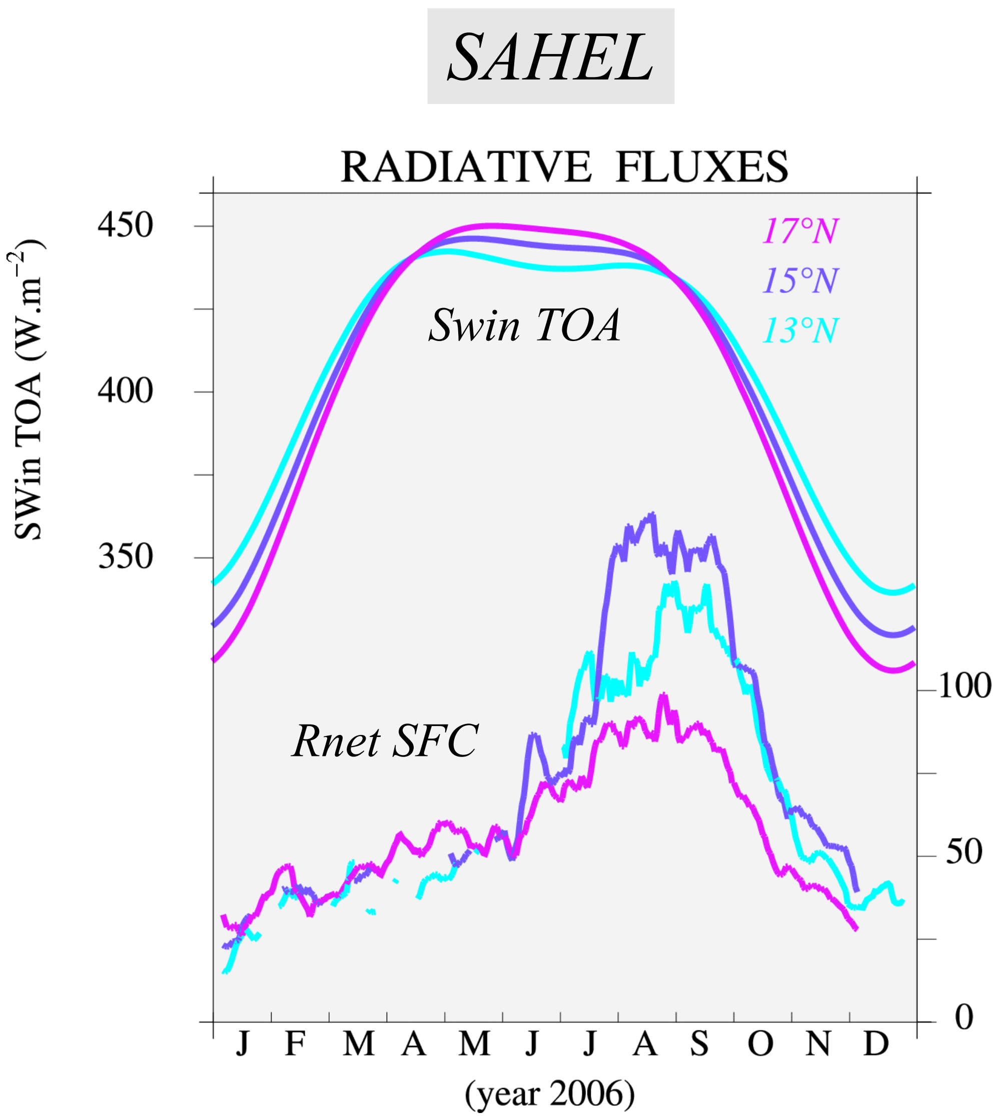
example for a subset of profiles in the Sahel during the monsoon

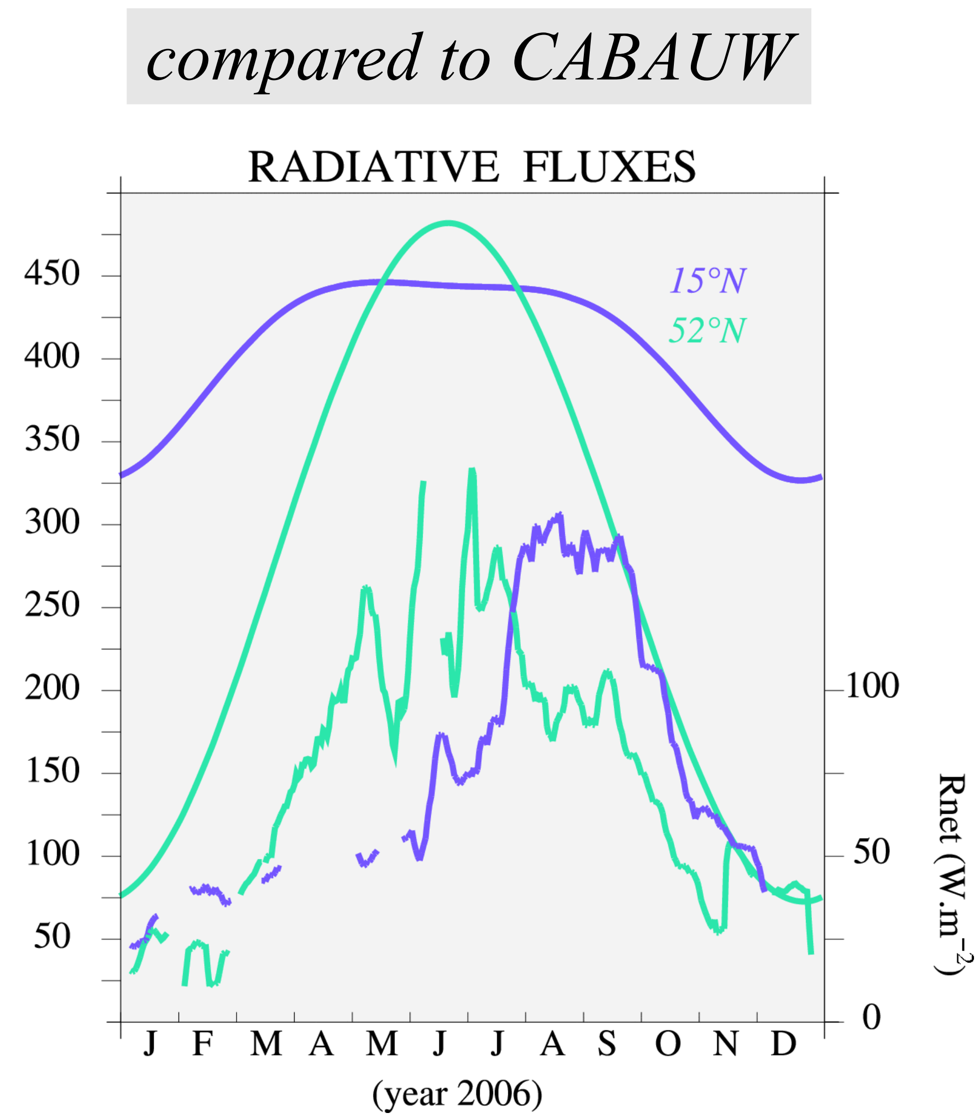


example of a simple comparison model-obs at 6h, 12h & 18h (monthly mean)



Surface energy budget: what is specific about the Sahel



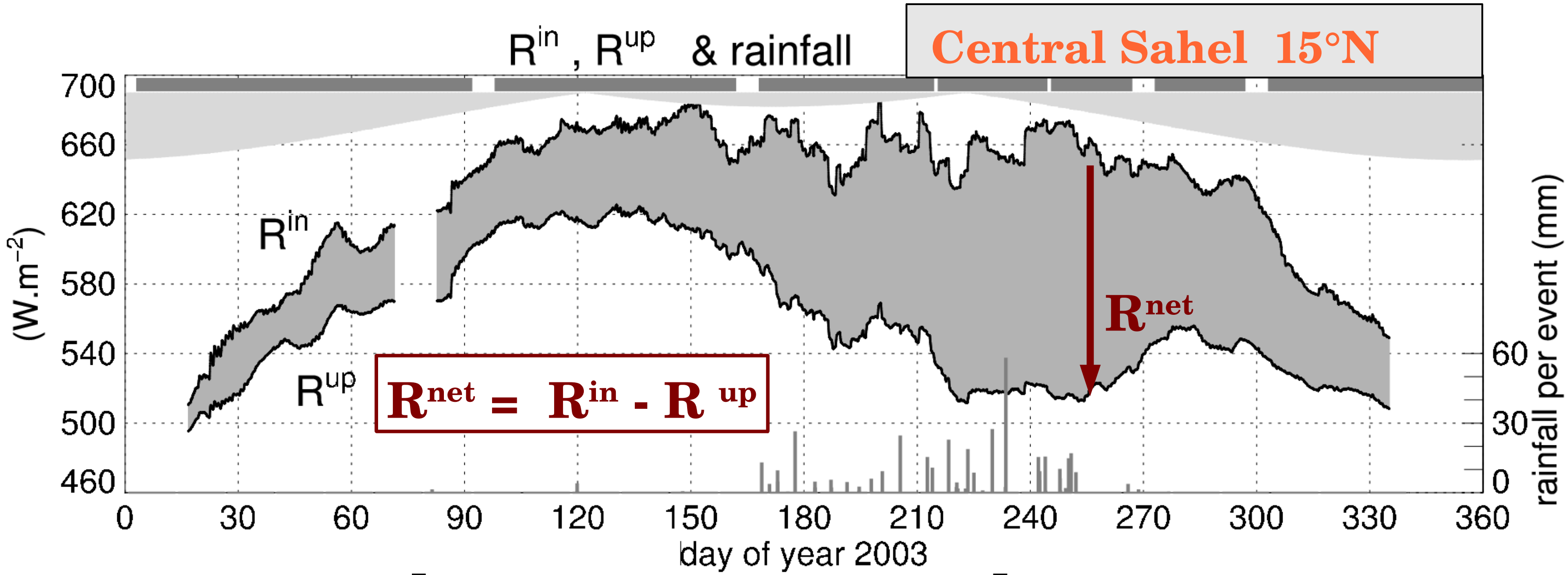


Guichard et al. (2012)

From June to September, variations of R^{net} (↑) driven by R^{up} (which ↓)

does not mean that radiative impact of clouds & aerosols negligible !

but does not mean either that it plays the central role in interannual variability



Guichard et al. (2009)

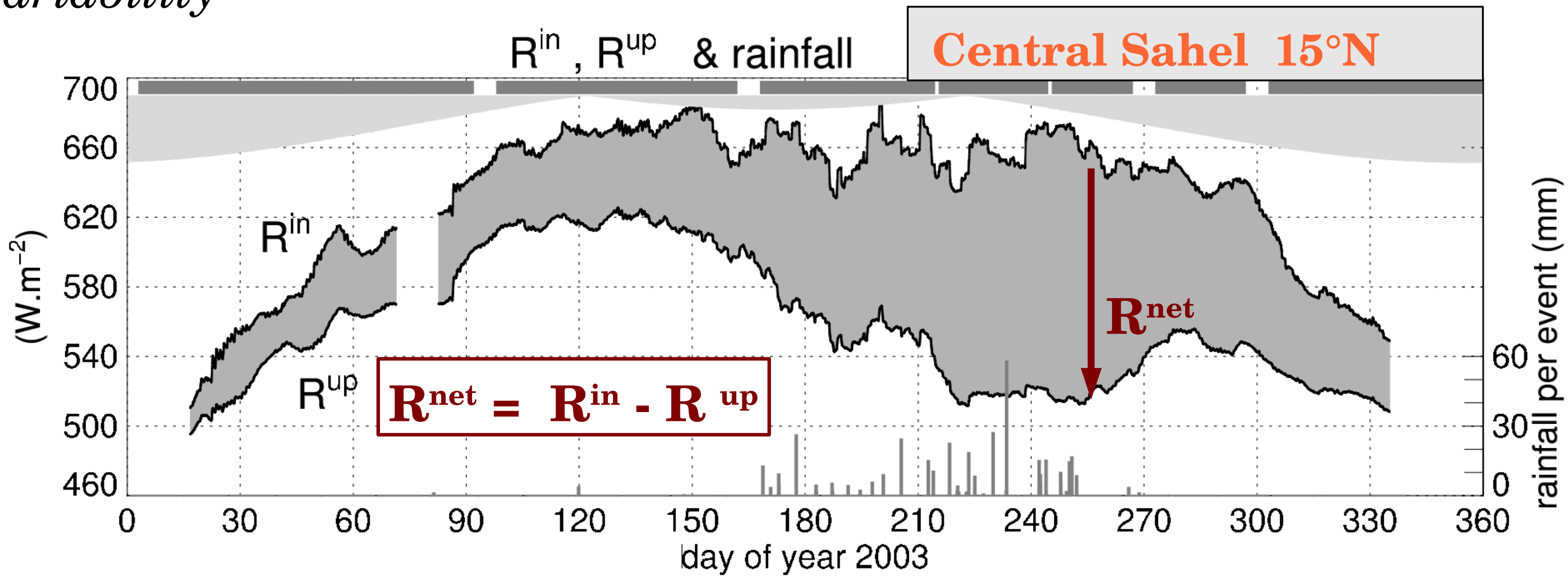
surface cooling

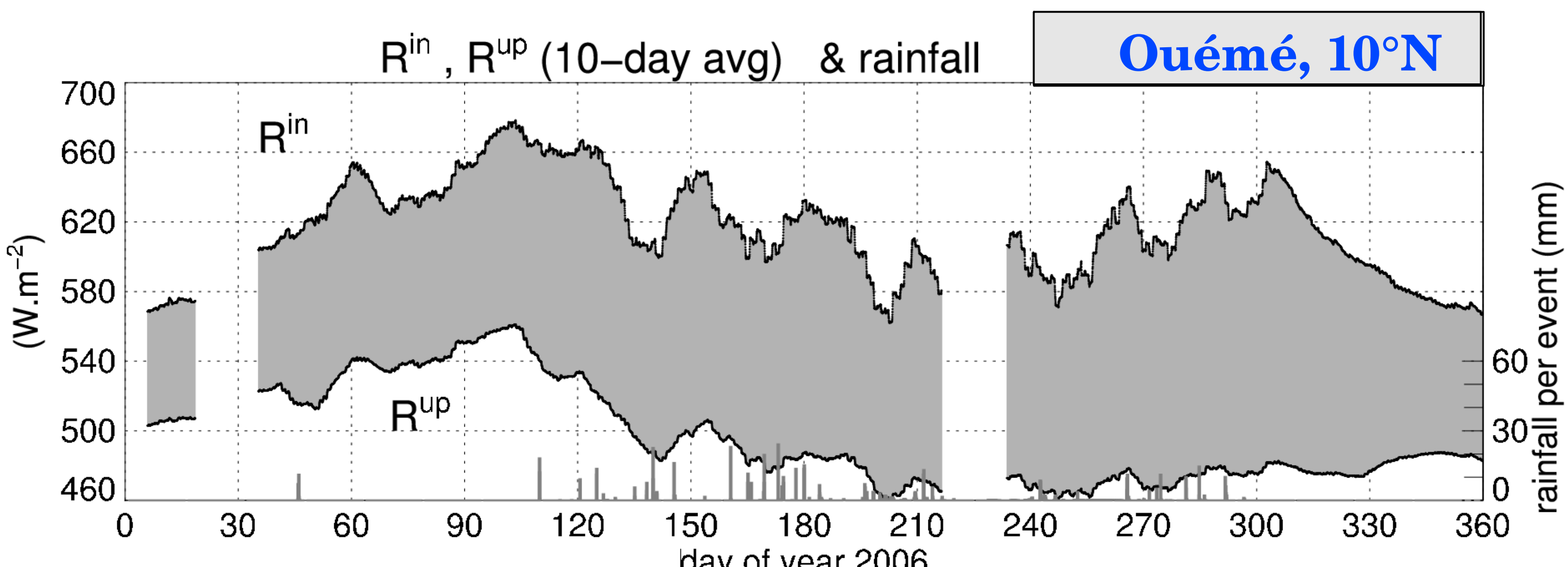
surface albedo (vegetation, Samain et al. JGR 2008)

Photo V. Le Dantec

similarities with seasonal cycle of surface radiative budgets for Niger sites (Slingo et al. 2009, Ramier et al. 2009)

From June to September, variations of R^{net} (↑) driven by R^{up} (which ↓)
does not mean that radiative impact of clouds & aerosols negligible !
but does not mean either that they play an important role in interannual variability



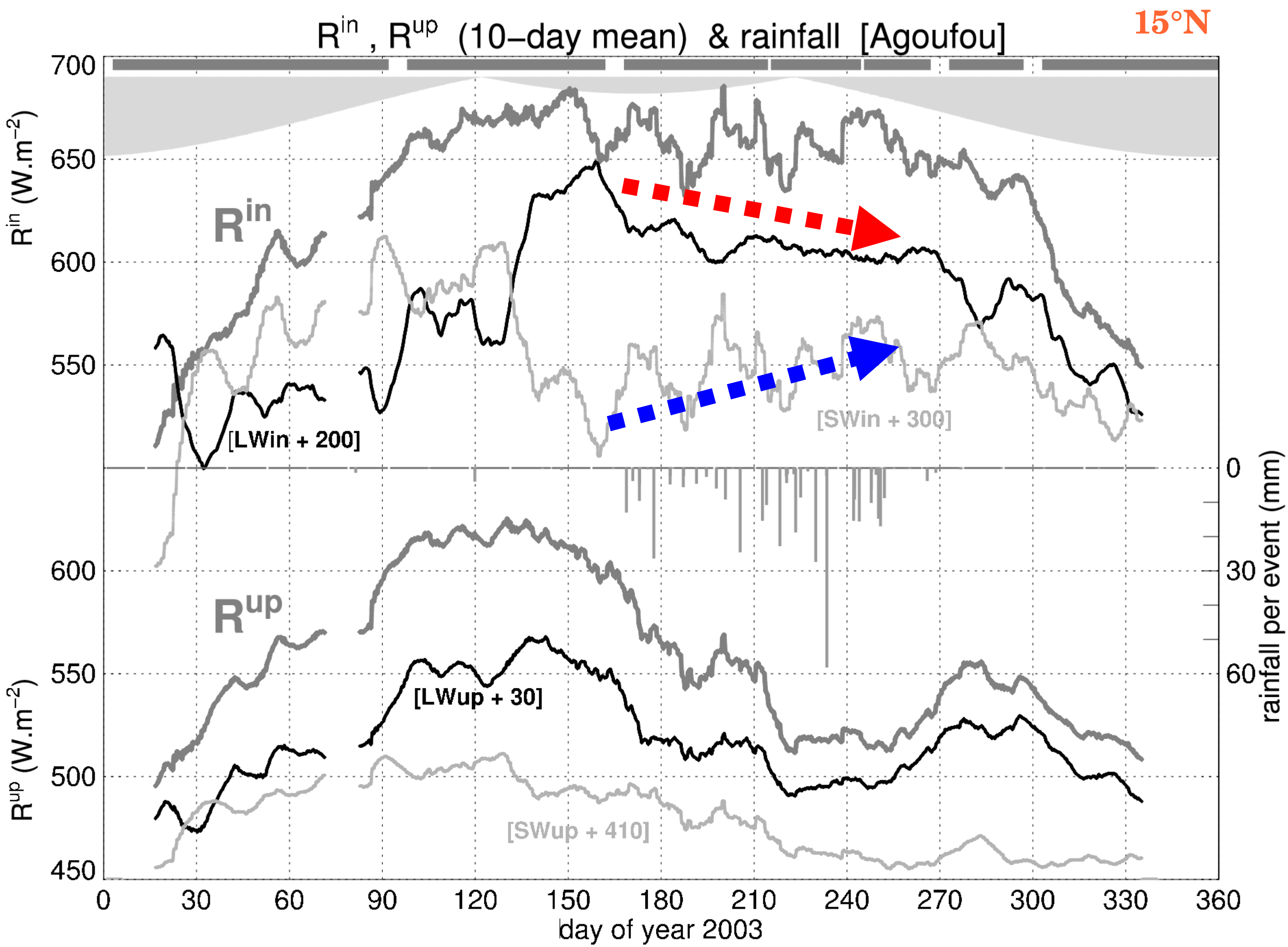


* Rin, Rup more strongly coupled at this scale

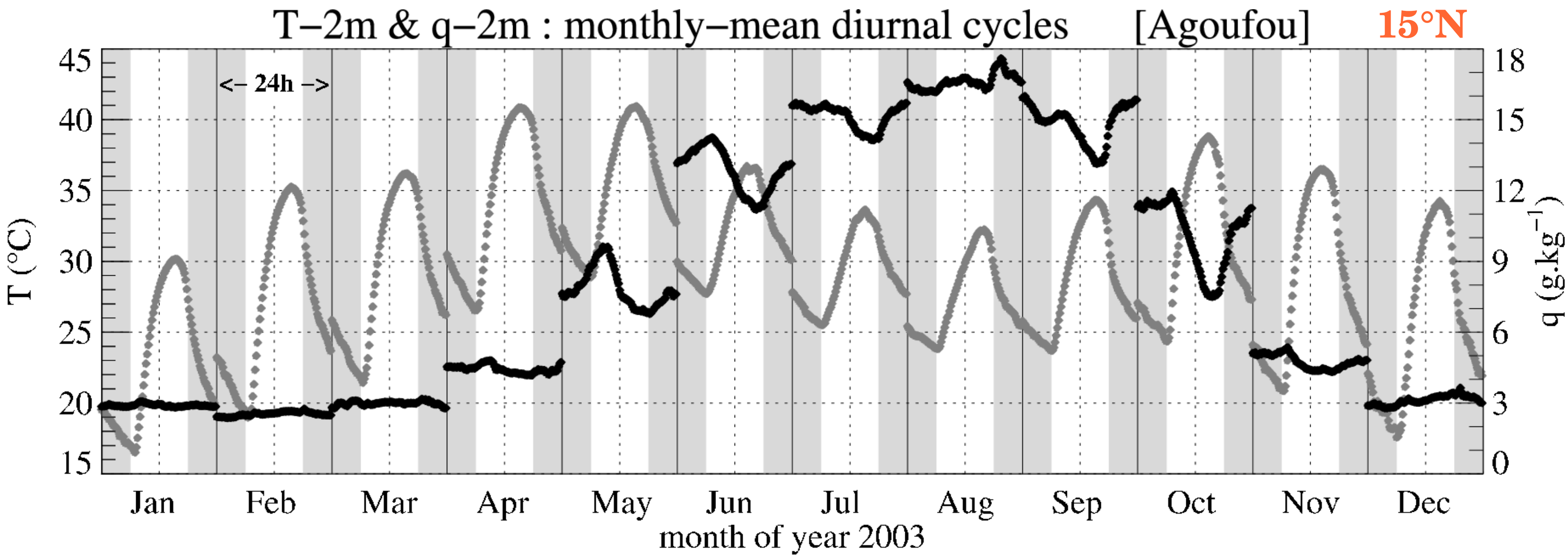
* significance of cloud SW radiative forcing

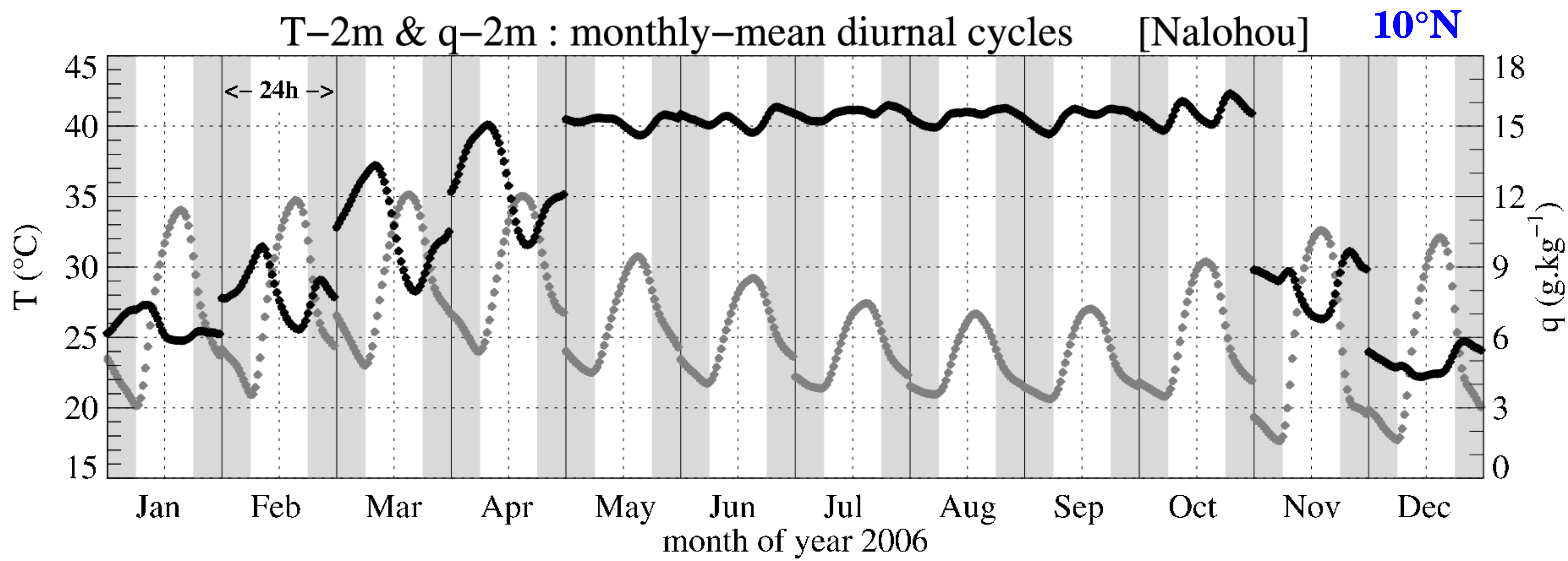
seasonal cycle of surface radiative fluxes

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

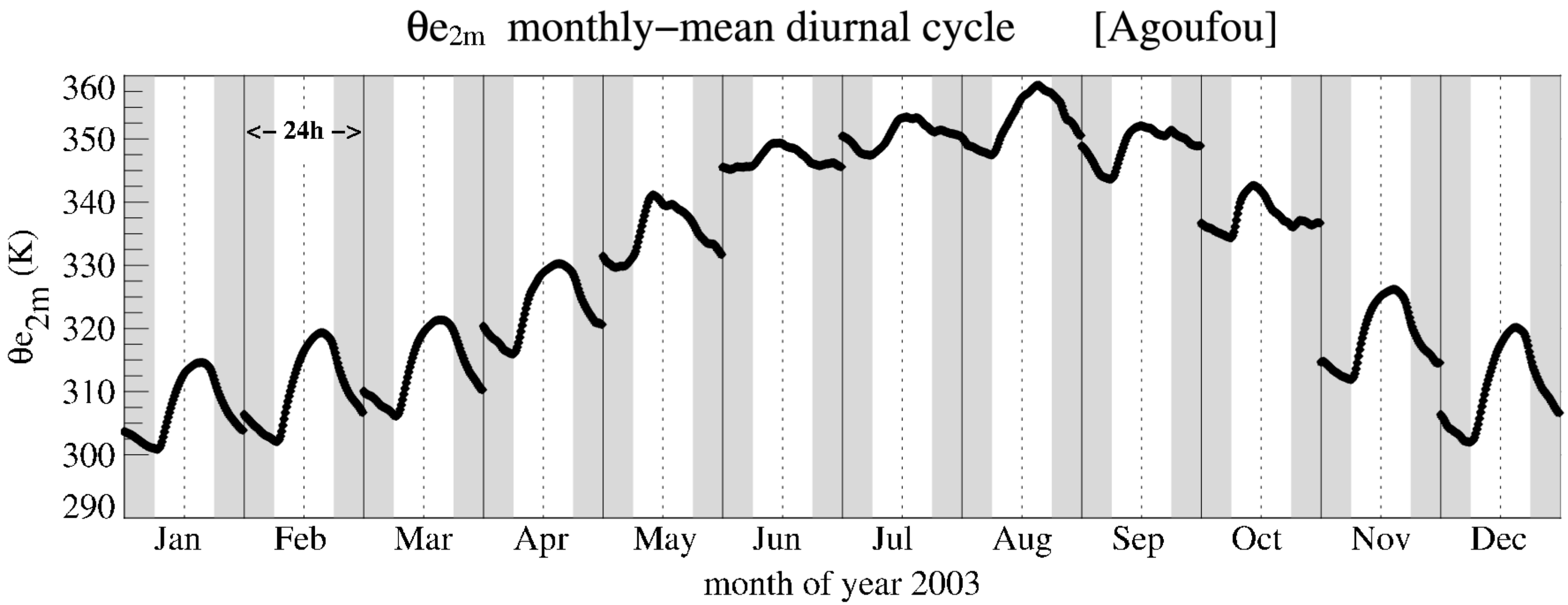


seasonal changes of the diurnal cycles



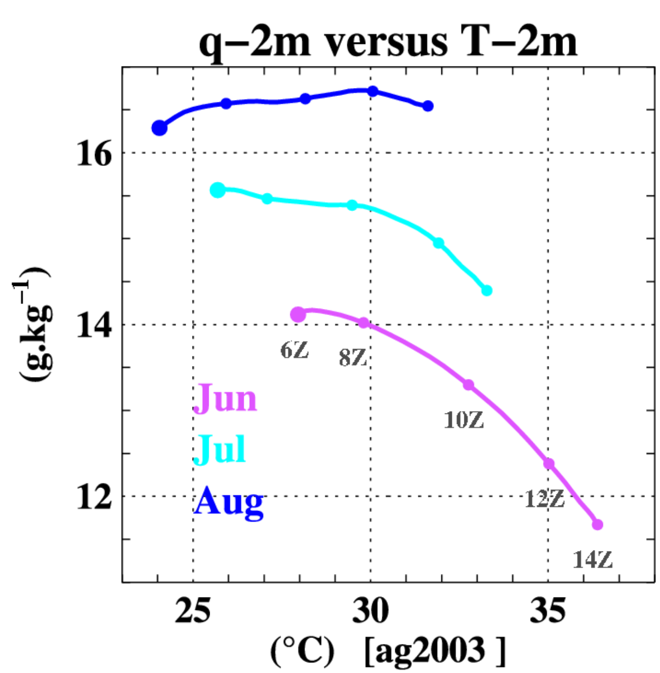


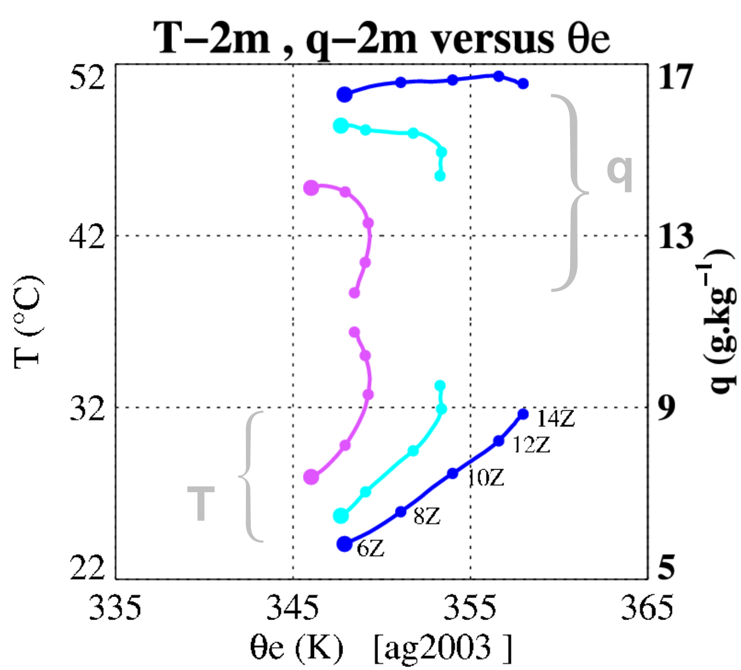
seasonal changes of the diurnal cycles



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)





thermodynamic-radiative coupling during the monsoon

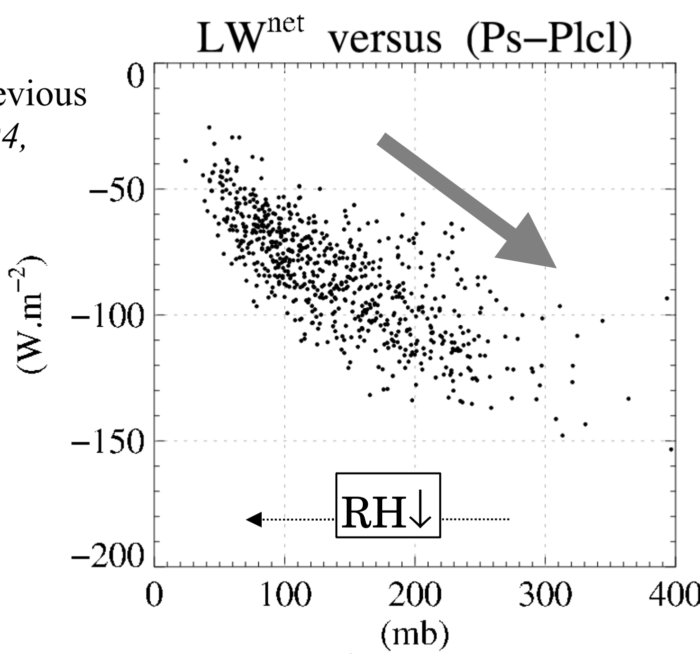
24-h mean values, JJAS 2002 to 2007, Central Sahel 15°N

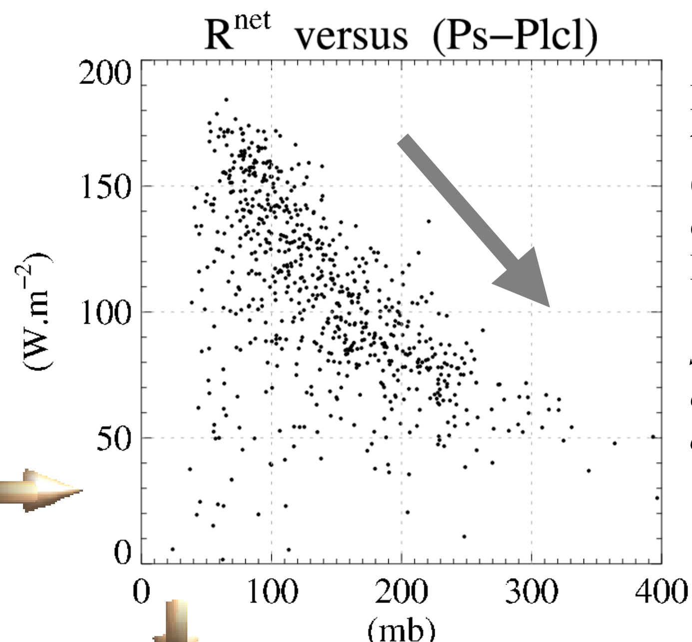
(1)

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

extended to dryer ranges

valid throughout the year

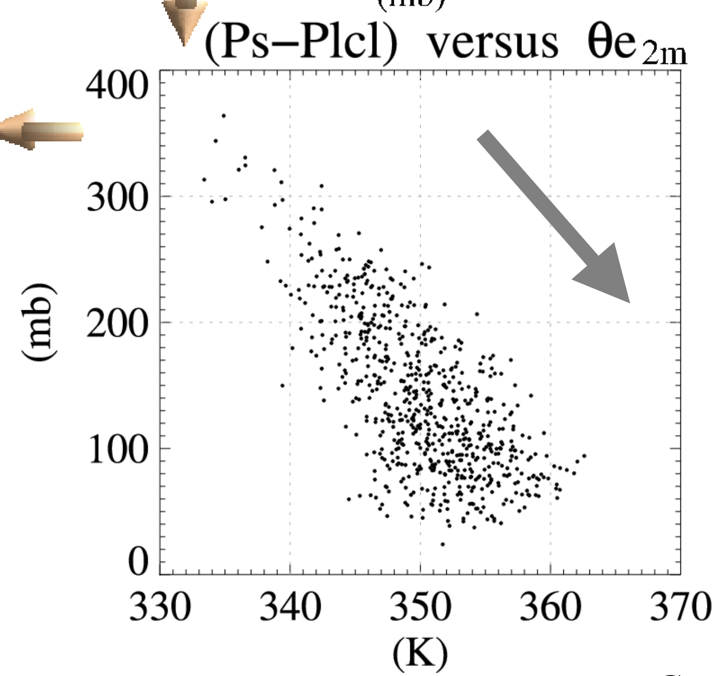




(2)

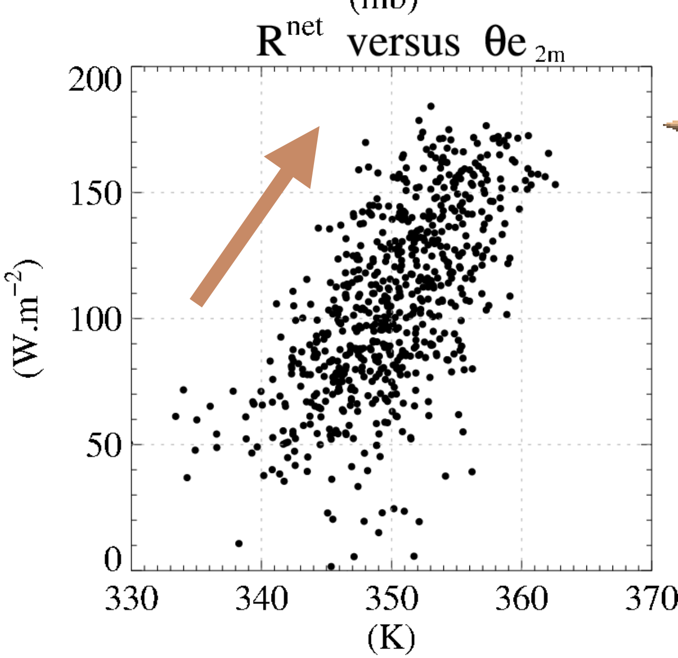
R^{net} increases even more than LW^{net} with Plcl (& RH) because SW^{net} does not decreases as RH increases

semi-arid region cloud impact does not dominate



(3)

Increase of θe coupled to increase of Plcl, RH



(4)

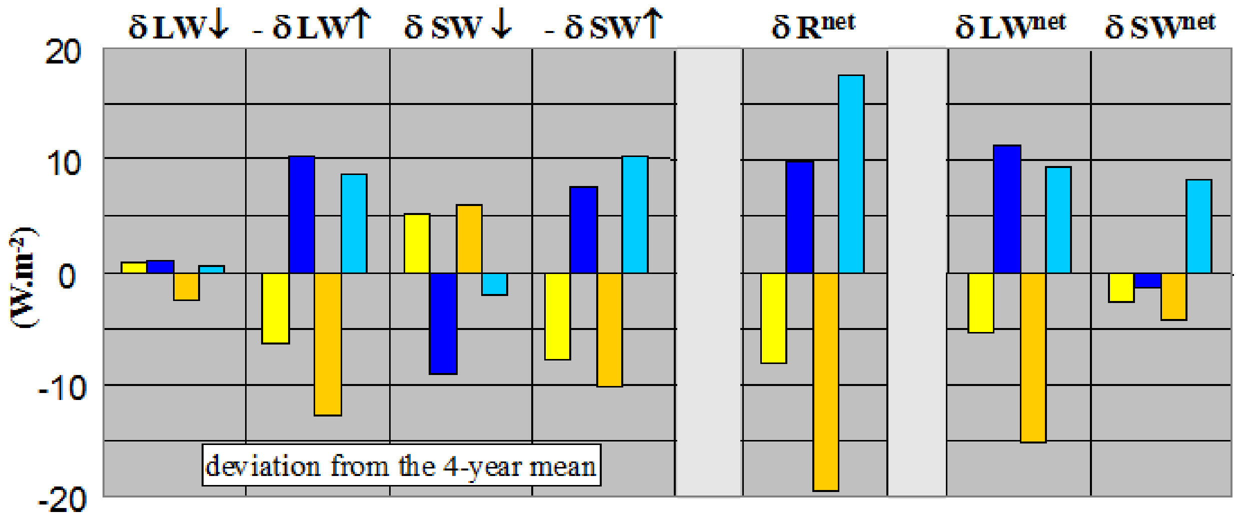
R^{net} and θe correl > 0

involves seasonal transformations

not well simulated

Guichard et al. (2009)

interannual variability



(2002 to 2004) **15°N**

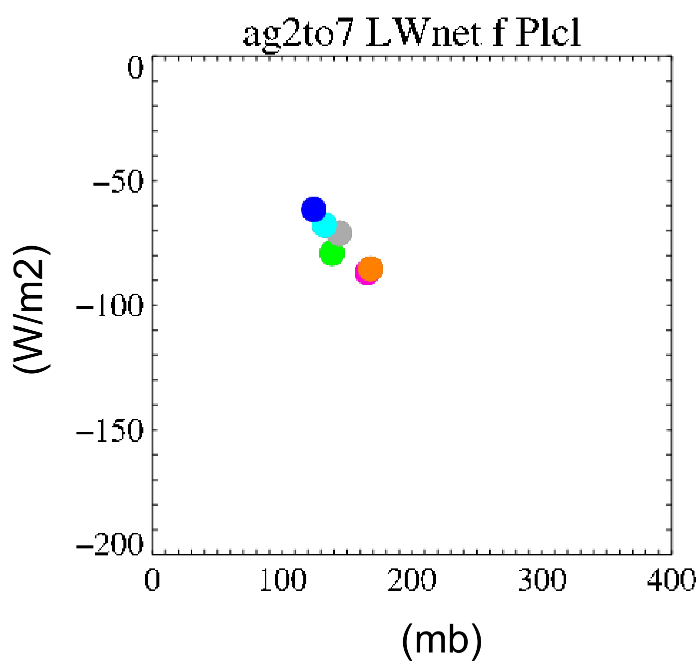
$\Delta(R^{net}) \sim$ 20-35 W.m^{-2}
for R^{net} values~ 120 W.m^{-2}

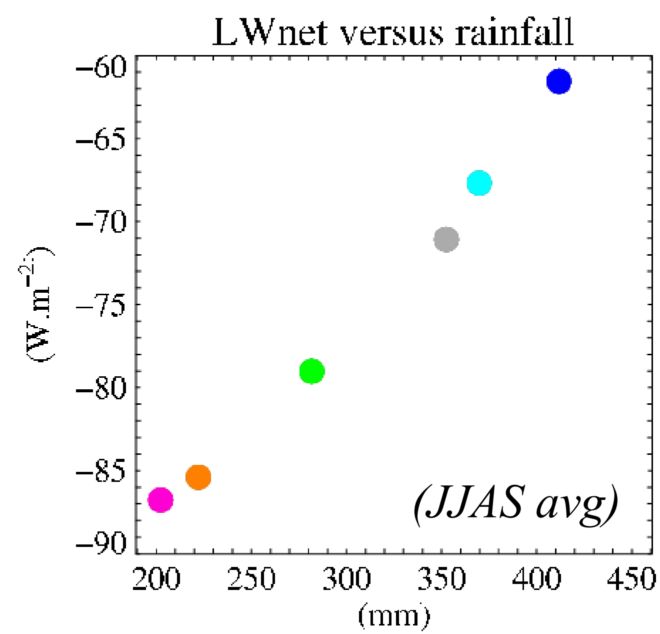
weaker albedo in Aug
[2003 & 2005] / [2002 &2004]
more that compensates
lower SW^{in}

consistent with a more cloudy atmosphere for rainier years

variations of LW^{up} dominate

coupling of water and energy cycles



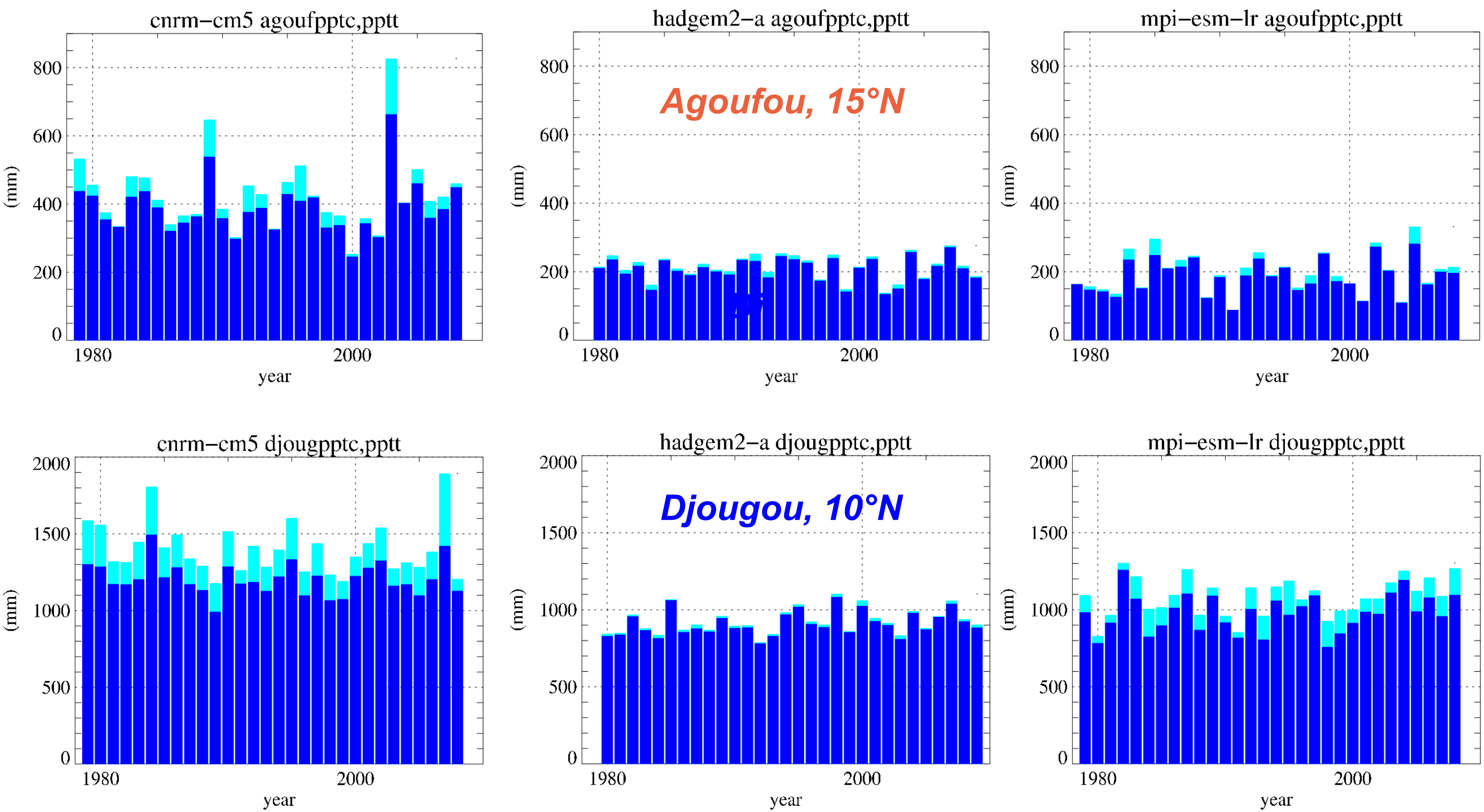


A preliminary broad overview of the cfSites outputs, AMIP runs

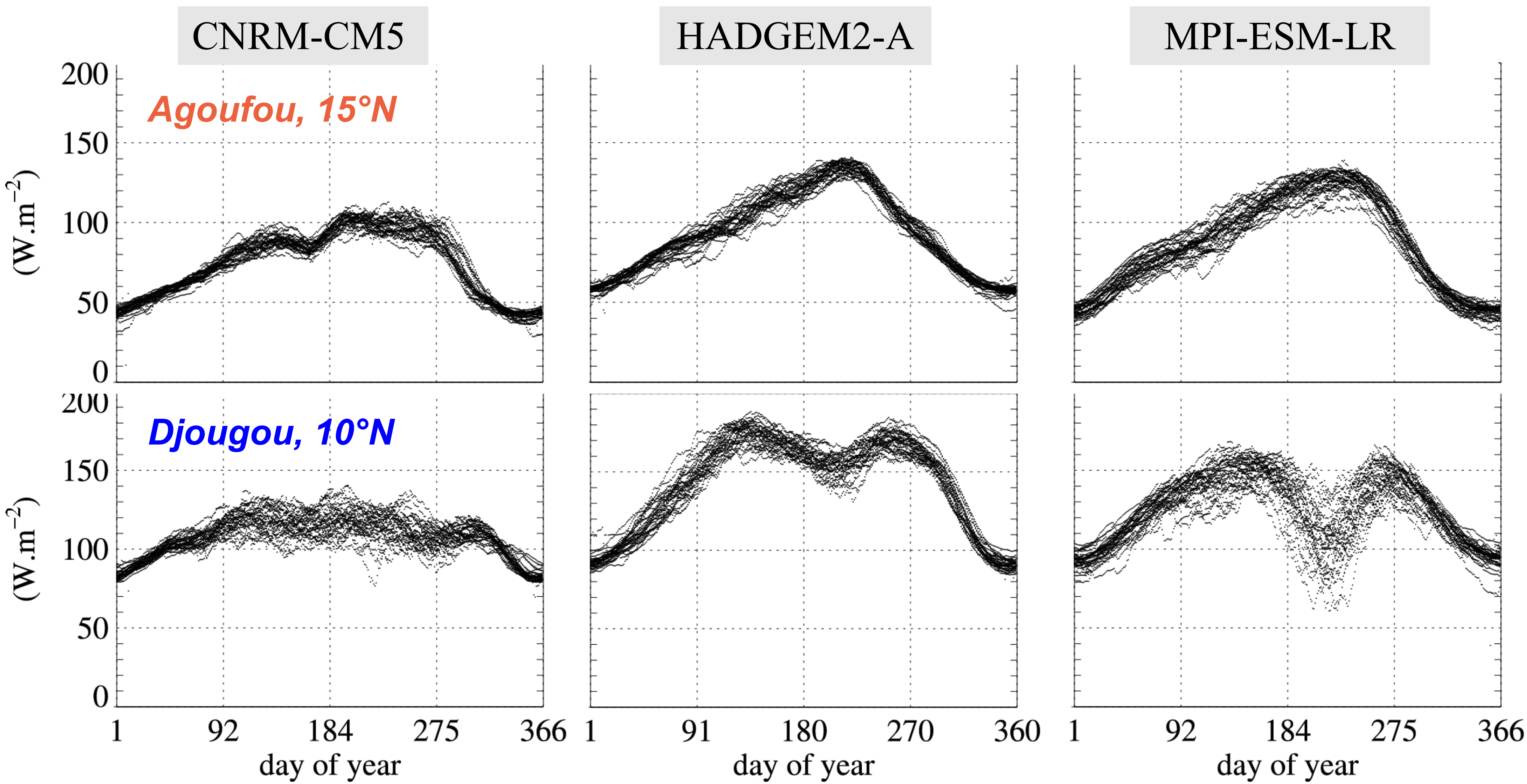
2 points: 10°N et 15°N

3 models: CNRM-CM5, HADGEM2-A, MPI-ESM-LR

Annual precipitation



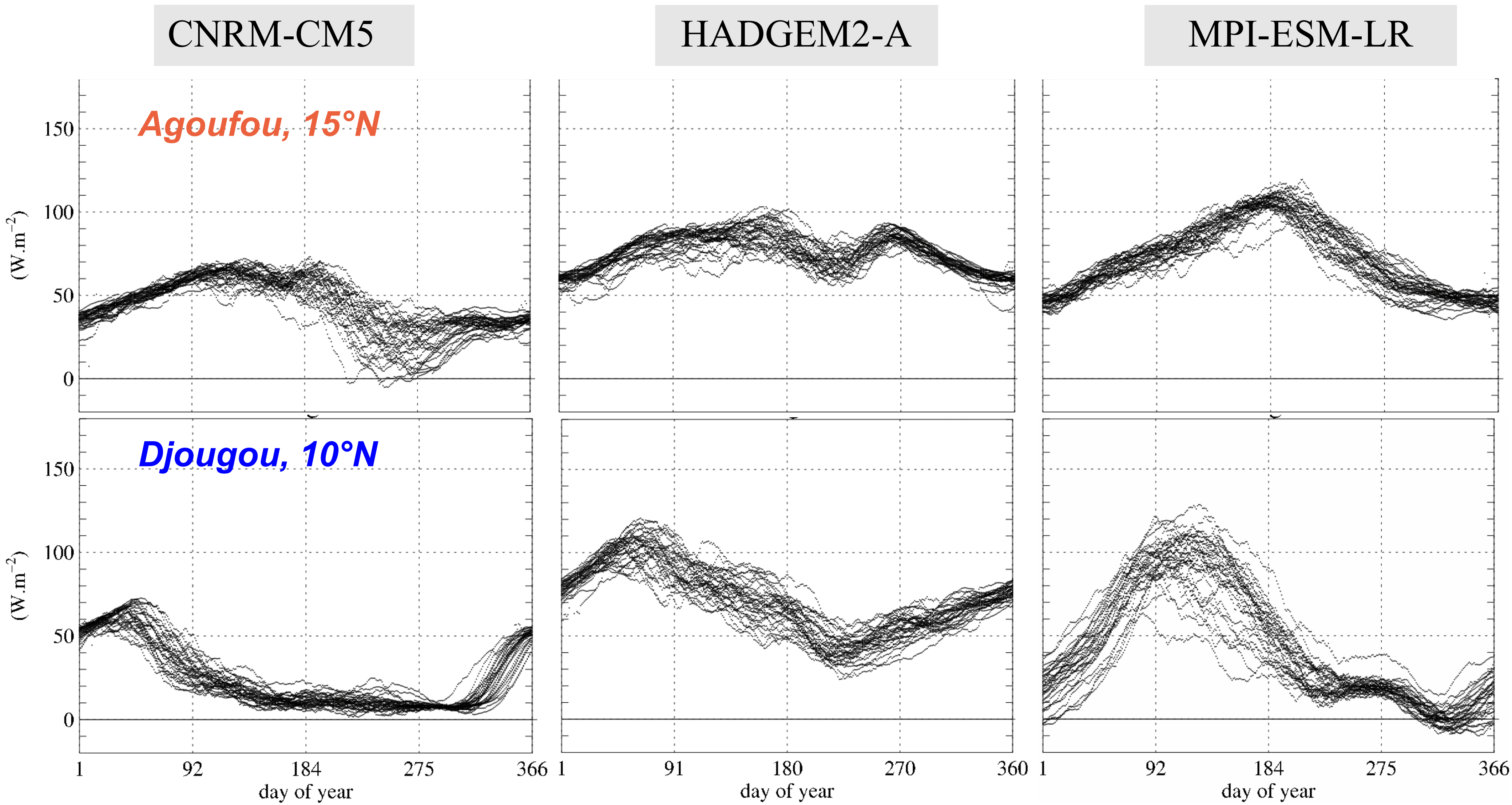
Rnet sfc , 31-day running mean



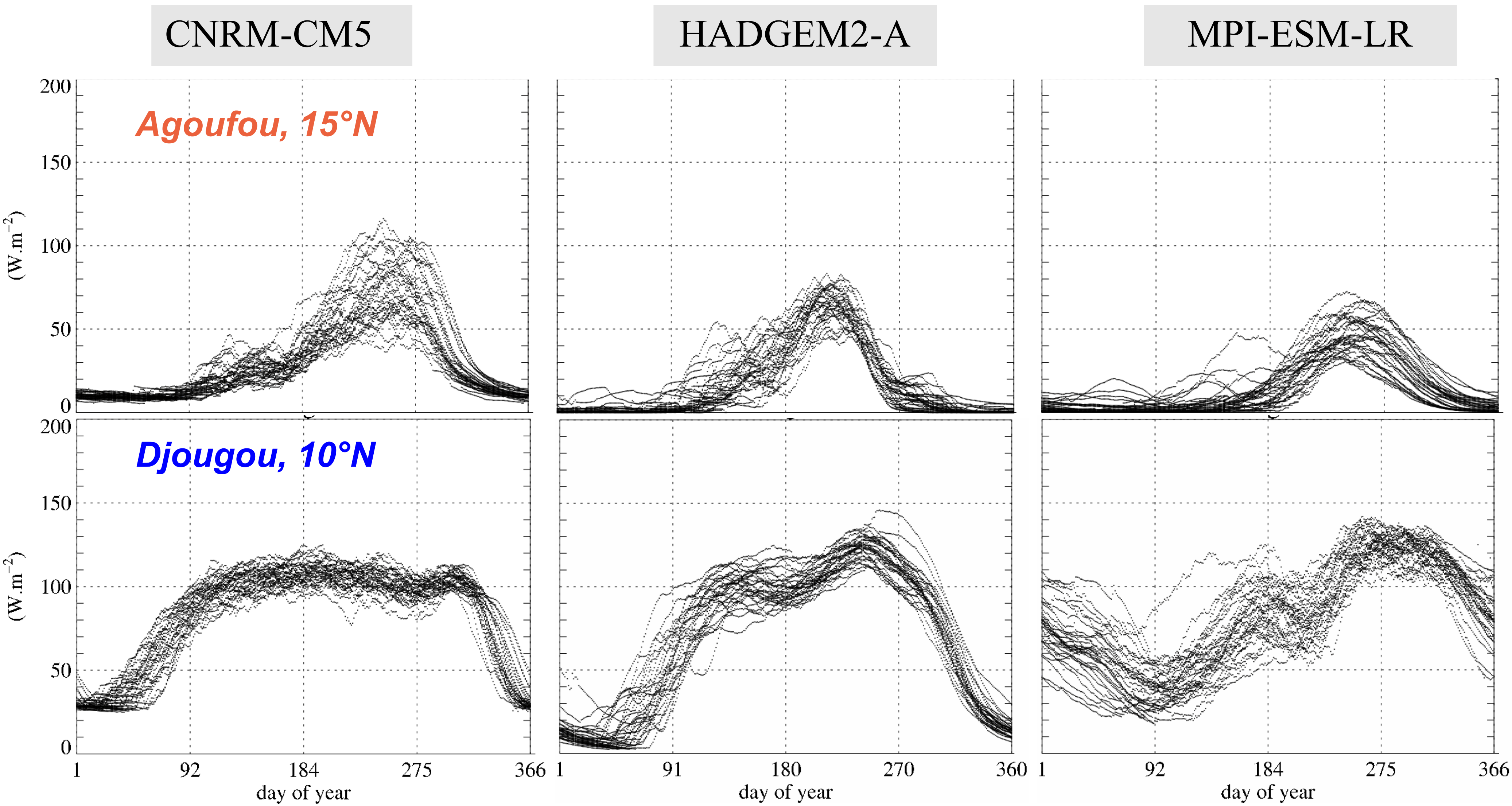
15°N: a tendency to overestimate Rnet in Spring (consistent with Traore 2011)

Stronger Rnet for models with lower rainfall, not fully consistent with observations

Surface sensible heat flux H , 31-day running mean



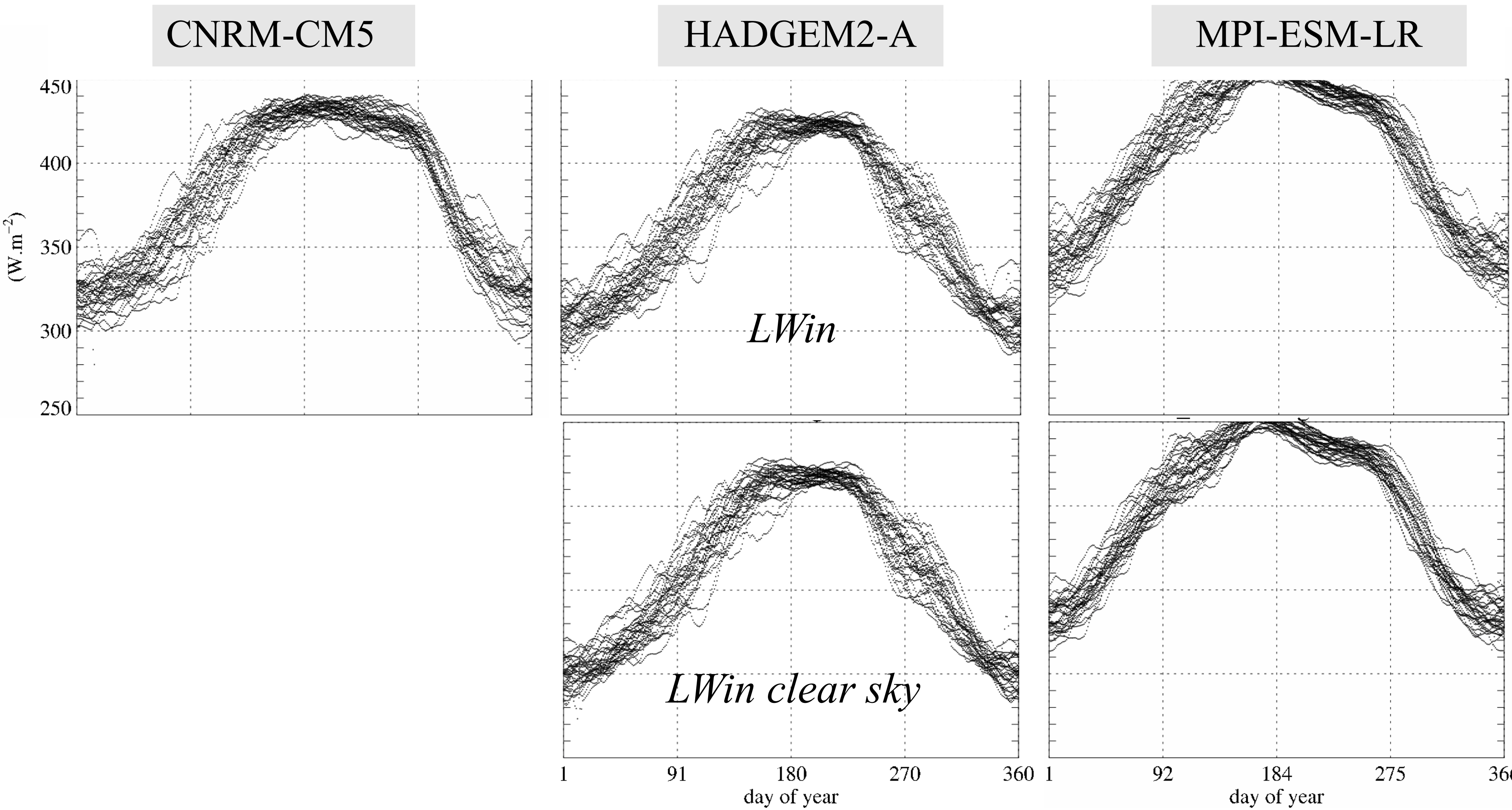
Surface latent heat flux LE , 31-day running mean



Which couplings of these differences in H and LES with differences in BL, low clouds and deep convection?

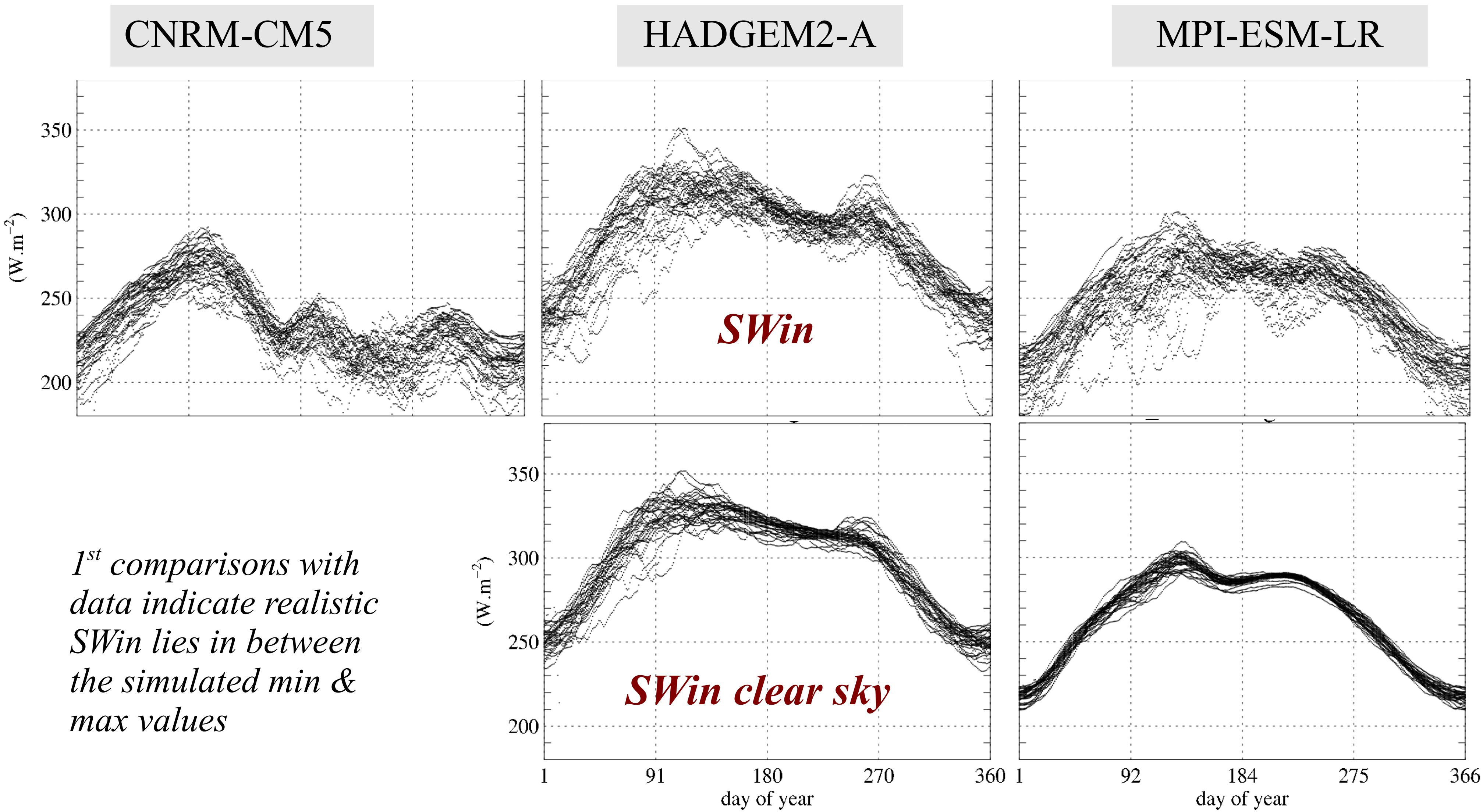
LWin , 31-day running mean

Agoufou, 15°N



Differences in LWin clear sky: a role for aerosols?

SWin , 31-day running mean   *Agoufou, 15°N*

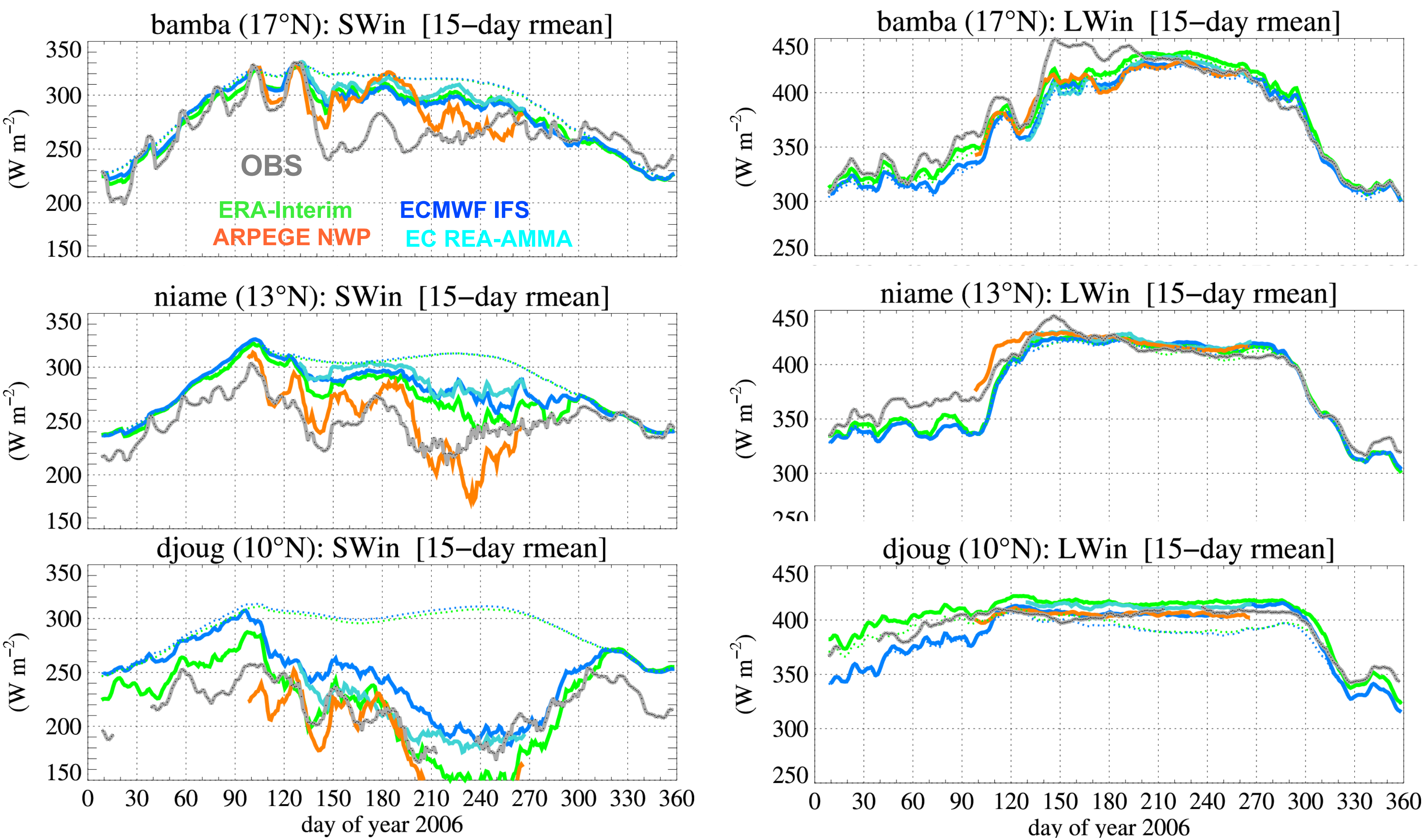


1st comparisons with data indicate realistic SWin lies in between the simulated min & max values

Differences in SWin clear sky: impact of T & q structures, a role for aerosols?

interest of 1D radiative transfert model for further investigation, Olivier Geoffroy

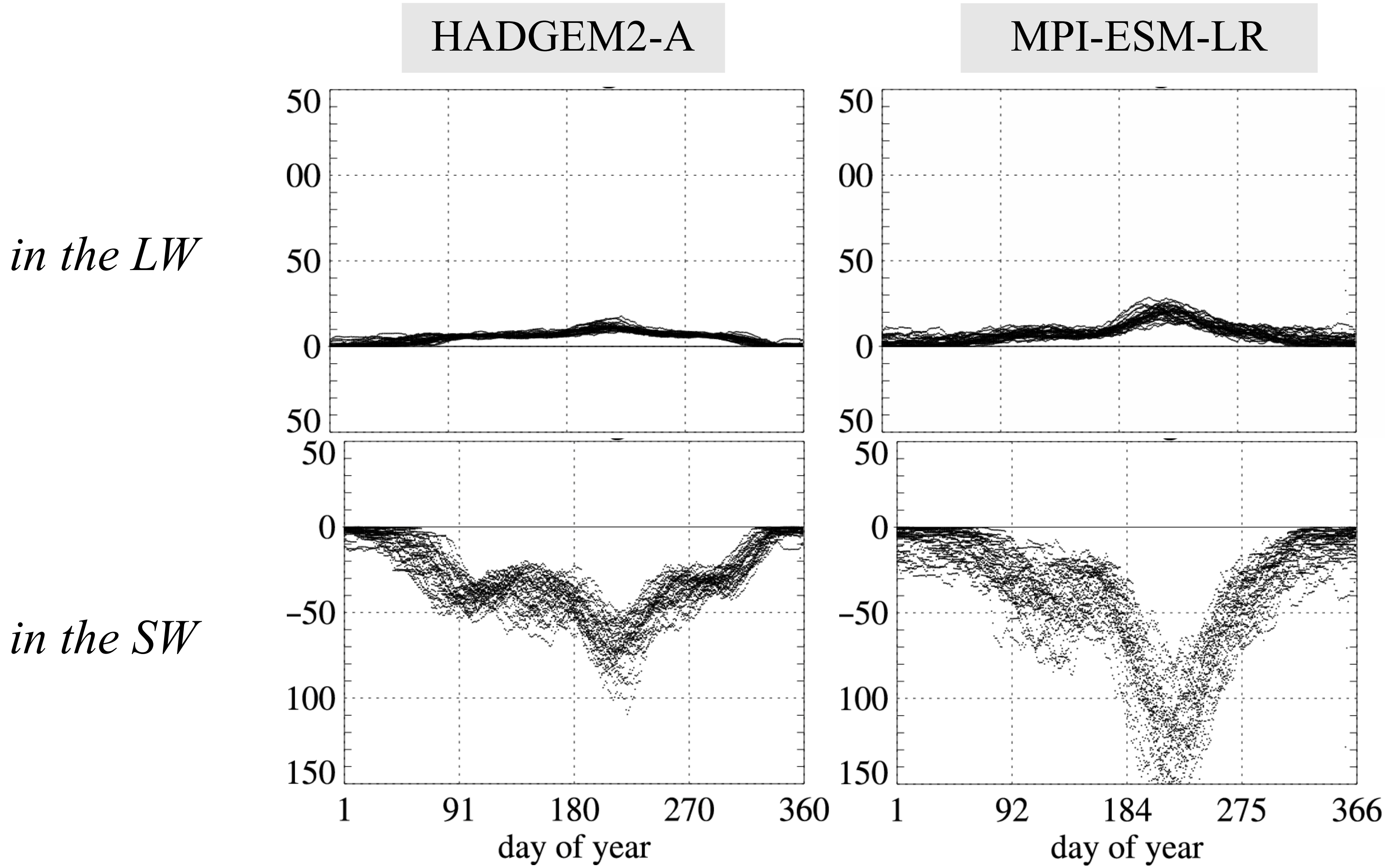
surface incoming radiation in NWP models



Large and distinct departures from observations in the SW
LW bias reduced during the monsoon, not much sensitivity to differences in clouds
significance of aerosols in Spring, early Summer, but still, cloud equally important

Djougou, 10°N

Cloud radiative forcing

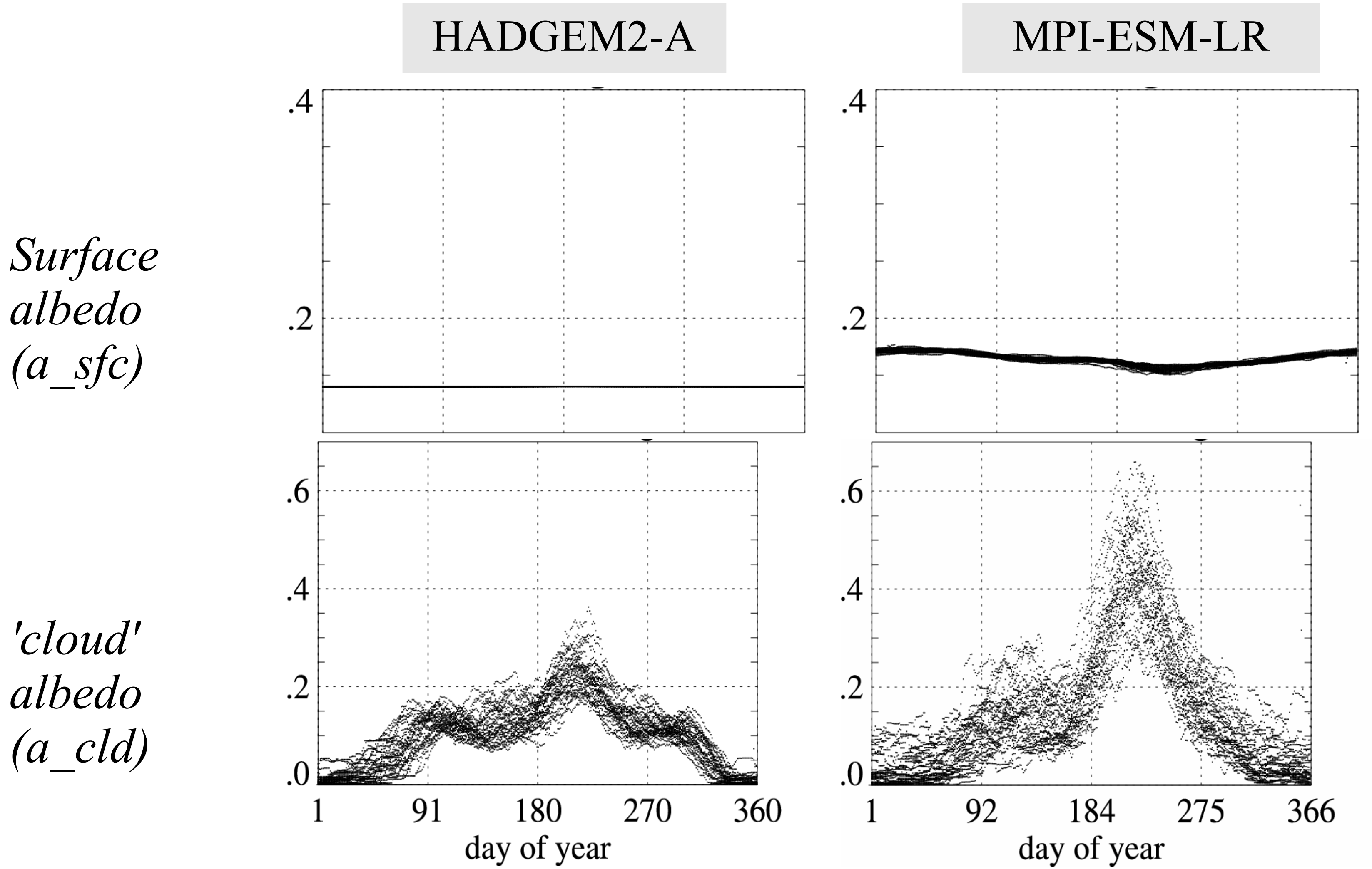


SW cloud forcing dominates (distinct behaviour compared to TOA)

Comparison with observations: first rough calculations indicate underestimation in HADGEM, suggest overestimation in CRM-CM5

ALBEDOS SWnet = (1 – a_sfc) (1 – a_cld) SWin_clear_sky

Djougou, 10°N



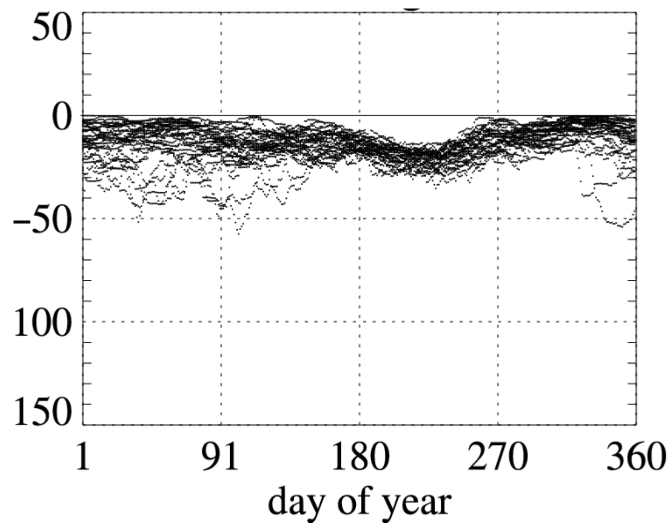
Interannual variability of surface albedo in Spring in MPI: spectral response with a role of aerosols again? (would be consistent with observations, Samain et al. 2008)

Cloud radiative forcing

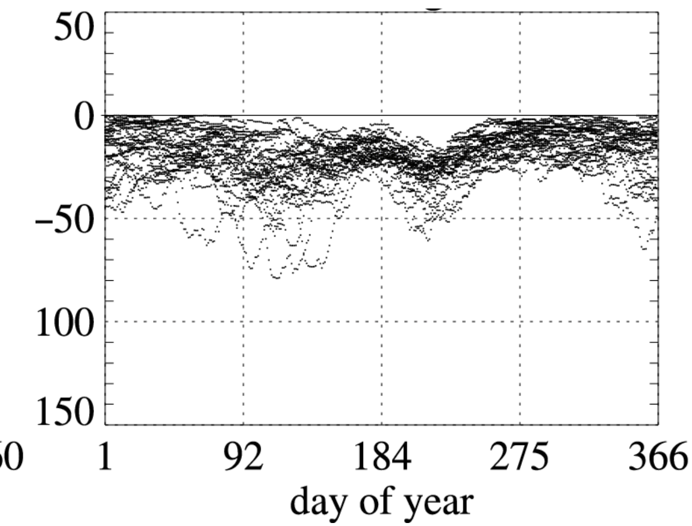
Agoufou, 15°N

in the SW

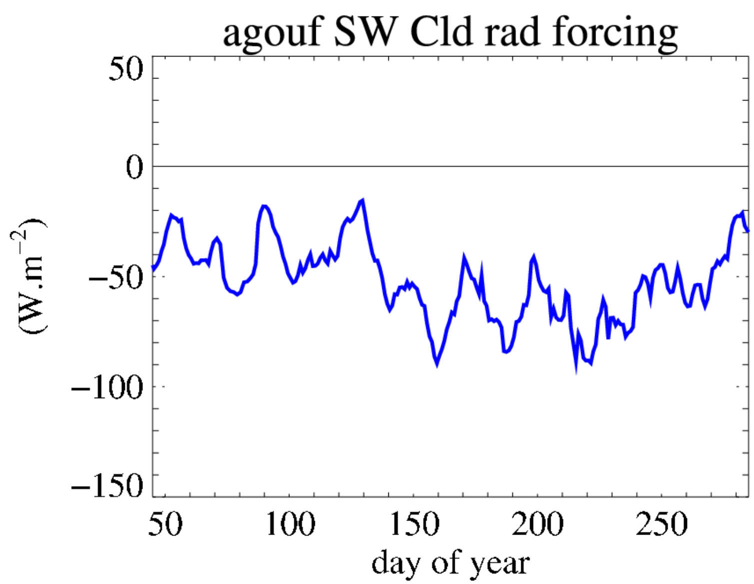
HADGEM2-A

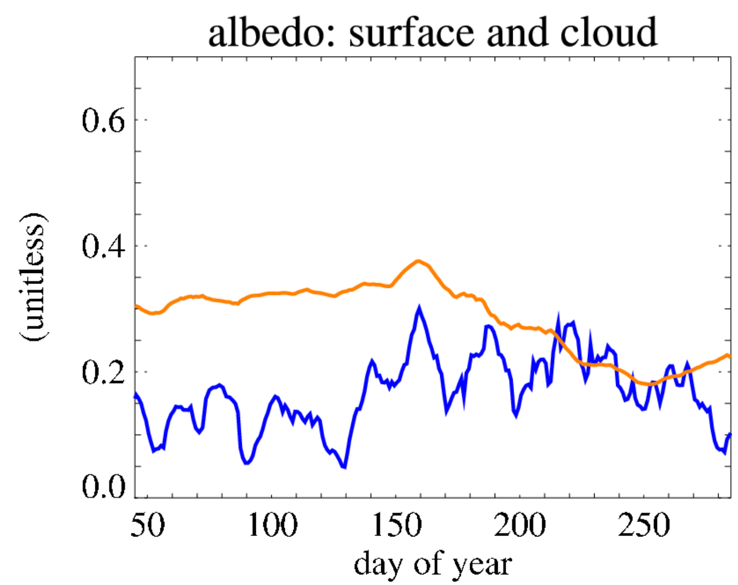


MPI-ESM-LR

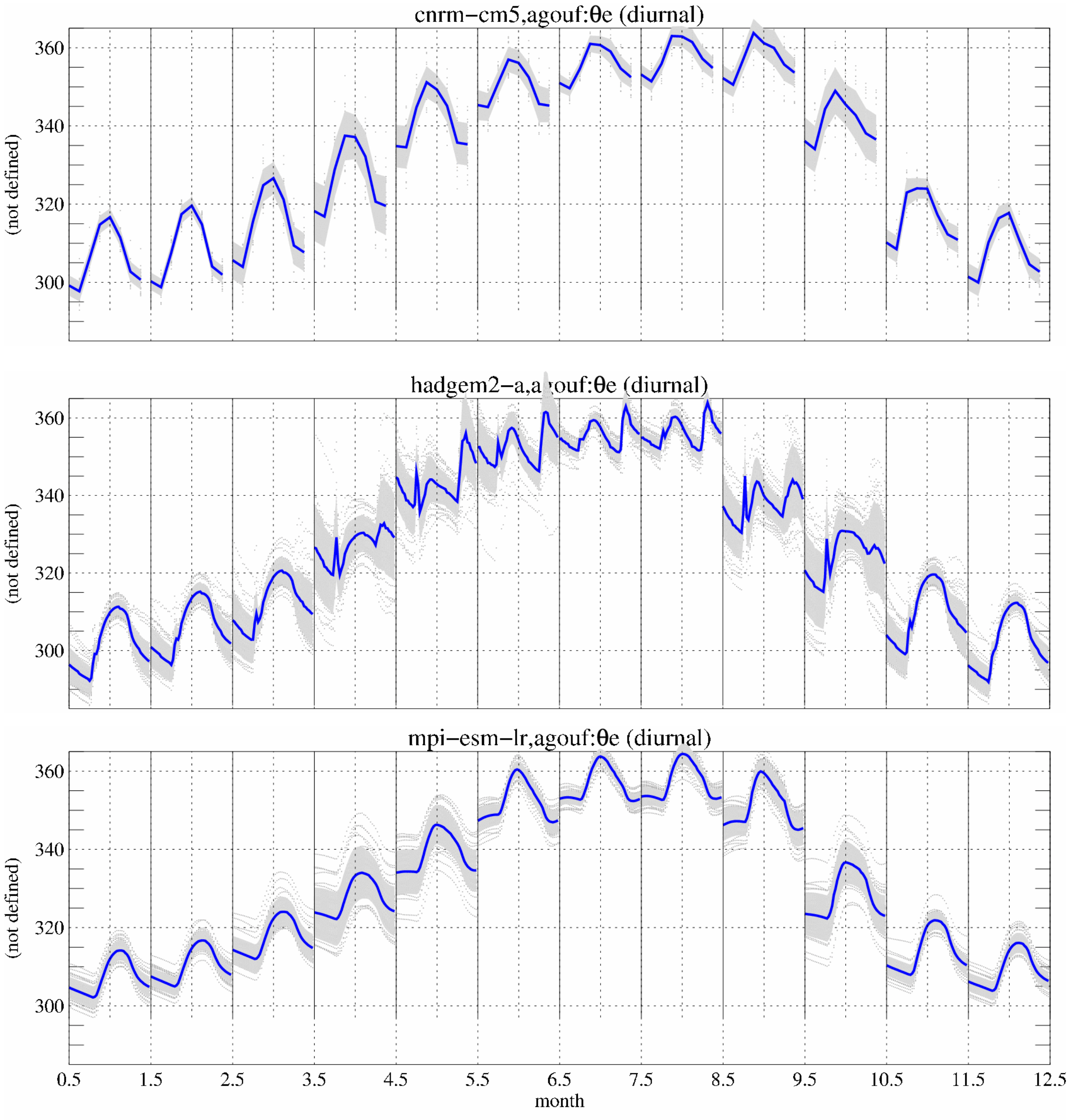


Data
very rough
estimation





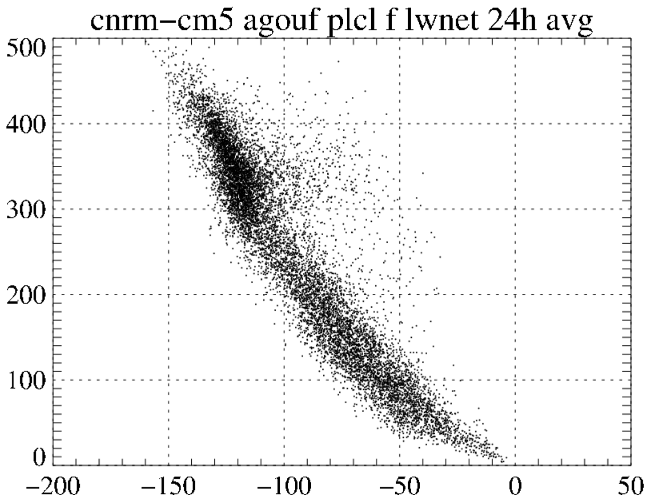
seasonal changes of the diurnal cycles



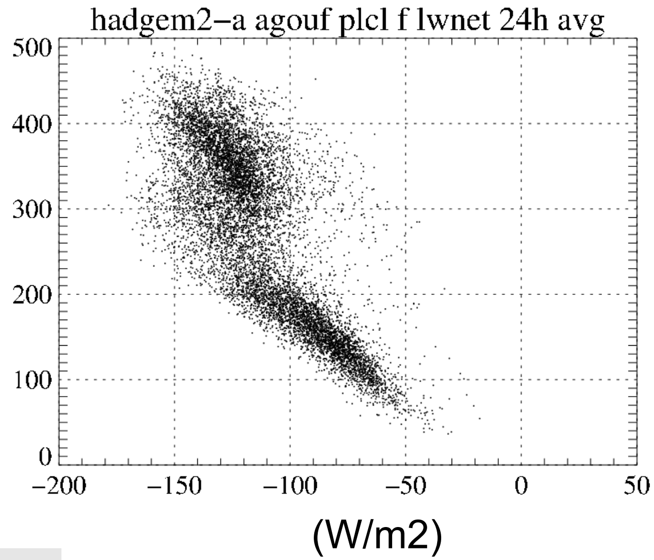
couplings LWnet, Plcl (~ RH)

Agoufou, 15°N

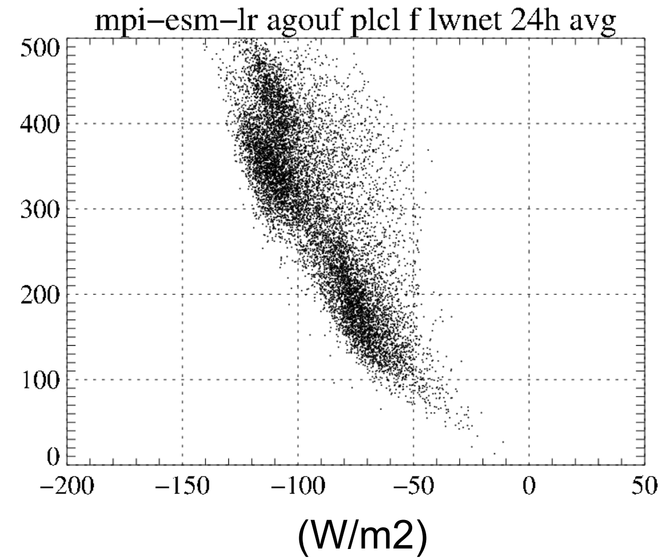
CNRM-CM5



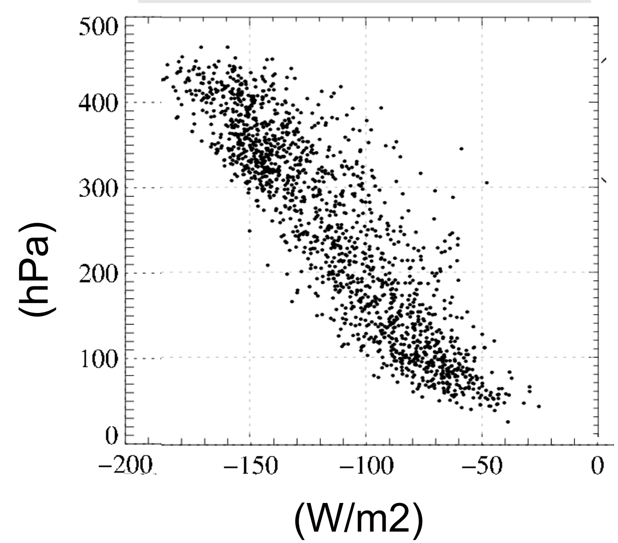
HADGEM2-A



MPI-ESM-LR



OBSERVATIONS



Need to understand better the cloud-related sources of differences

Link between Plcl and actual cloud base

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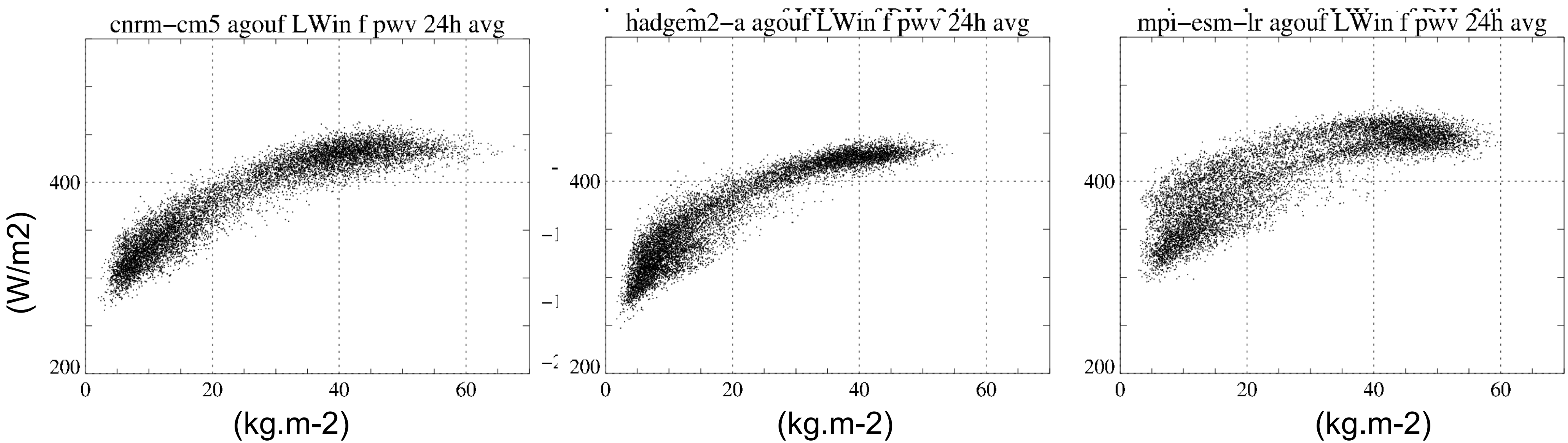
Agoufou, 15°N

Couplings LWin, PWV

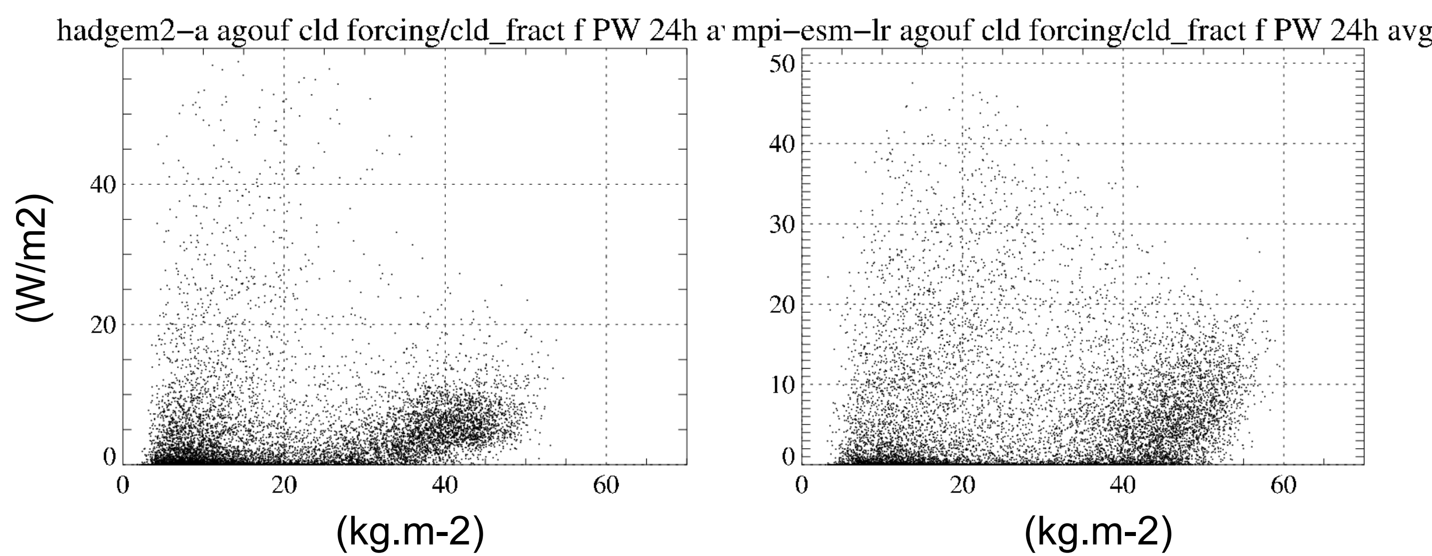
CNRM-CM5	HADGEM2-A	MPI-ESM-LR



Larger LWin and enhanced spread in MPI associated with aerosols? (use observations)

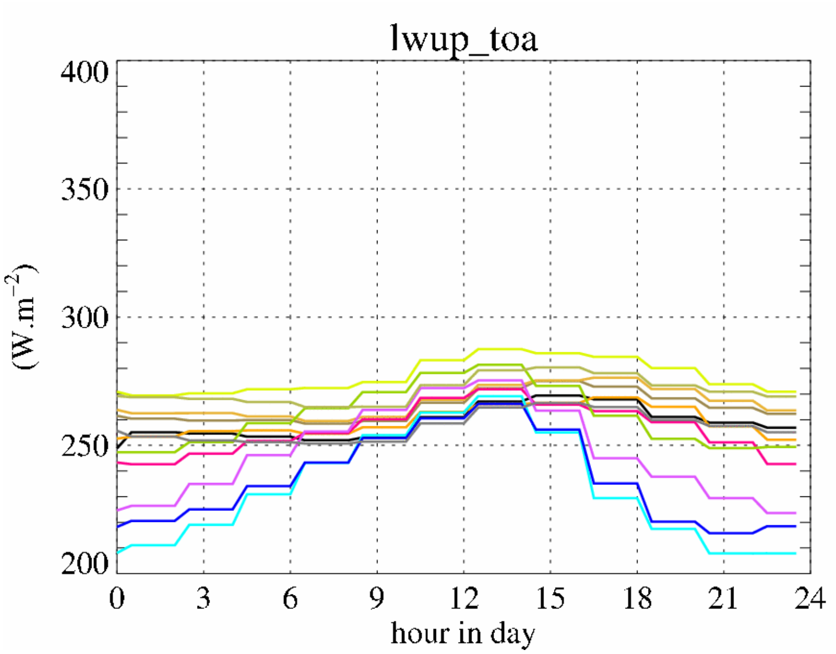
Sensitivity of cloud LW forcing to PWV

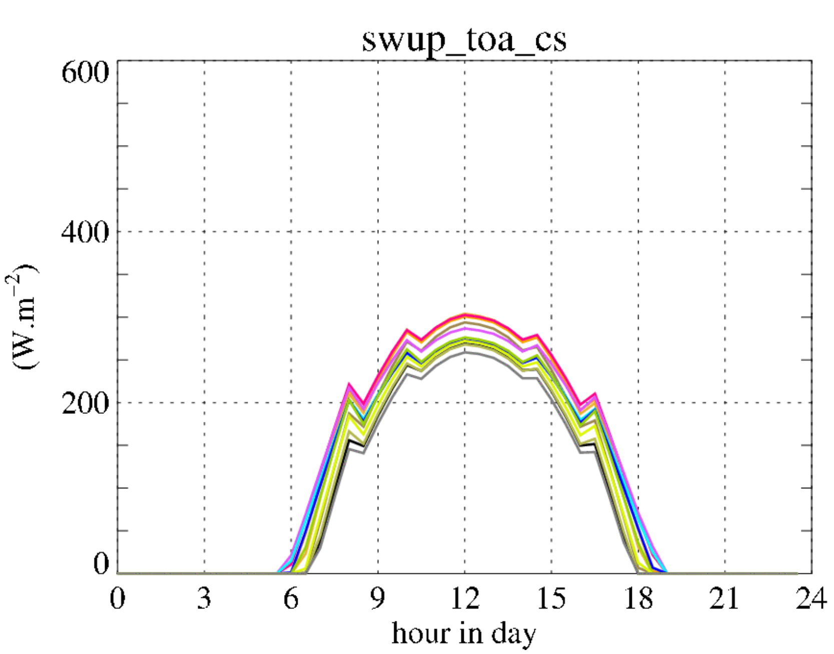
- *Stronger CR impact for smaller values of PWV*
- *Consistent with Bouniol et al. (2012)*
- *Qualitatively satisfying*



A few technical issues and questions

- Time step for radiative computations and implications for analysis
- Information on aerosols and on their optical properties in the simulations
- More up to date references about parametrizations, e.g. for convection-cloud interactions
- Interest of one or a few EUCLIPSE names/contacts for each model?





Summary

Really the very beginning of the analysis...

All three models depict a number of reasonable features, some qualitatively and others with more accuracy.
Difference among models tend to dominate over interannual variability of each.

Develop evaluations using more of the AMMA datasets (soundings, T, RH, PWV, H, LE)

Strong cloud SW radiative impact. Need to investigate more their diurnal timing.

Cloud LW radiative forcing at the surface is the strongest in Spring and Autumn (for lower PWV). Need to precise more which type of clouds, their properties...

Explore how clouds are involved in the simulated interannual variability (data suggest that it depends on regime)

Interest :

- to further the analysis along the meridional transect (provide larger scale context) (continuation of Hourdin et al. 2010)
- to distinguish between different regimes, associated cloud types & transitions

Develop more accurate estimation of cloud radiative forcing at the surface, explore possible links between cloud types, cloud radiative forcing and radiative biases (O. Geoffroy)