

The surface energy budget over land & its couplings with water vapour, convection and clouds in CMIP5 climate simulations: analysis of the West African cfSites

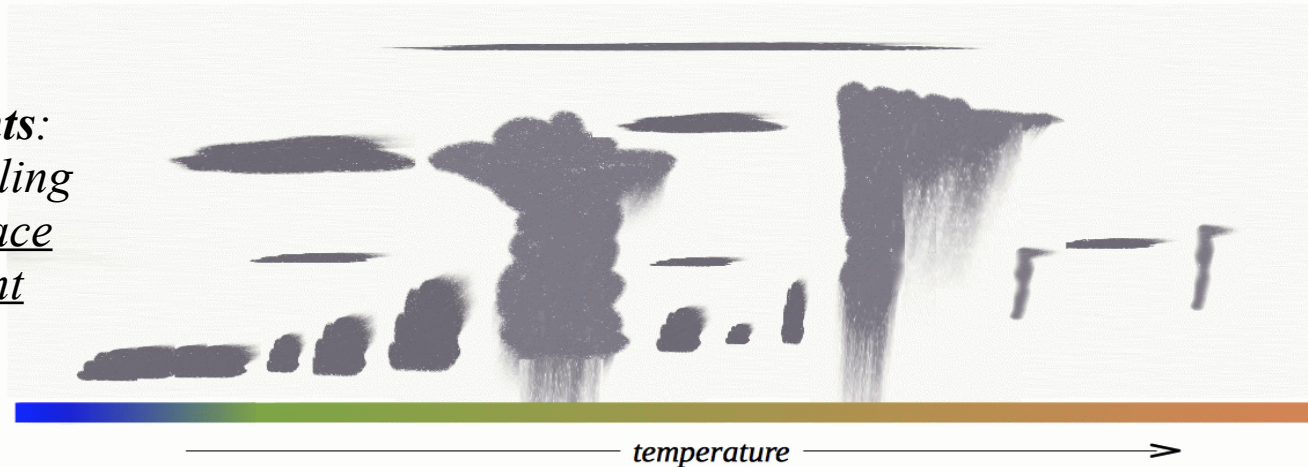
Françoise Guichard, Dominique Bouniol, Fleur Couvreur

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

Ground-based observations: AMMA-Catch, 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*



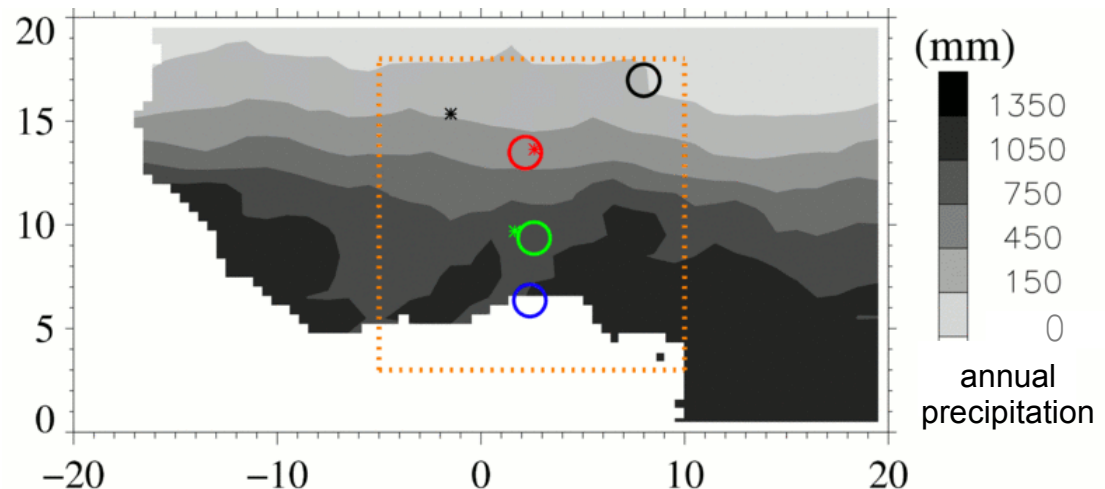
- West African Monsoon, common view: importance of the **lower troposphere**, of aerosols, strong couplings between **convective rainfall**, **surface** processes & surface energy budget
- However, **clouds** themselves are also **important players** in the **surface energy budget** there, in the wet 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 + very partial)

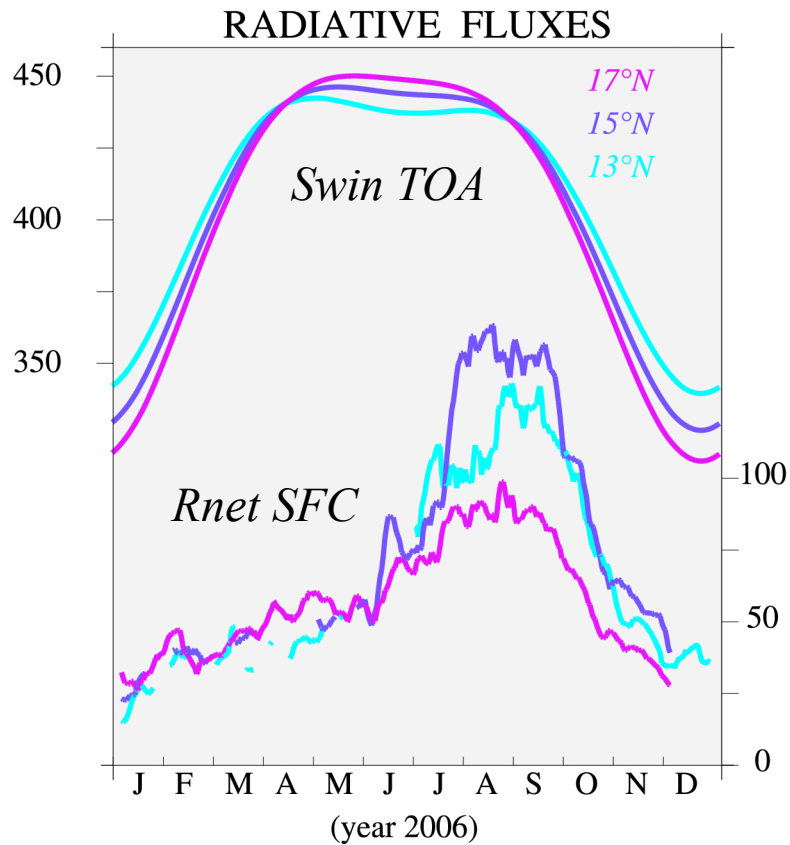
various sets of ground-based observations/measurements, available over periods ranging from ~ a year to several years to a few decades

- automatic weather stations and flux stations (AMMA-Catch) along a meridional climatic gradient - sfc meteo, radiative fluxes, 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 ($\Delta t = 3$ h, 6 h, 12 h or more) [Parker et al. 2008] - a wide variety of boundary layers in space and time
- Precipitable water (GPS, $\Delta t = 1$ h) [Bock et al. 2008]
- SYNOP data ($\Delta t = 3$ h to daily)
- low-resolution GTS soundings

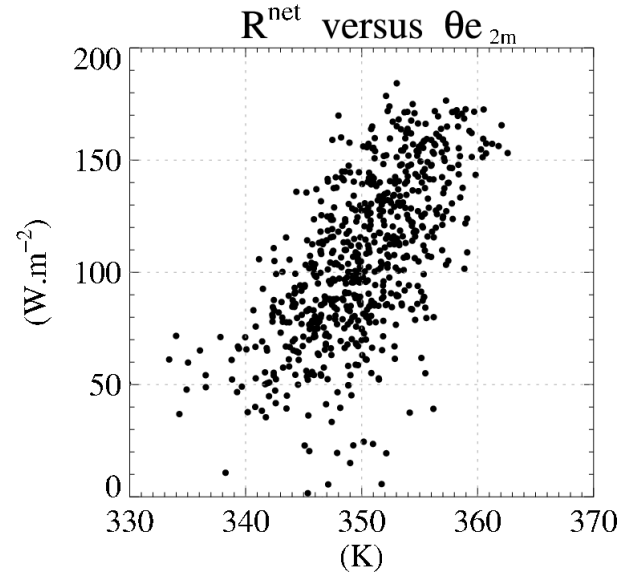
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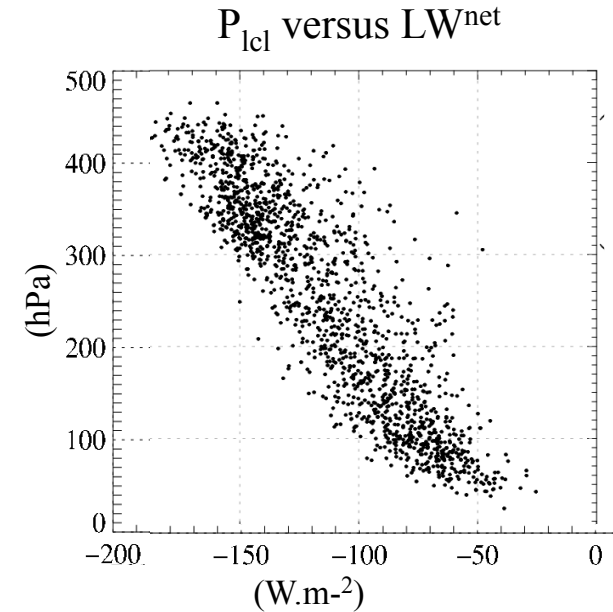
Surface energy budget: specificities of the Sahel



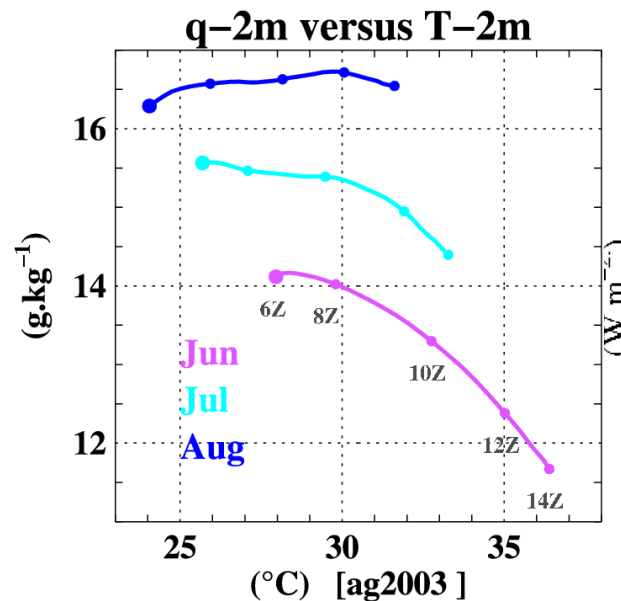
JJAS, daily values



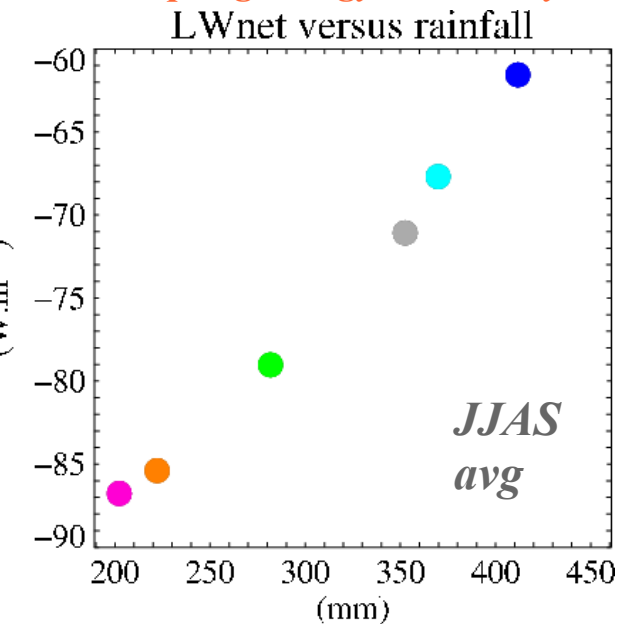
All year, daily values



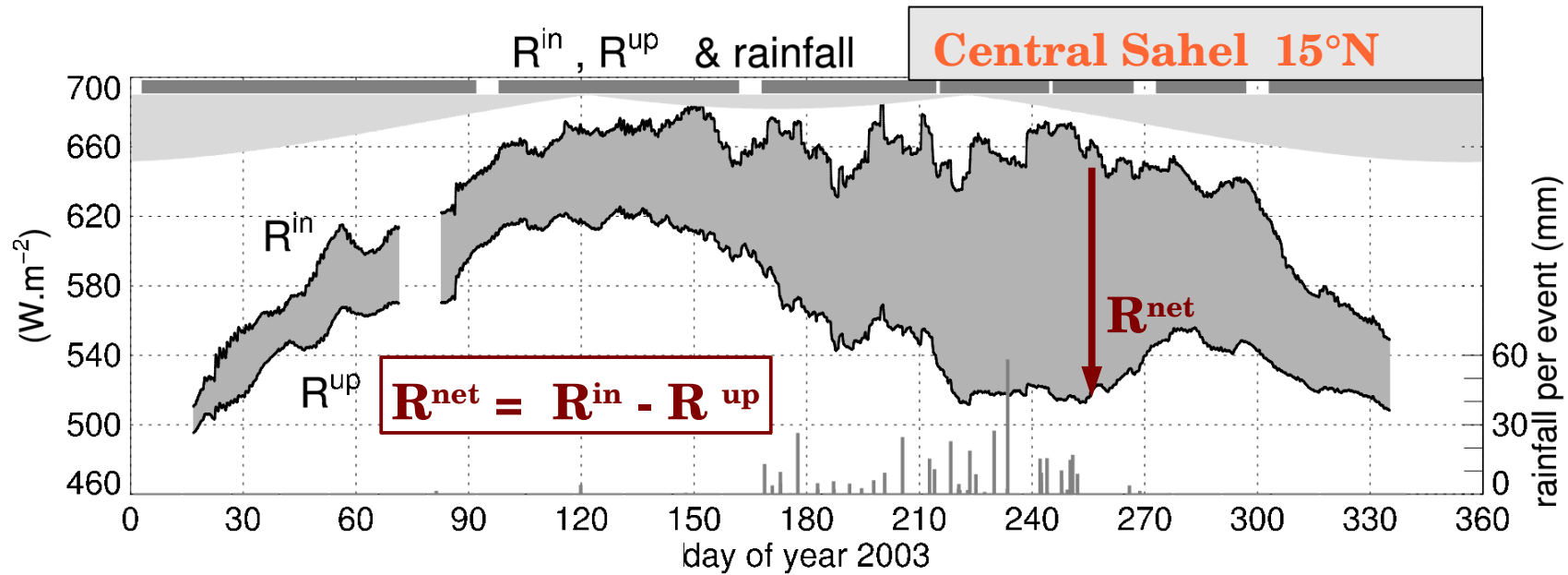
BL depth & diurnal cycle



*Interannual variability
coupling energy & water cycle*



From May to September, variations of R^{net} ($\uparrow$) driven by R^{up} (which $\downarrow$)
does not mean that radiative impact of clouds & aerosols negligible !
but does not mean either that it plays the central role in interannual variability



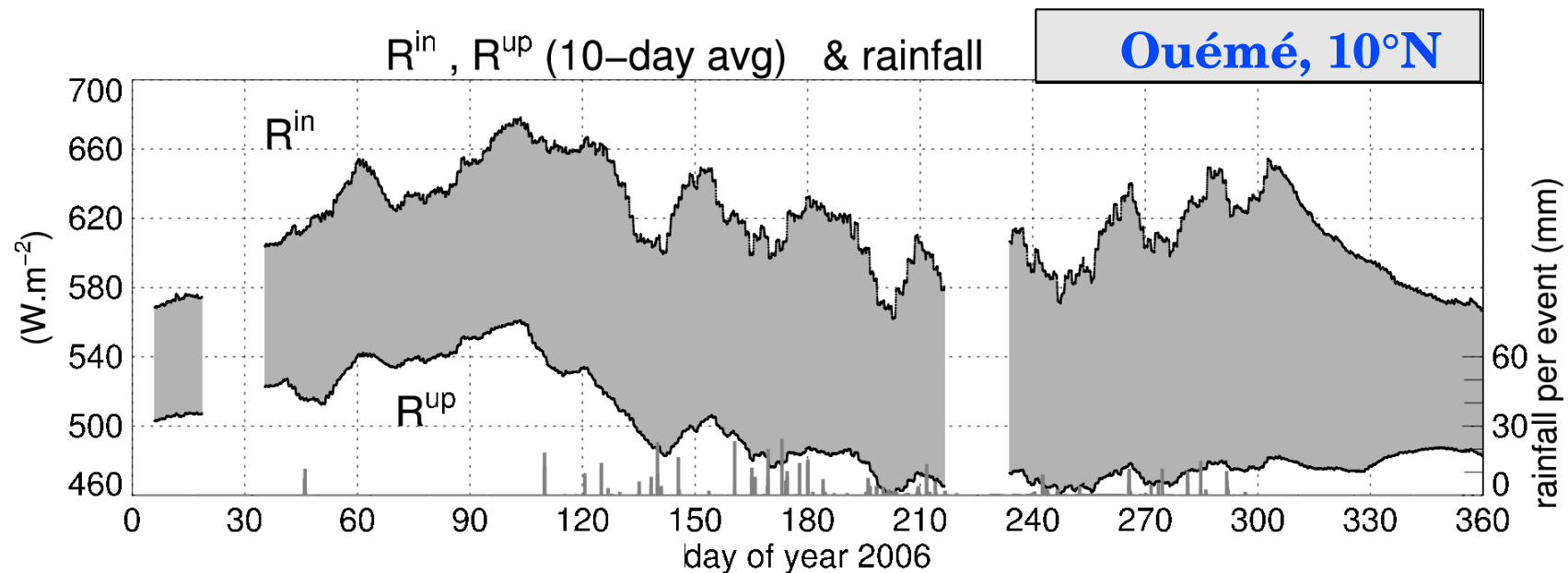
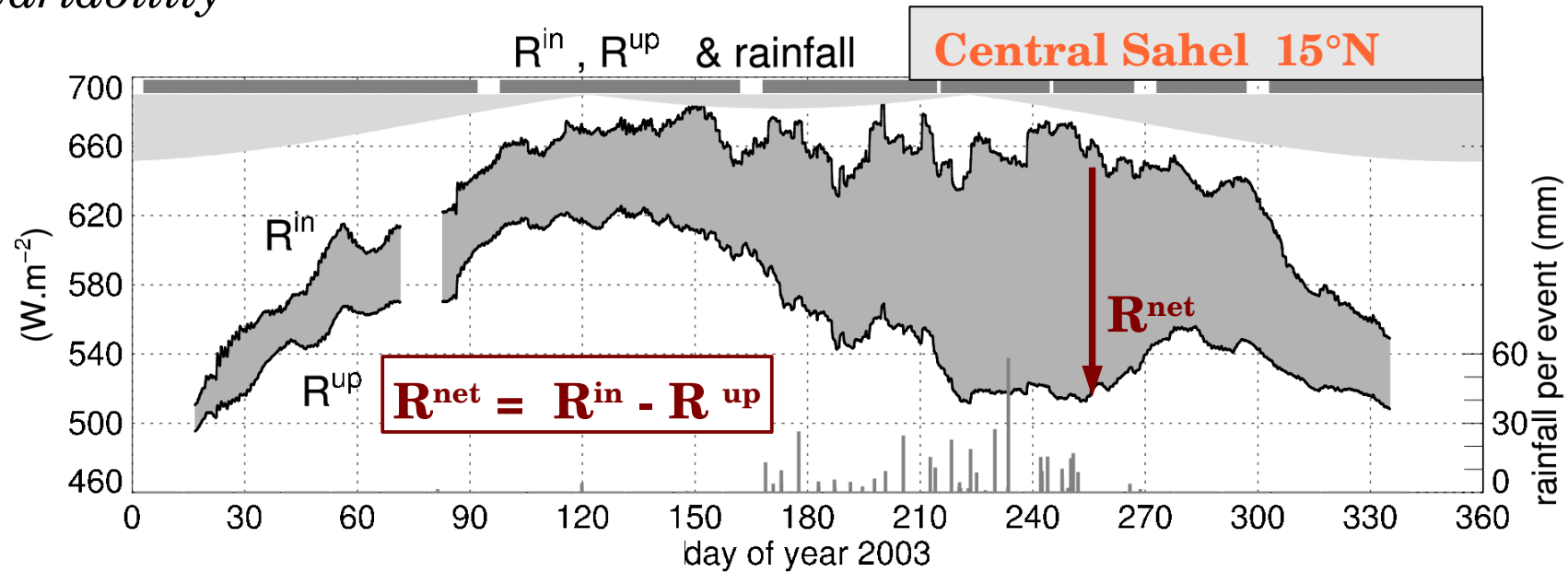
*Guichard
et al. (2009)*

surface cooling

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

*(consistent with
Slingo et al. 2009,
Ramier et al. 2009)*

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

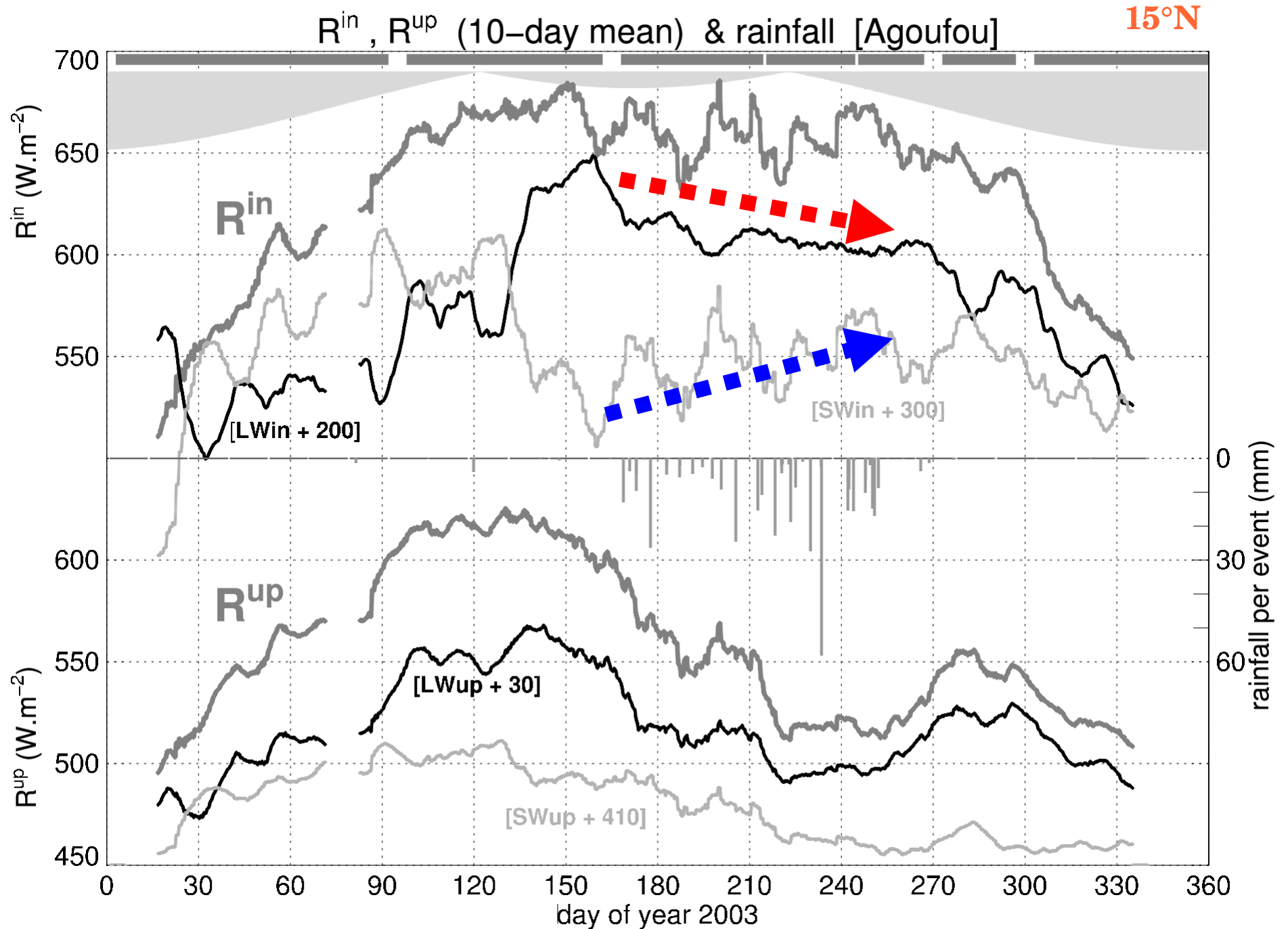


* R^{in} , R^{up}
 more strongly
 coupled at
 this scale

* significance
 of cloud SW
 radiative
 forcing

seasonal cycle of surface radiative fluxes

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

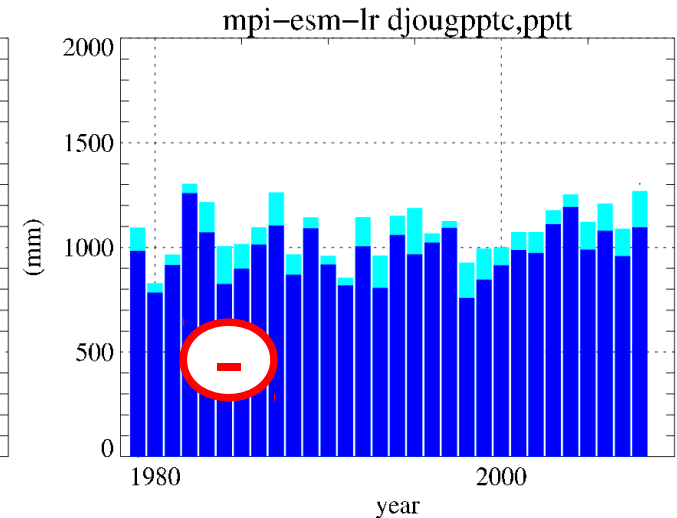
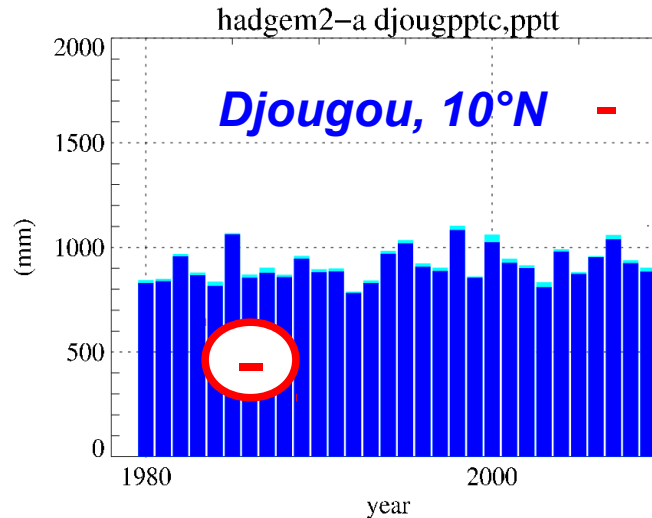
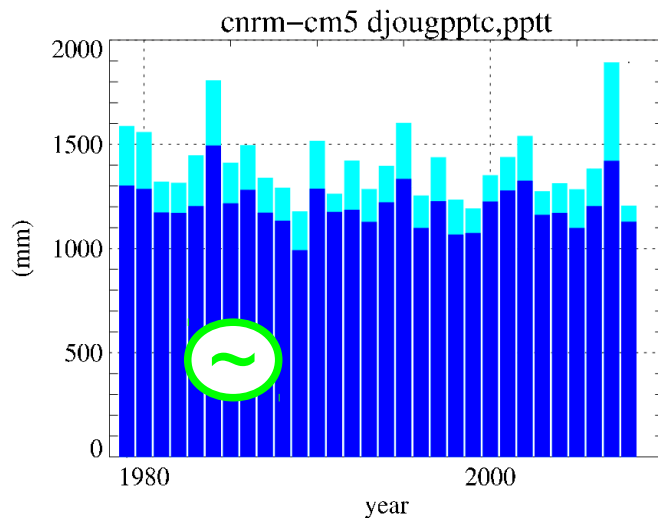
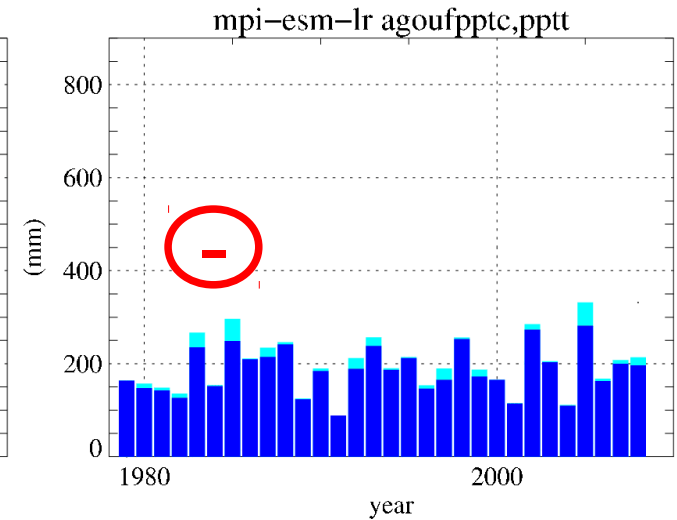
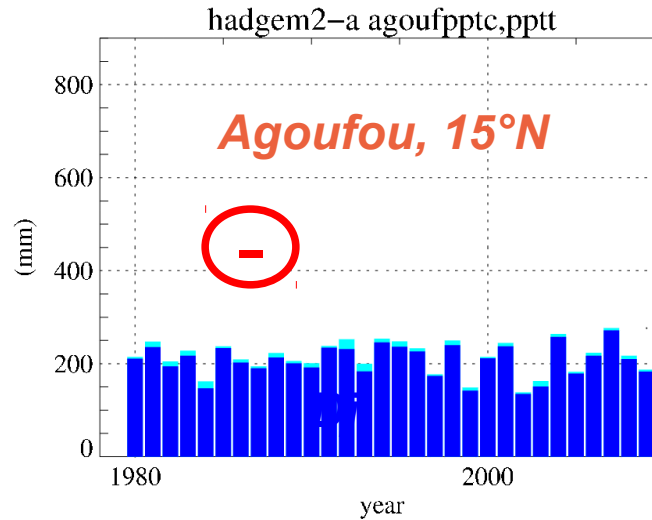
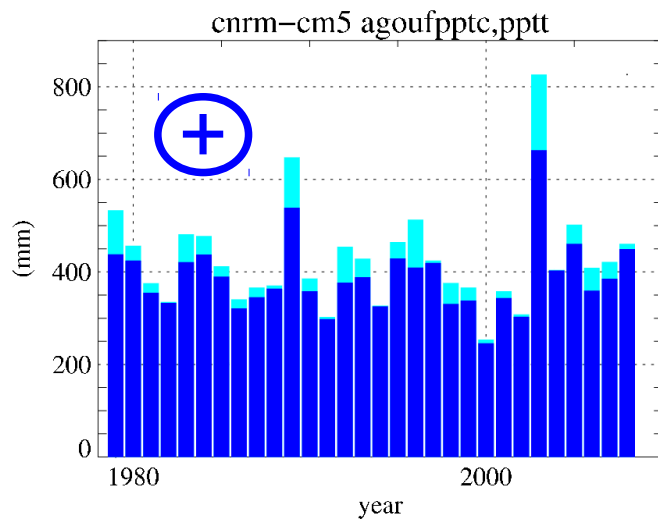


A preliminary broad overview of the cfSites outputs, AMIP runs

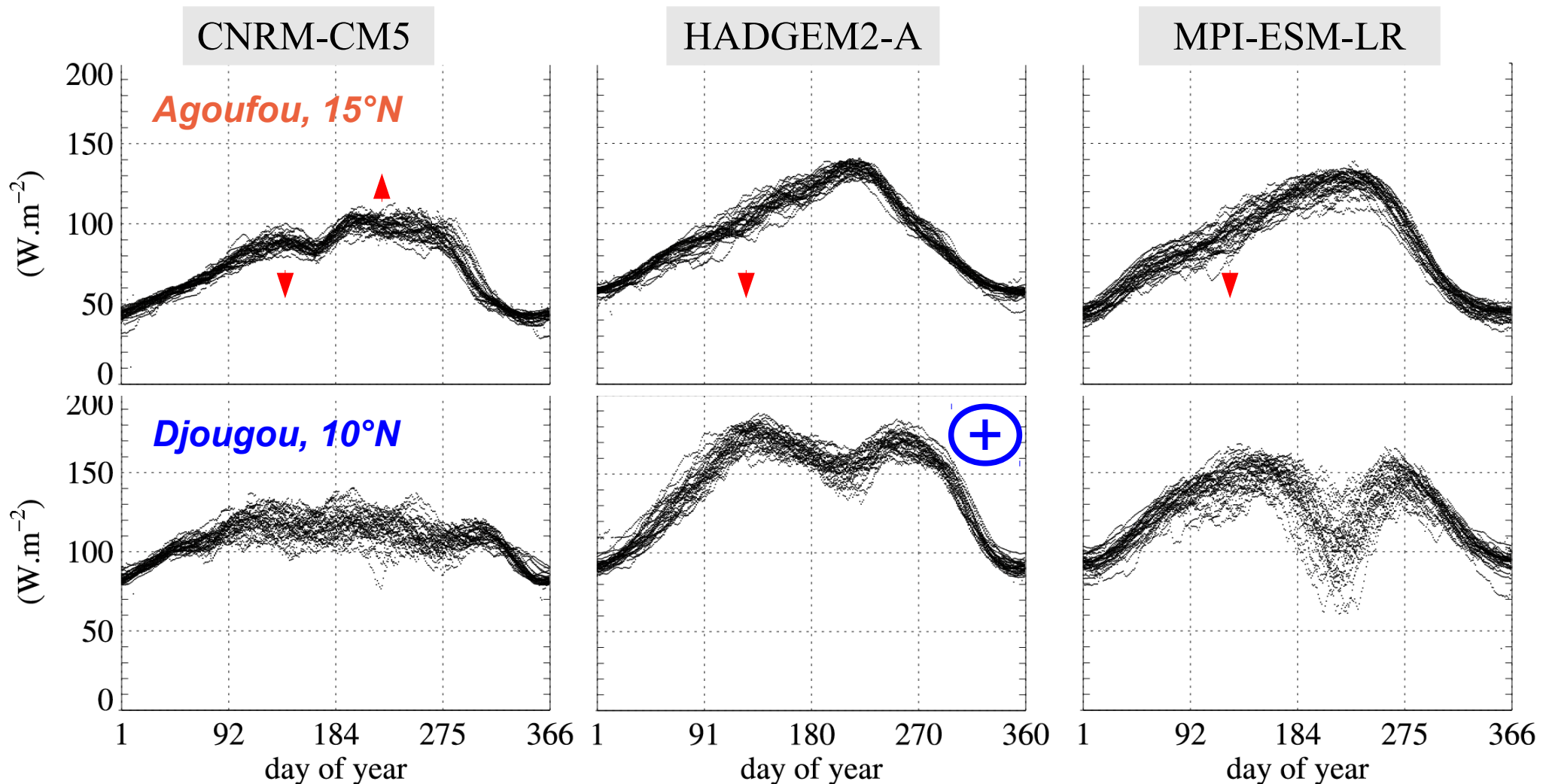
2 points: 10°N et 15°N

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

Annual precipitation



Rnet sfc , 31-day running mean

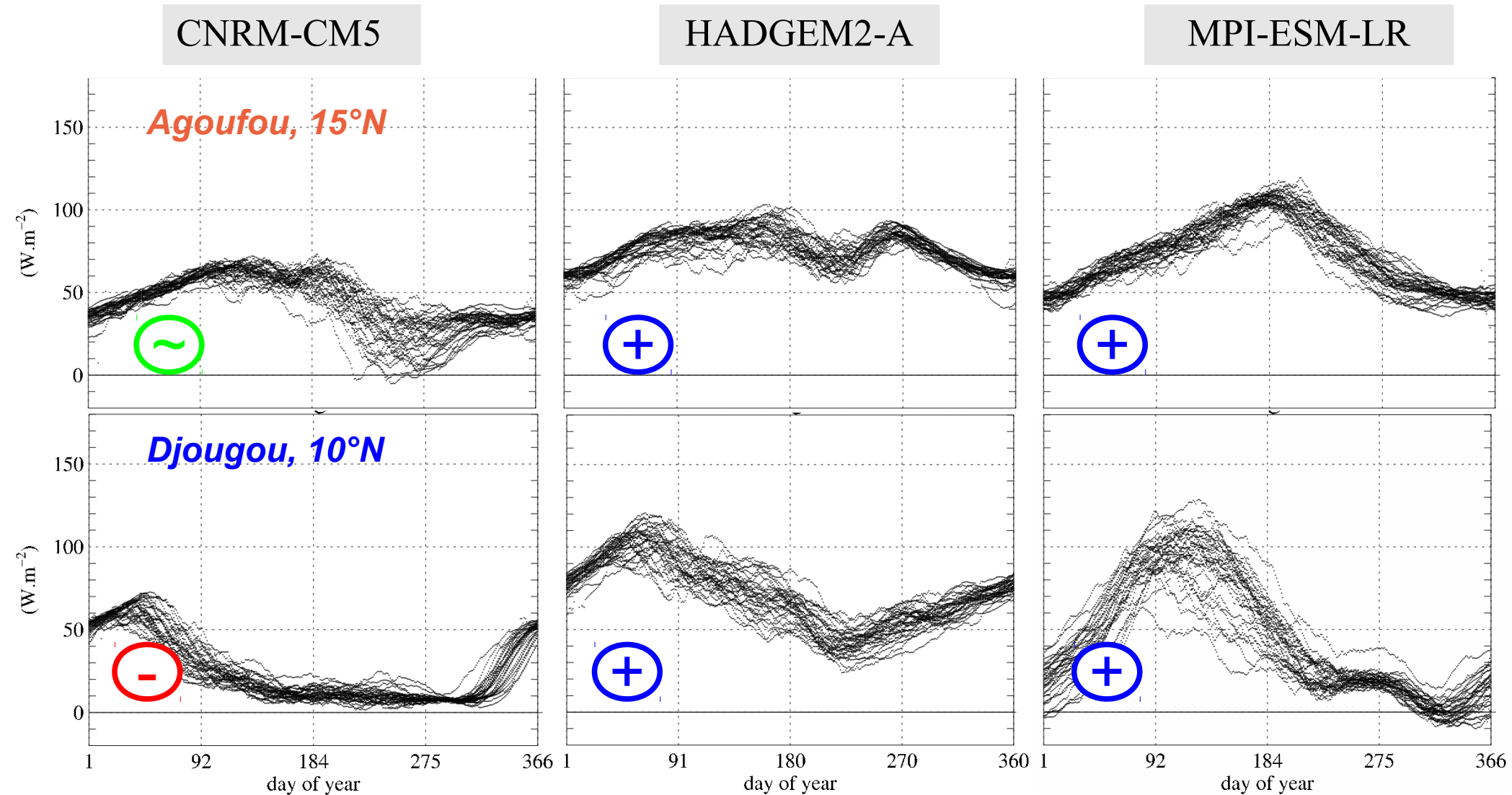


*15°N: a common tendency to **overestimate R_{net} in Spring** (consistent with Traore 2011)*

Stronger R_{net} for models with lower rainfall, the opposite in observations

Translates into errors in H and LE

Surface sensible heat flux H , 31-day running mean



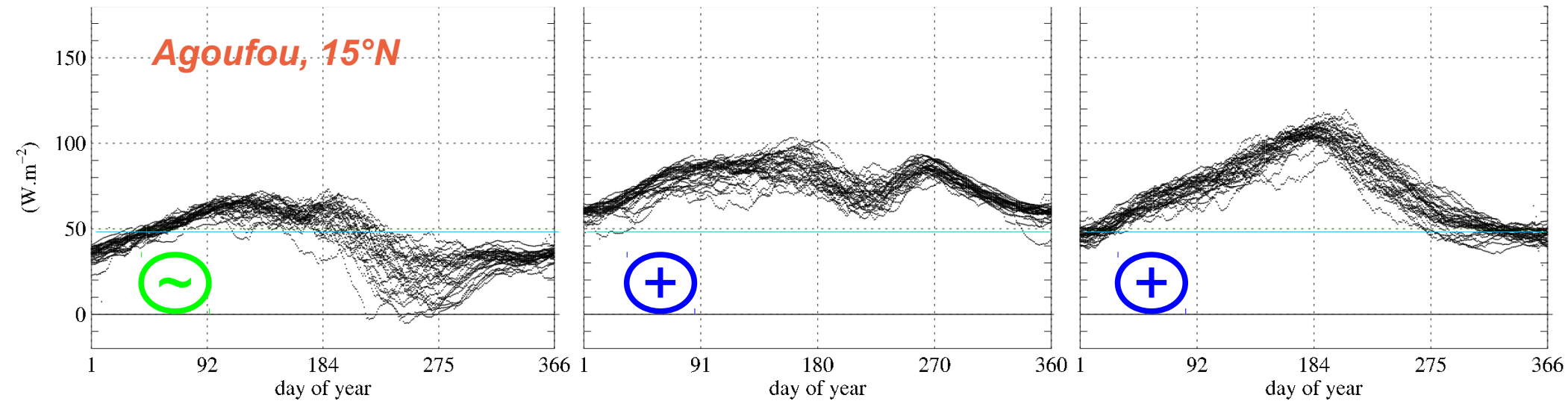
large differences among models, dominate over interannual differences

Surface sensible heat flux H , 31-day running mean

CNRM-CM5

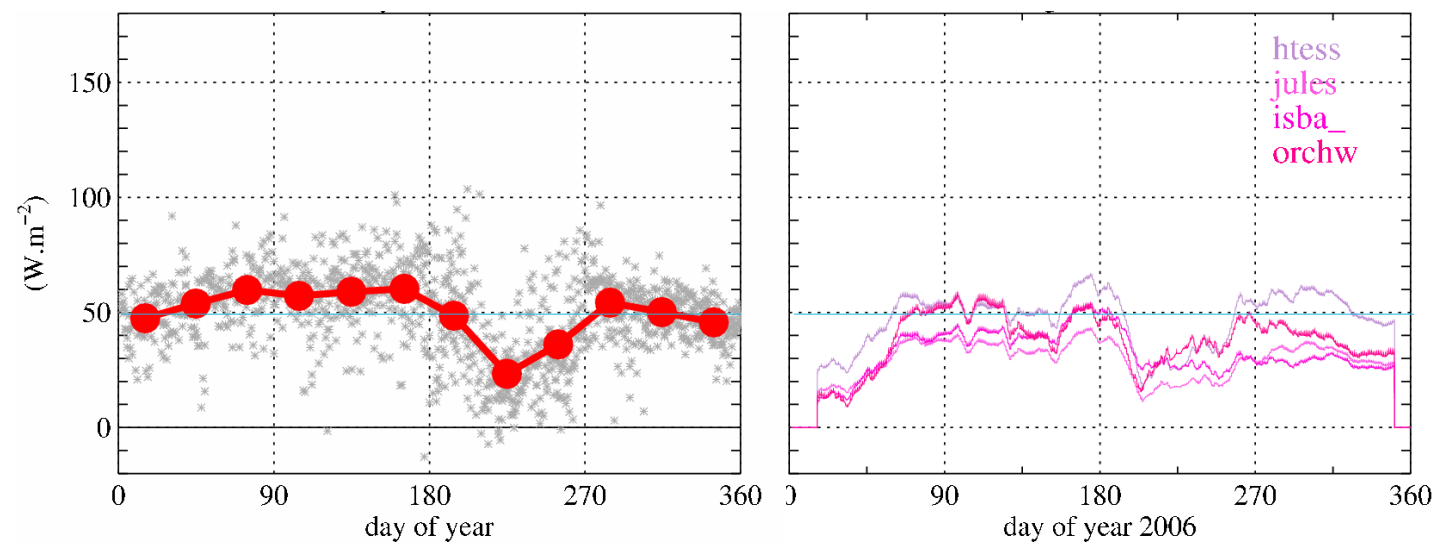
HADGEM2-A

MPI-ESM-LR



DATA

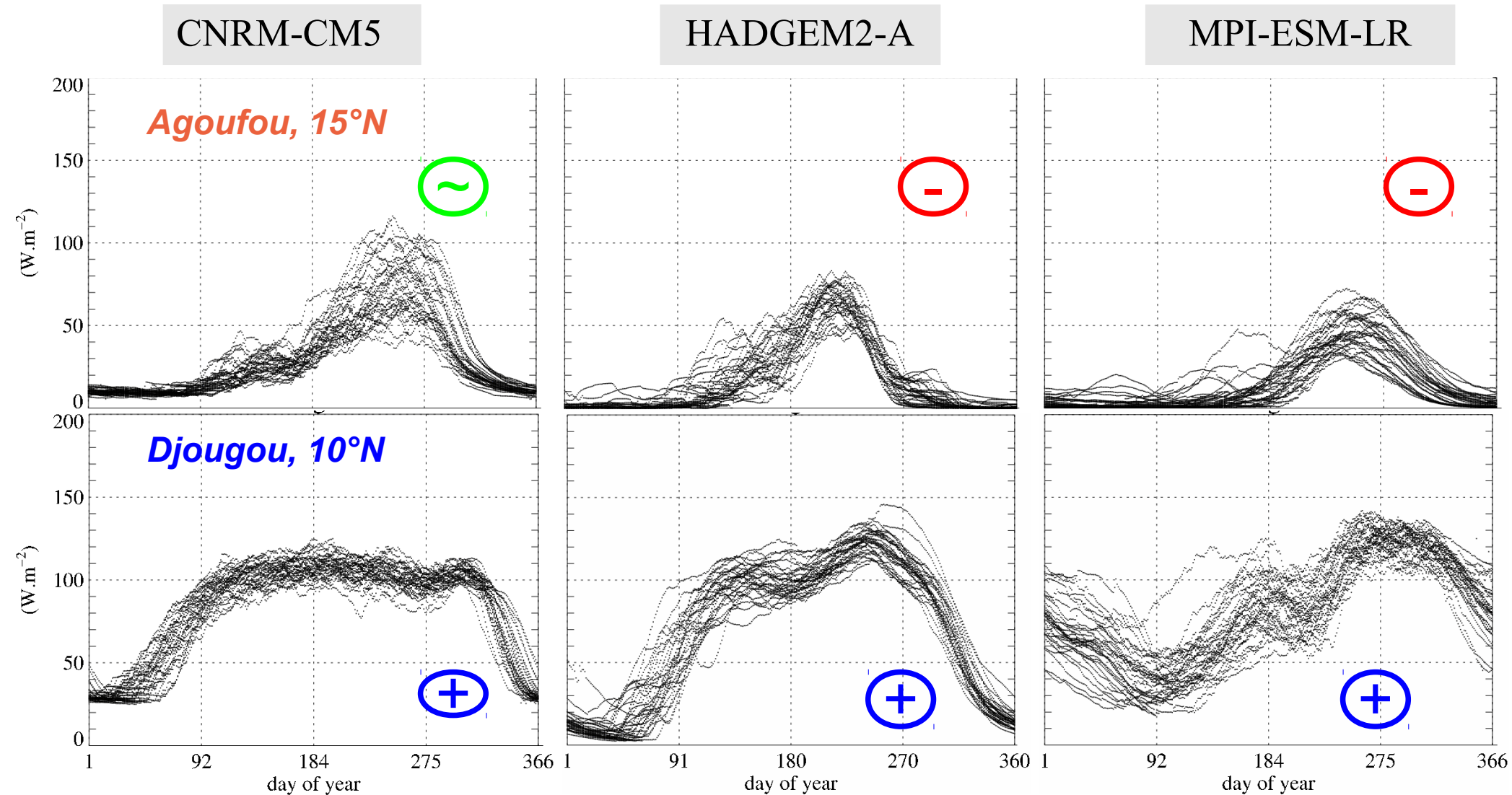
LSM modelling (ALMIP)



off-line runs forced
by “realistic
atmosphere”
different models
ALMIP regional
(Boone et al. 2009)

explain some of the
differences, not all

Surface latent heat flux LE , 31-day running mean



Which couplings of these differences in H and LE with differences in BL, low clouds and deep convection? (*budget analysis: surface-advection-cloud-precipitation equilibrium*)

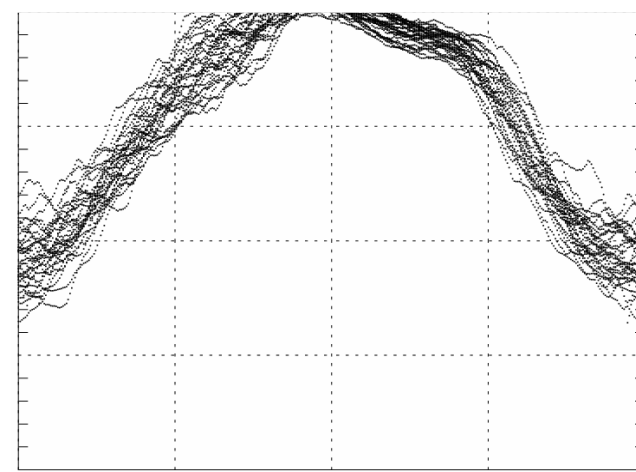
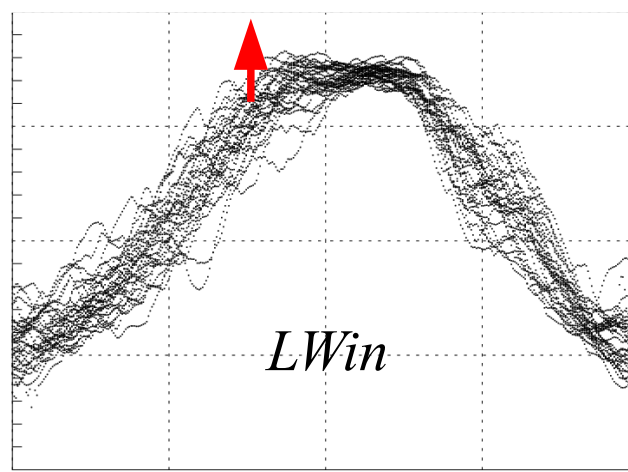
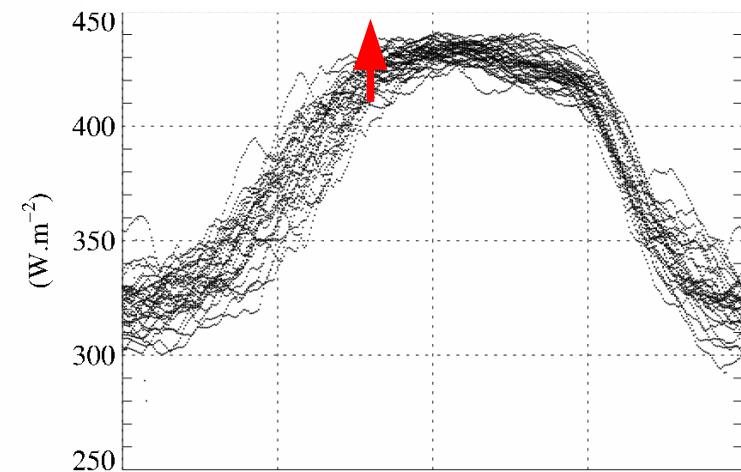
LWin , 31-day running mean

Agoufou, 15°N

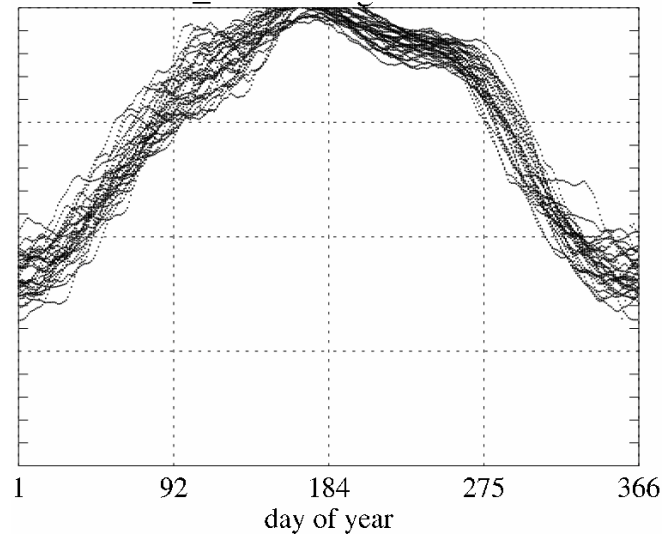
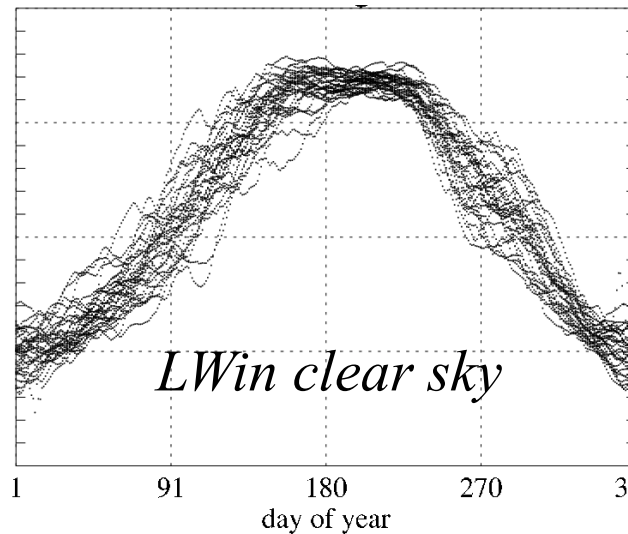
CNRM-CM5

HADGEM2-A

MPI-ESM-LR



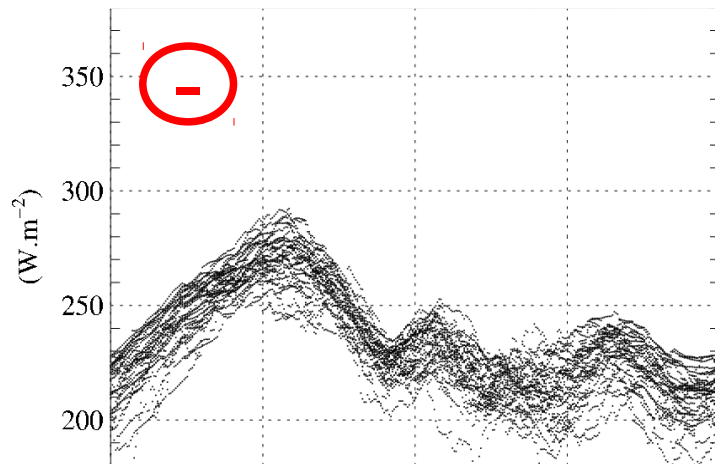
Differences in LWin
clear sky:
which role of aerosols?



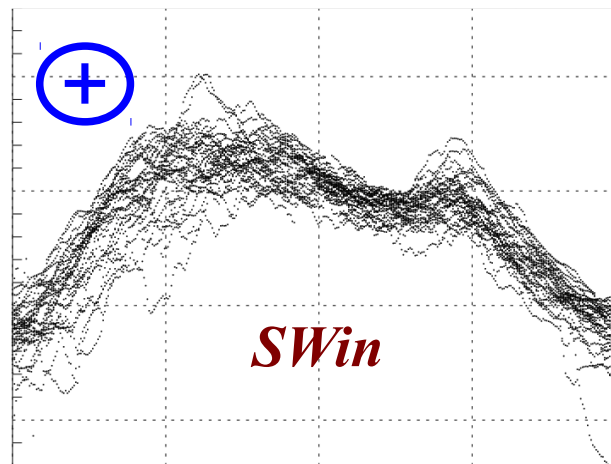
SWin , 31-day running mean

Agoufou, 15°N

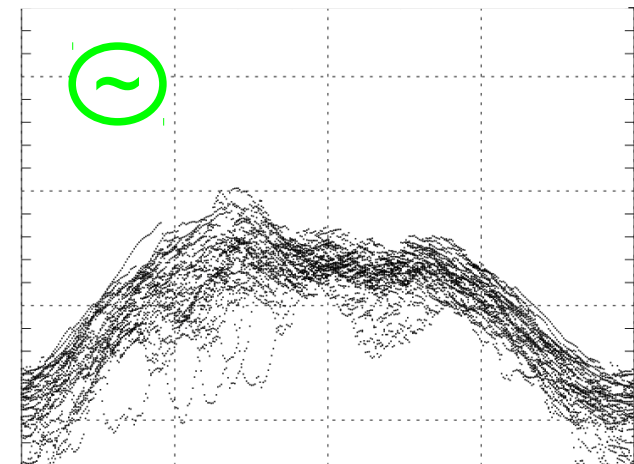
CNRM-CM5



HADGEM2-A

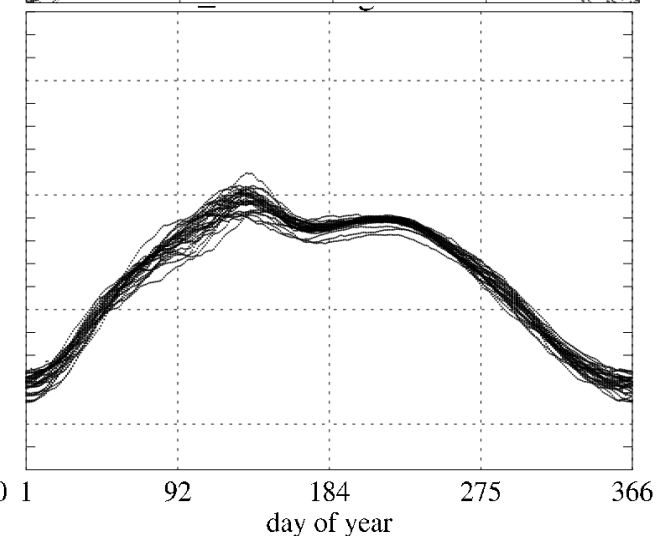
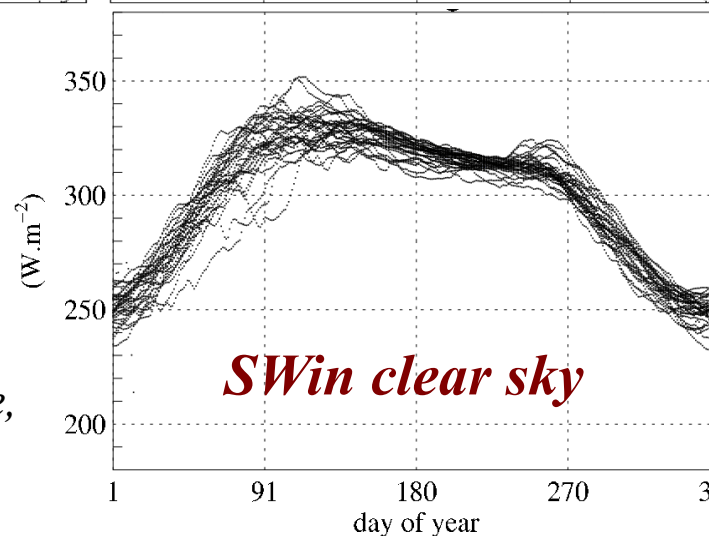


MPI-ESM-LR



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

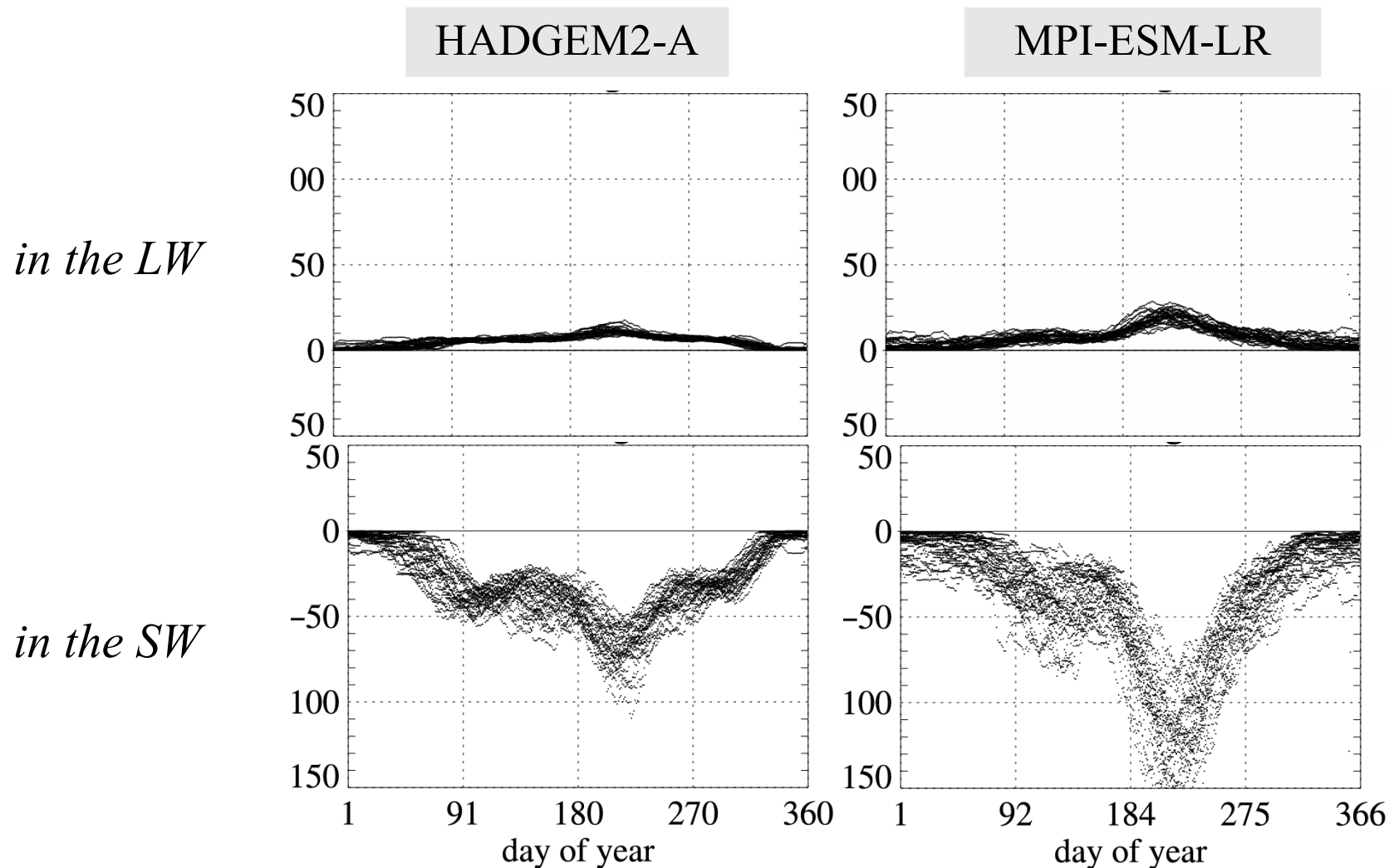
Reanalyses are not error free, nor satellite products either!



Differences in SWin clear sky: impact of T & q structures, a role for aerosols?
interest of 1D radiative transfert model for further investigation (O. Geoffroy Poster)

Cloud radiative forcing

Djoungou, 10°N



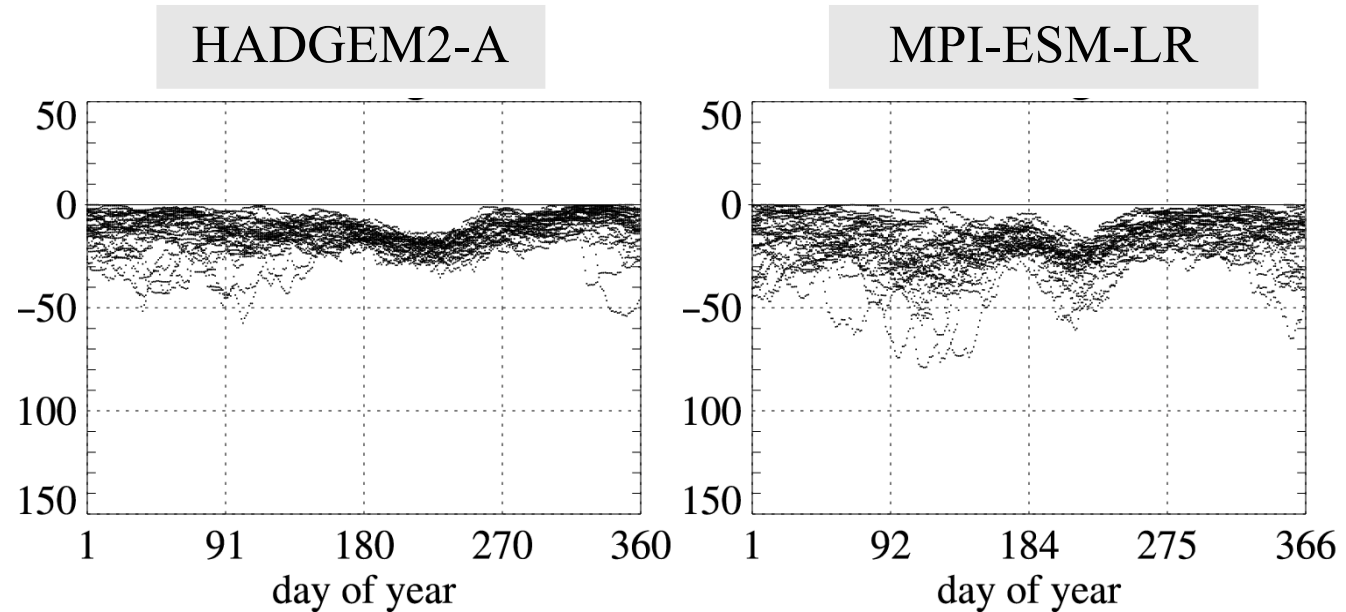
SW cloud forcing dominates (distinct behaviour compared to TOA)

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

Cloud radiative forcing

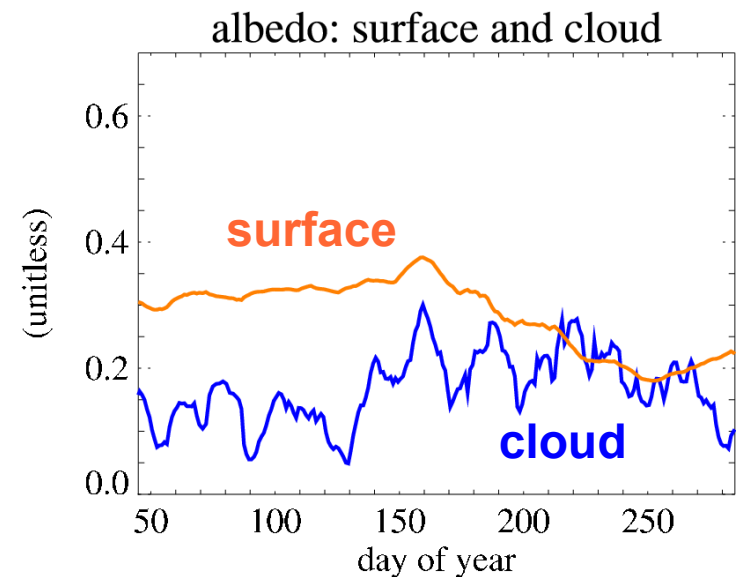
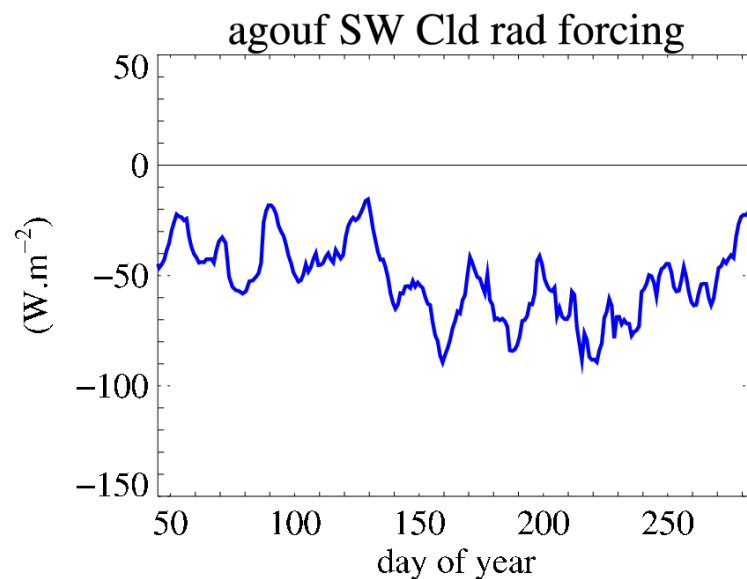
Agoufou, 15°N

in the SW



$$\text{SWnet} = (1 - a_{\text{sfc}}) \text{Swin}$$
$$(1 - a_{\text{sfc}}) (1 - a_{\text{cld}}) \text{SWin_clear_sky}$$

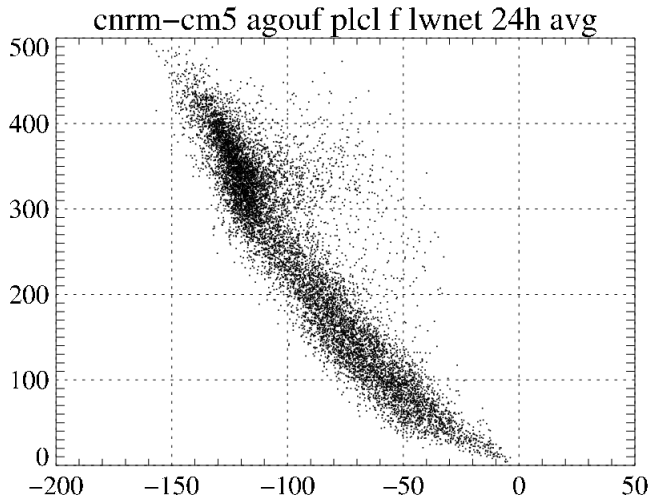
*Data
very rough
estimation*



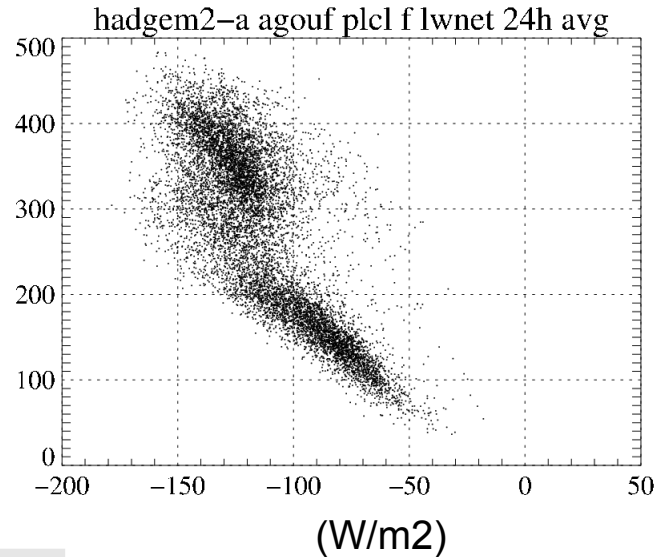
couplings LWnet, Plcl (~ RH)

15°N

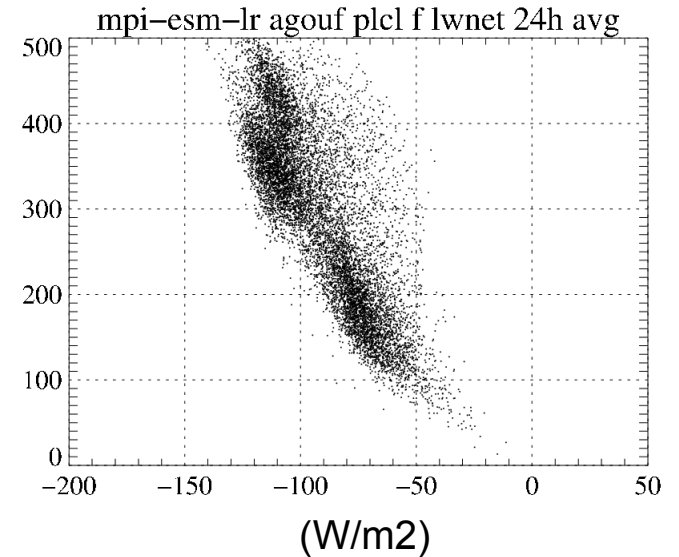
CNRM-CM5



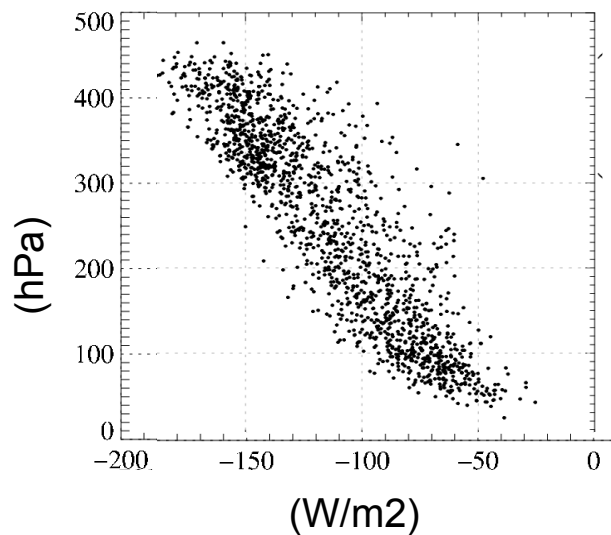
HADGEM2-A



MPI-ESM-LR



OBSERVATIONS

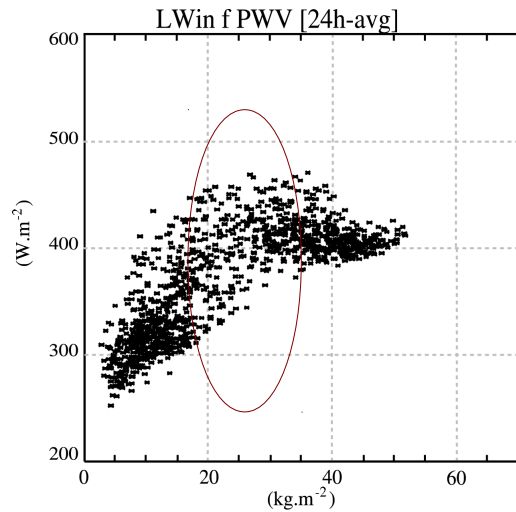


Need to understand better the cloud-related sources of differences

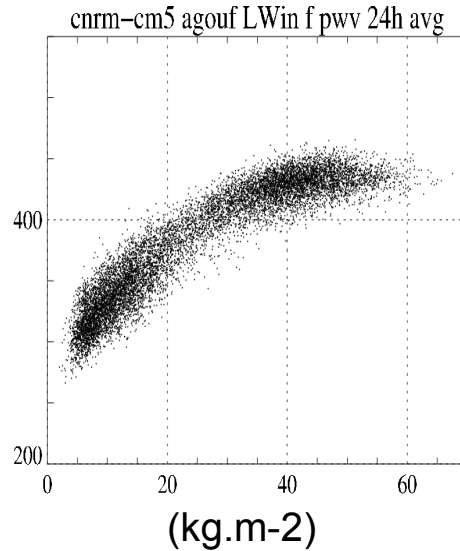
Link between Plcl and actual cloud base

Couplings LWin, precipitable water (PWV)

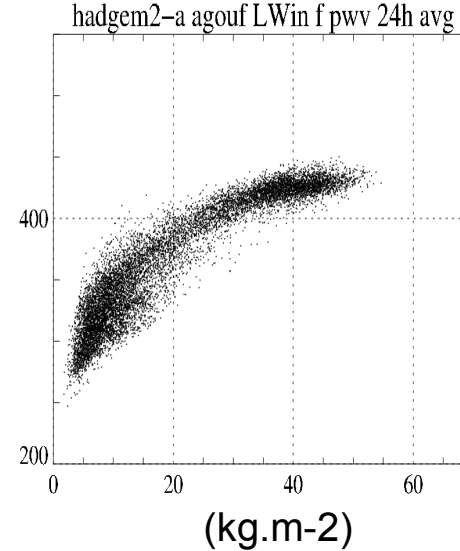
DATA



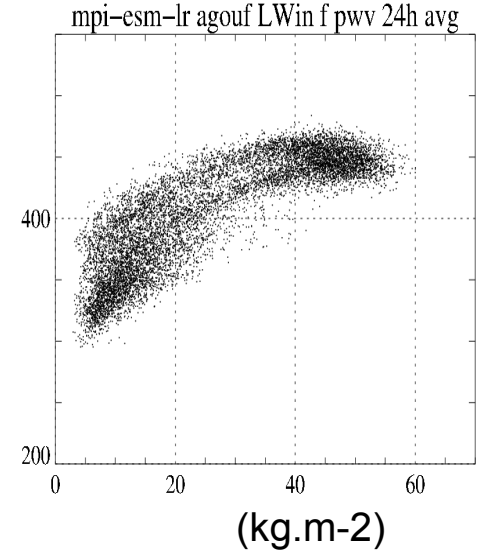
CNRM-CM5



HADGEM2-A



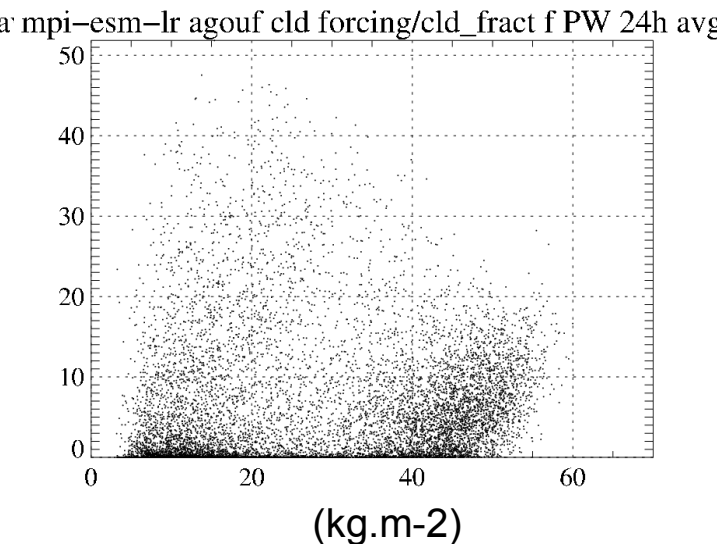
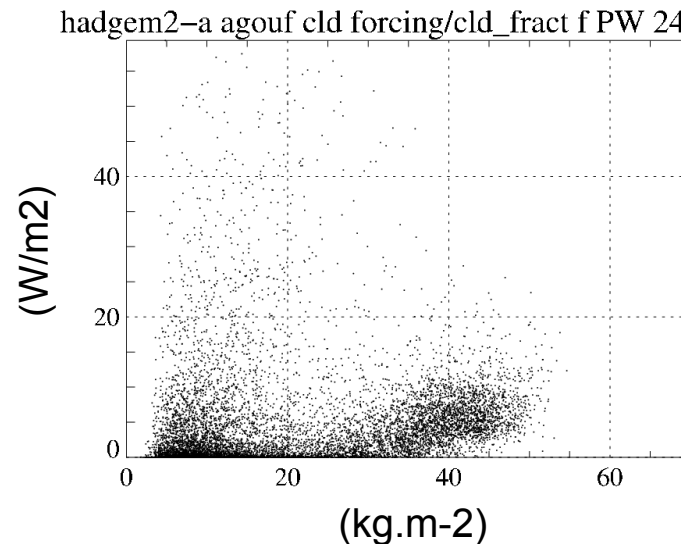
MPI-ESM-LR



A role of cloud at intermediate PWV values? Larger LWin, enhanced spread in MPI, aerosols?

Sensitivity of cloud LW forcing to PWV

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



Summary

Really the very beginning of the analysis...

A few issues/pieces of infos (Δt rad computations, aerosols,...): a climate modeller contact?

All three models depict a number of reasonable features, some qualitatively and others with more accuracy, errors in precipitation do not account for all cloud biases. Difference among models tend to dominate over interannual variability of each.

Develop evaluations using more of the AMMA datasets

surface - boundary layer - cloud - convection – advection in wet a moist conditions

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 intermediate PWV**). Need to precise which type of clouds, properties... (mid-level)

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

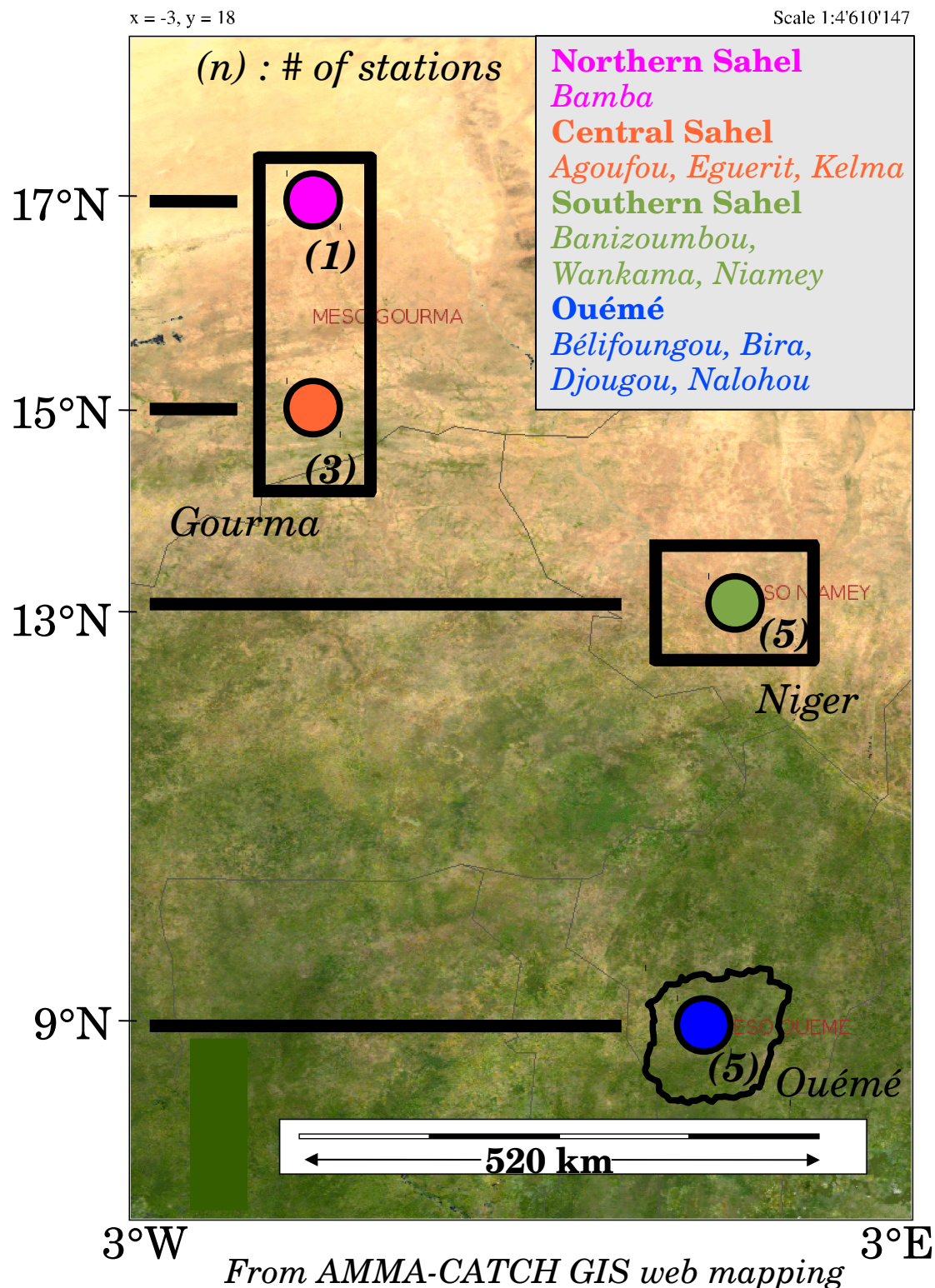
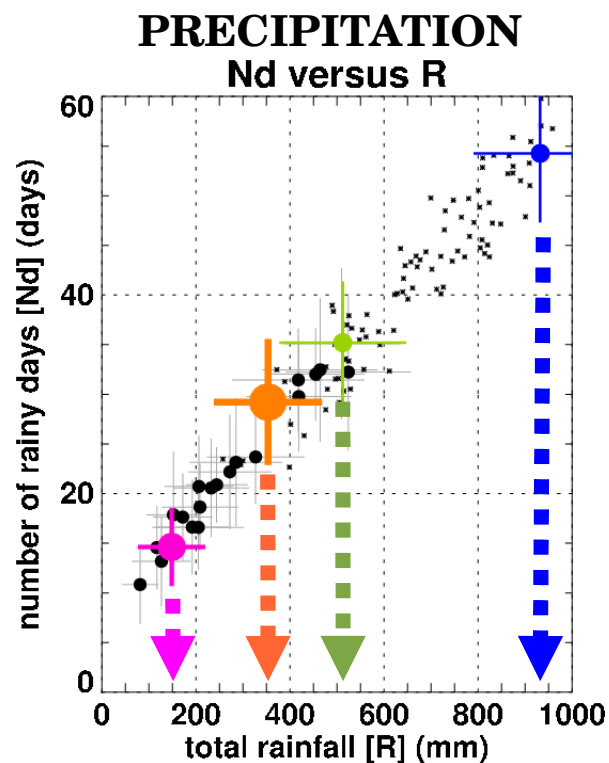
Develop more accurate estimation of cloud radiative forcing at the surface, explore possible links between cloud types, cloud radiative forcing and radiative biases

THE MEASUREMENT SITES AMMA-CATCH

Located along a meridional
climatological gradient

Over $\neq$ surface/vegetation types

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



thermodynamic-radiative coupling during the monsoon

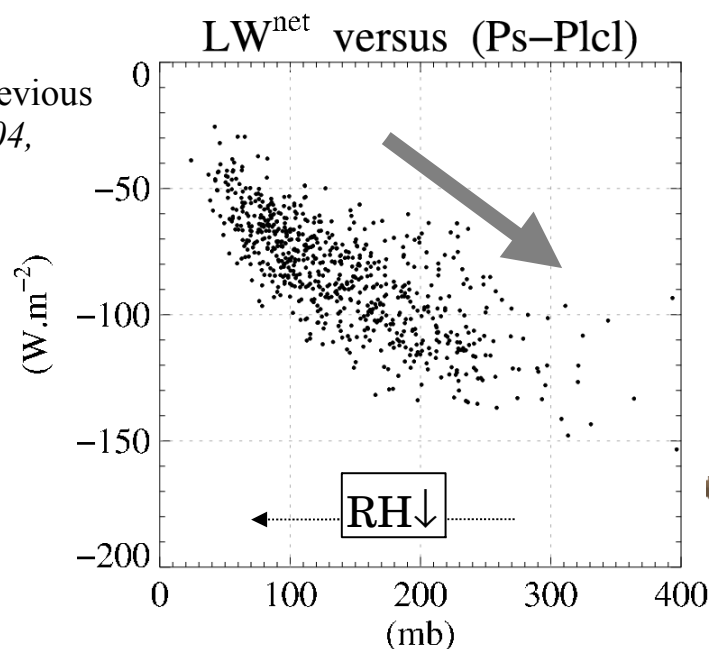
24-h mean values, JJAS 2002 to 2007, *Central Sahel 15°N*

(1)

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

extended to dryer ranges

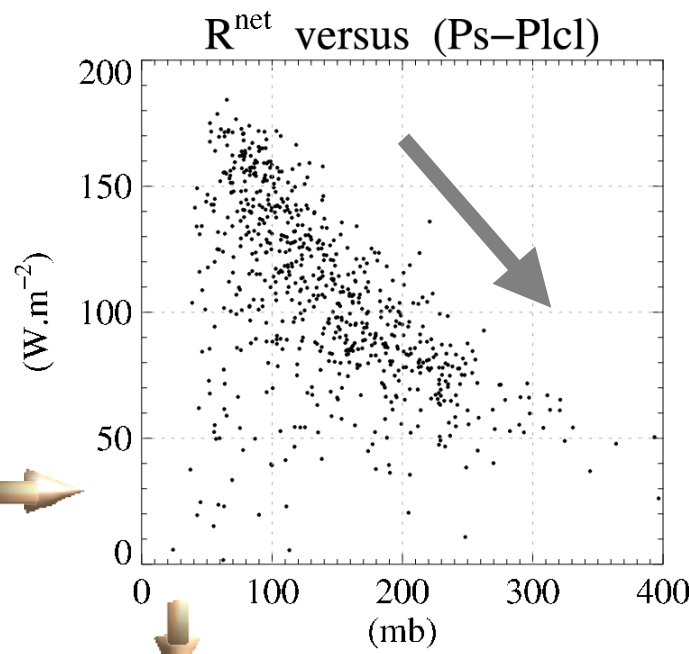
valid throughout the year



(2)

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

semi-arid region cloud impact does not dominate

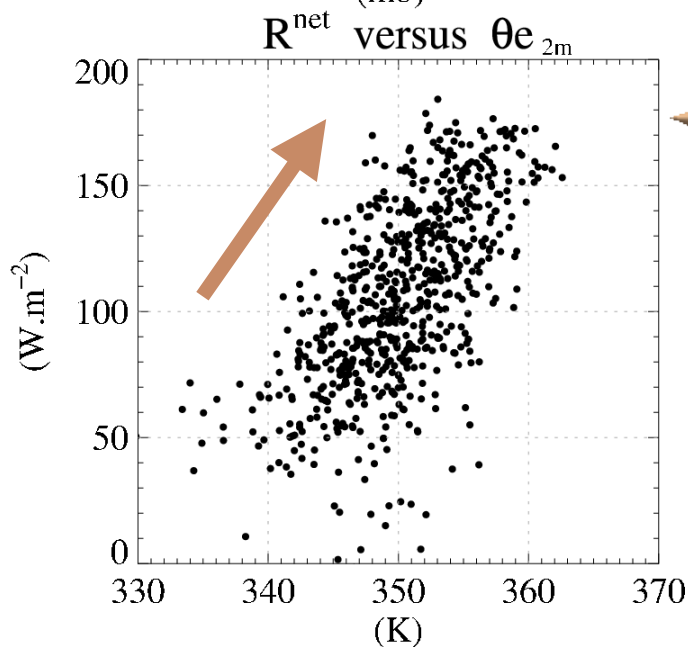


(4)

R^{net} and θ_e correl > 0

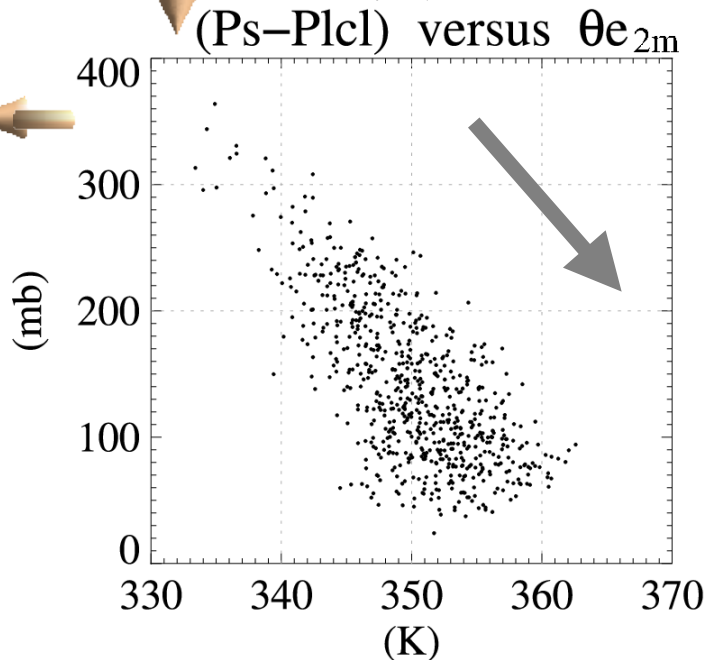
involves seasonal transformations

not well simulated

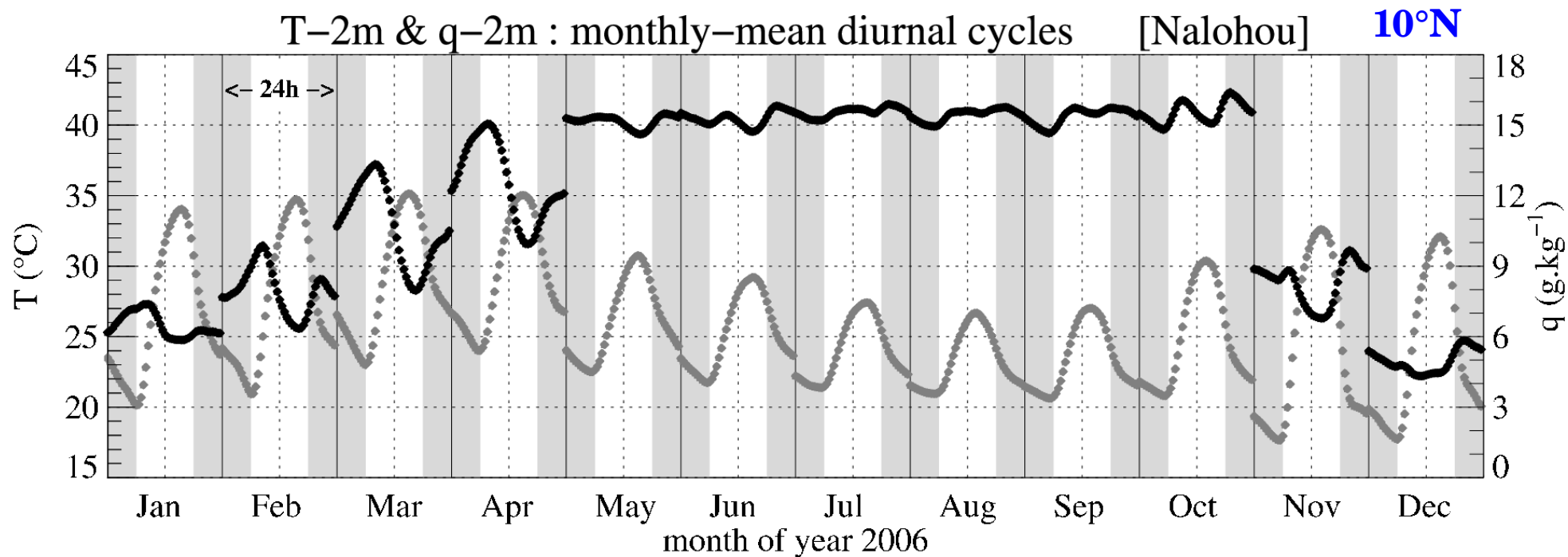
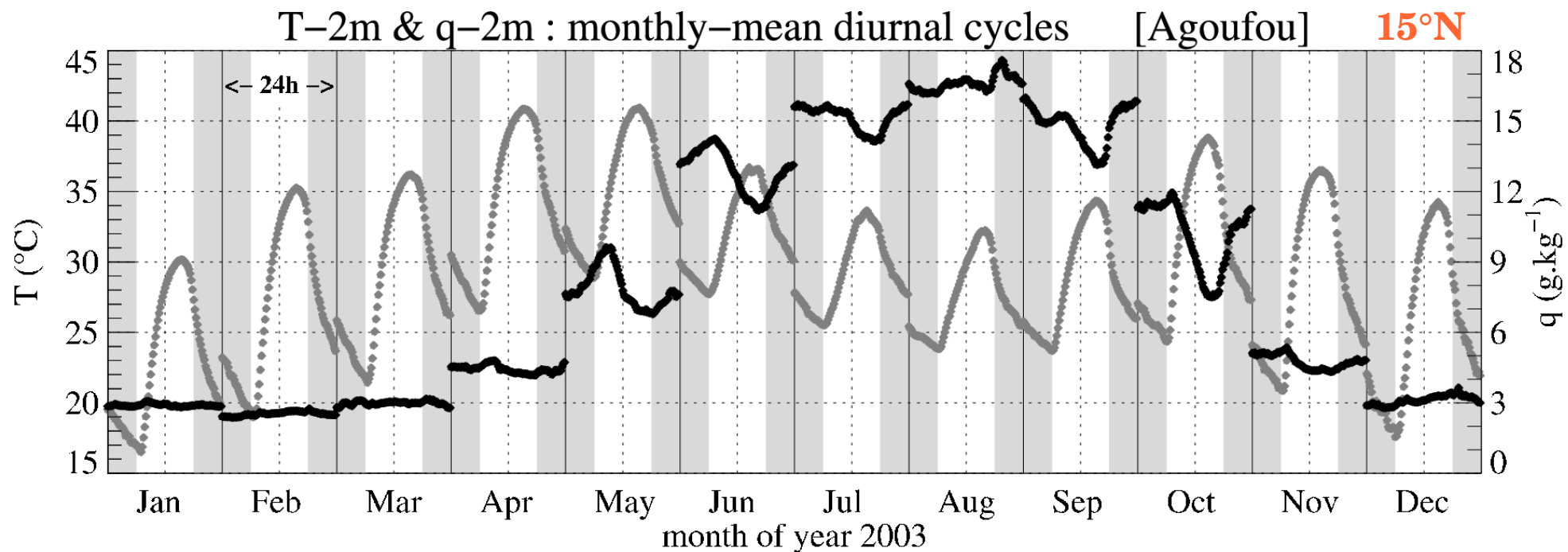


(3)

Increase of θ_e coupled to increase of Plcl, RH

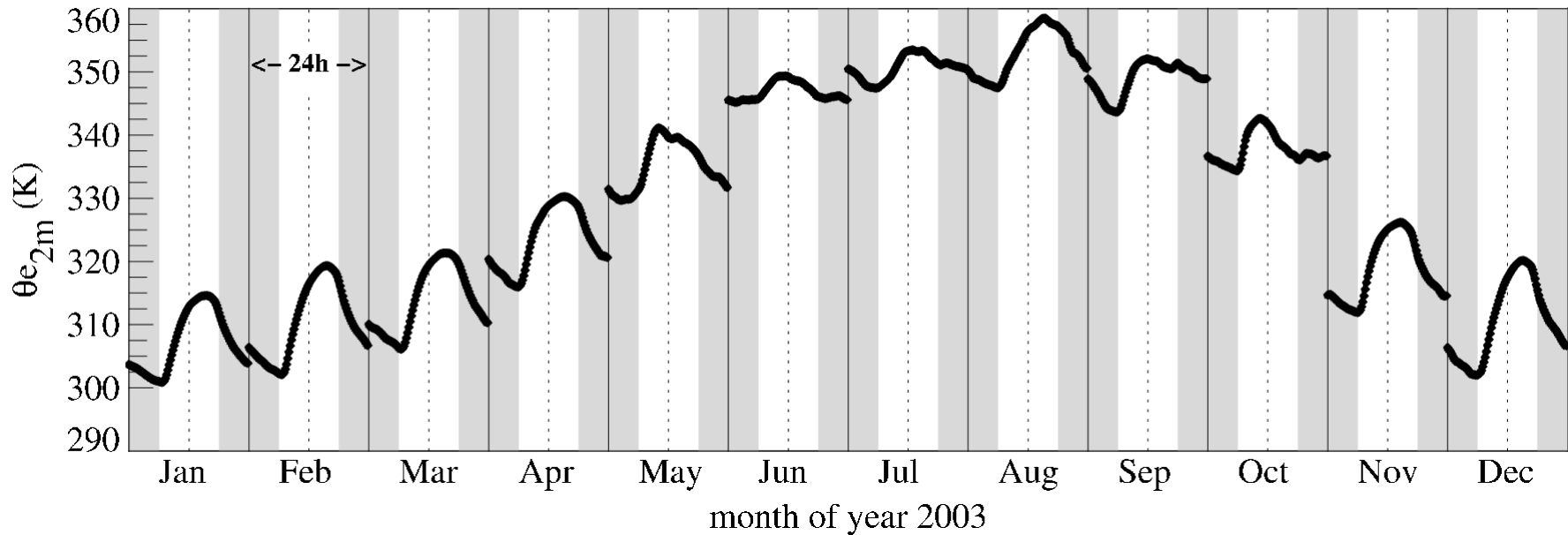


seasonal changes of the diurnal cycles



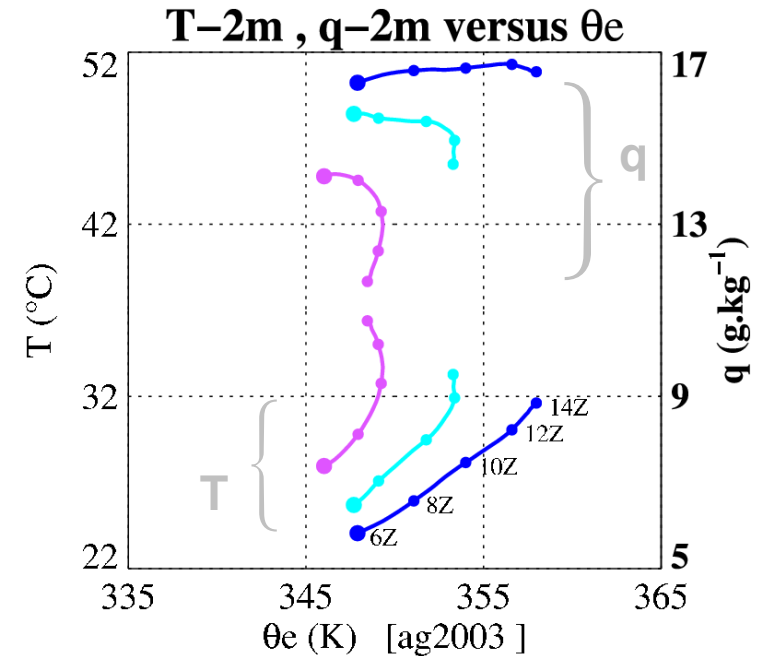
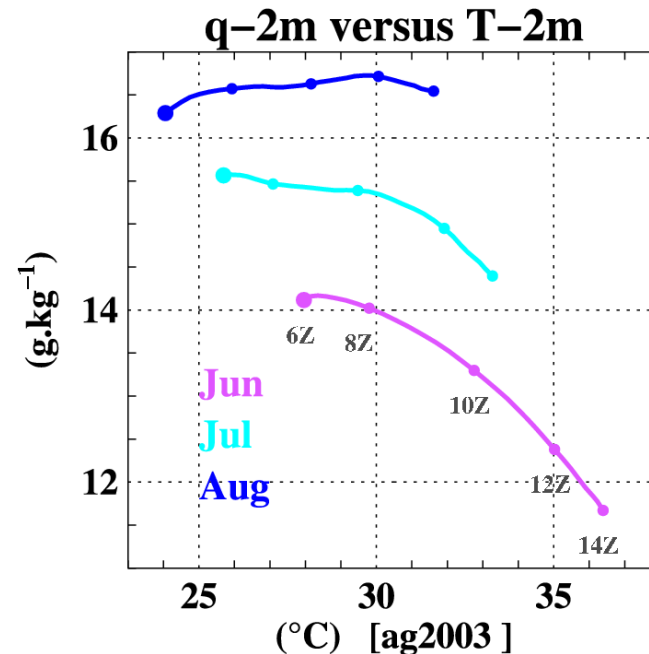
seasonal changes of the diurnal cycles

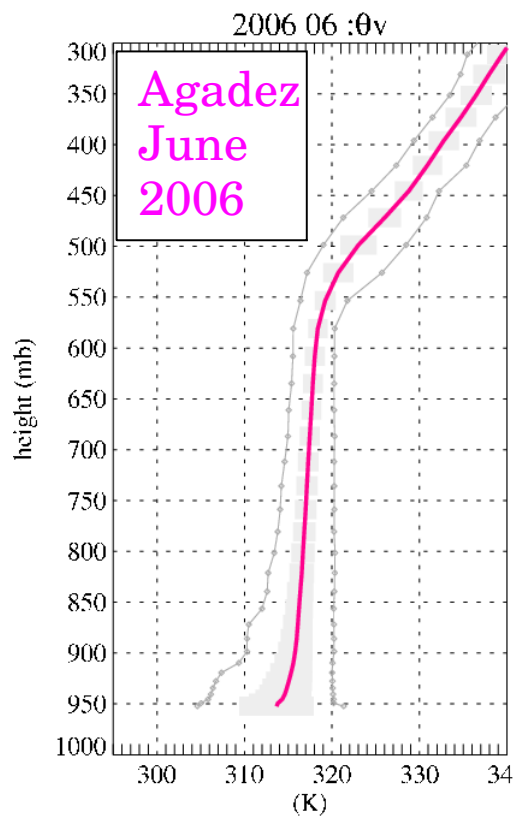
θ_{e2m} monthly-mean diurnal cycle [Agoufou]



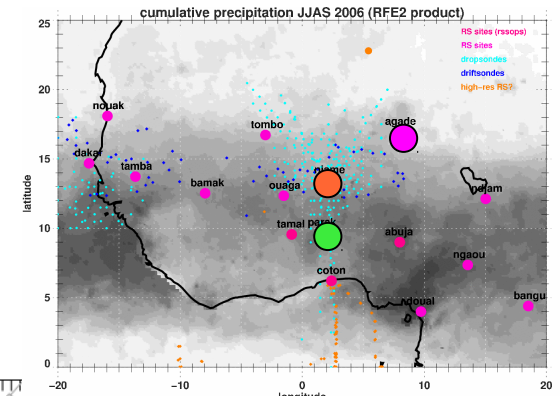
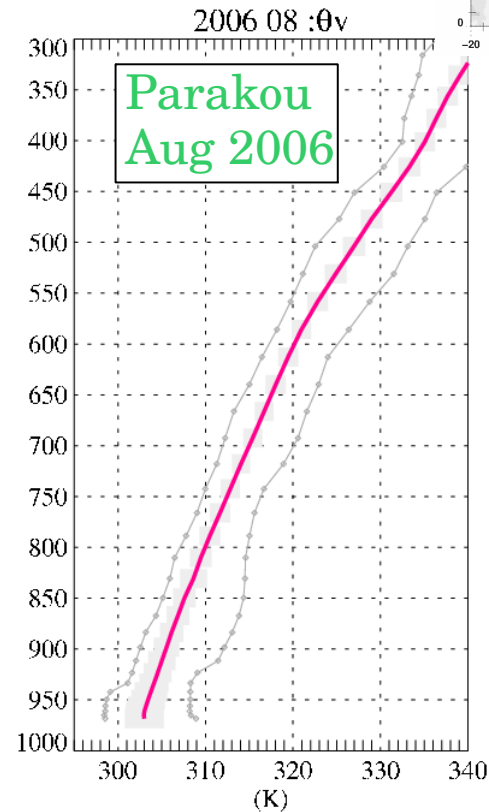
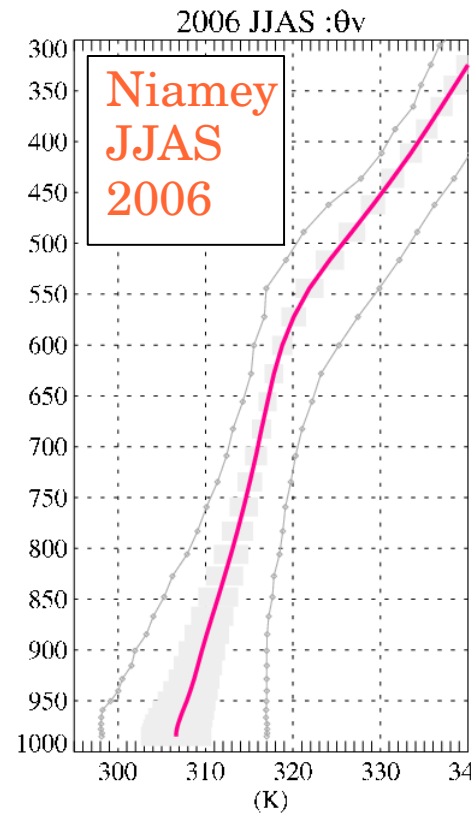
daytime drying:
strong impact on the
diurnal cycle of θ_e

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

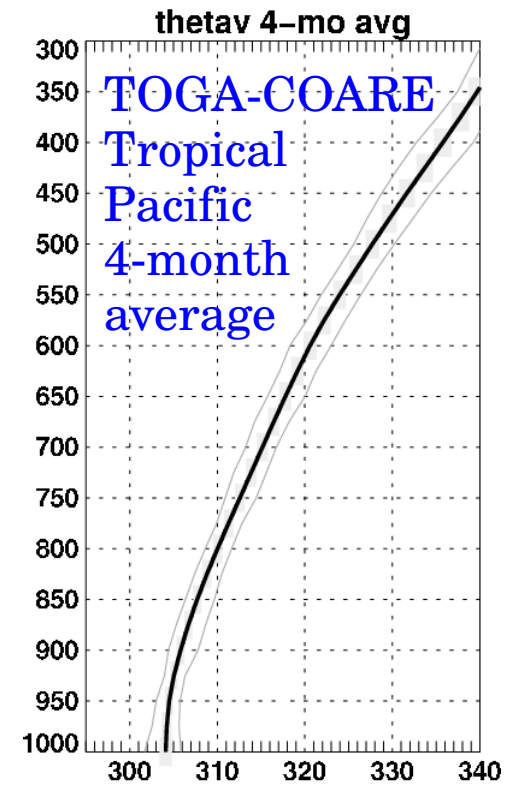




SOUNDINGS

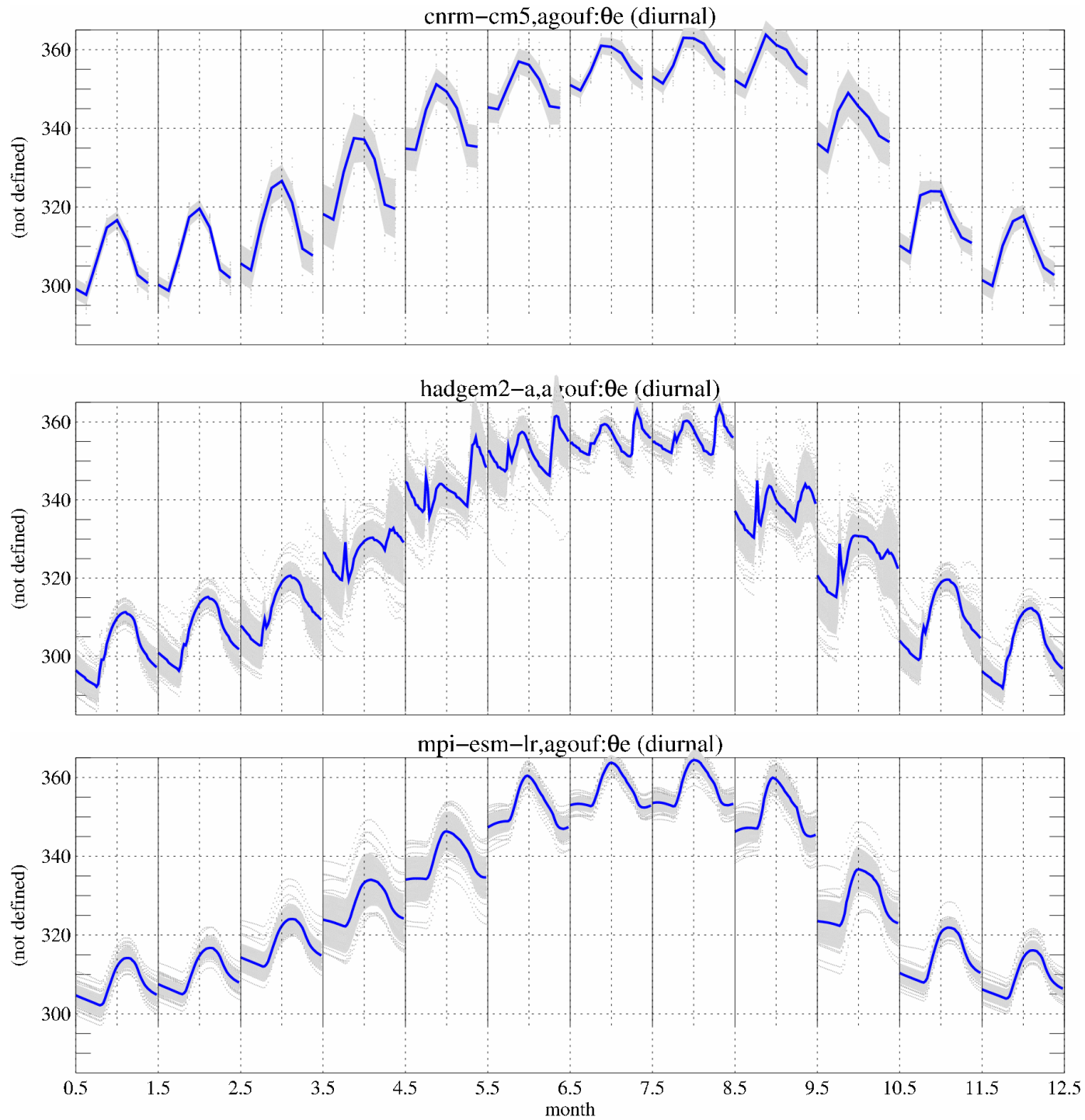


θ_v at different sites



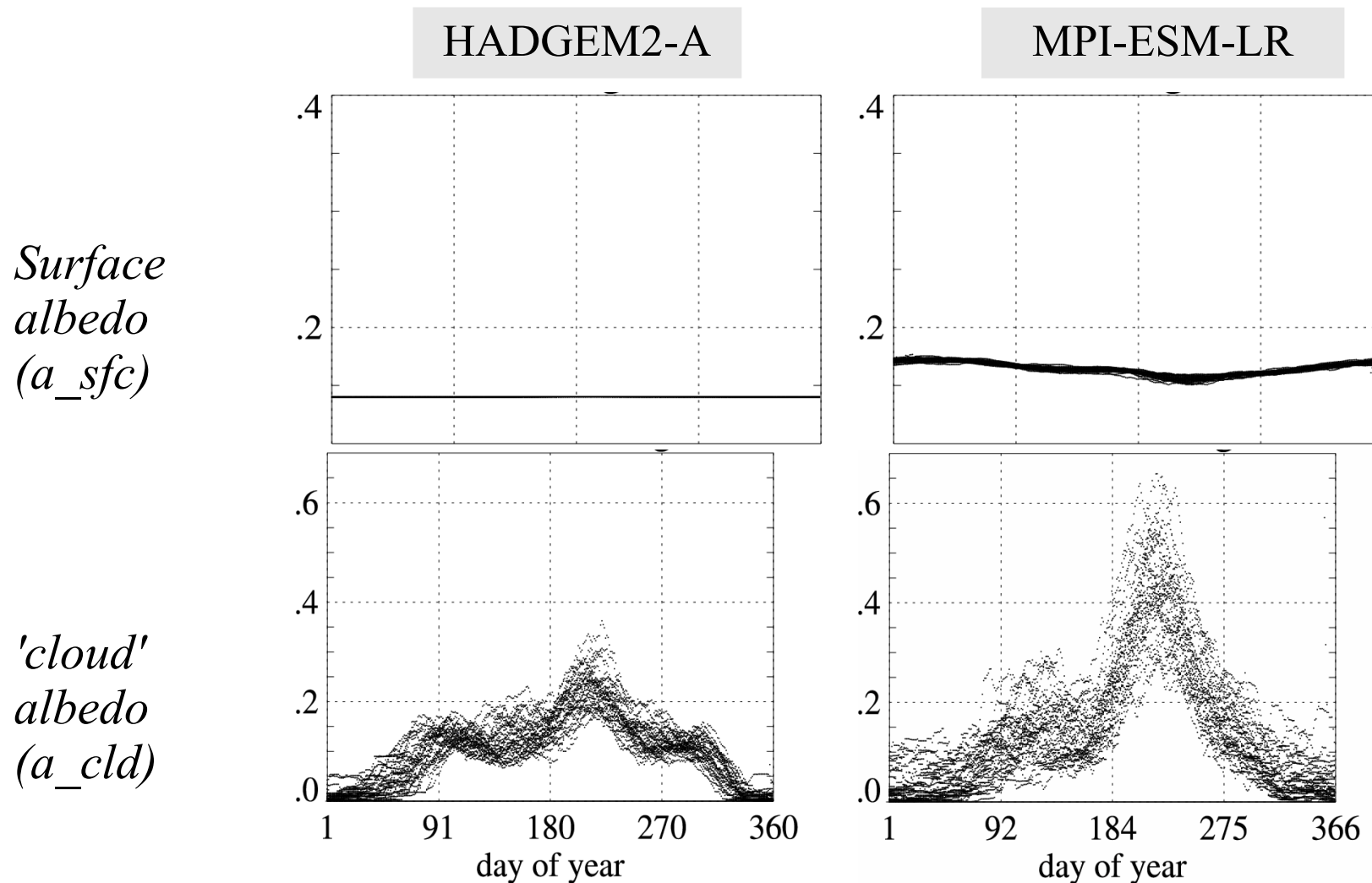
A wide variety of boundary layers and tropospheric structures in space and time

seasonal changes of the diurnal cycles



ALBEDOS $SW_{net} = (1 - a_{sfc}) S_{win}$
 $(1 - a_{sfc}) (1 - a_{cld}) S_{win_clear_sky}$

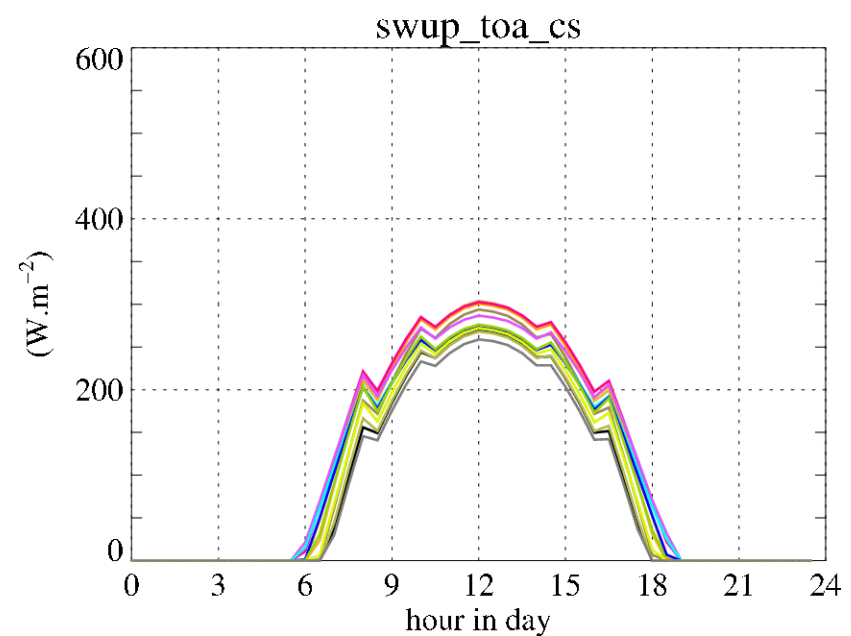
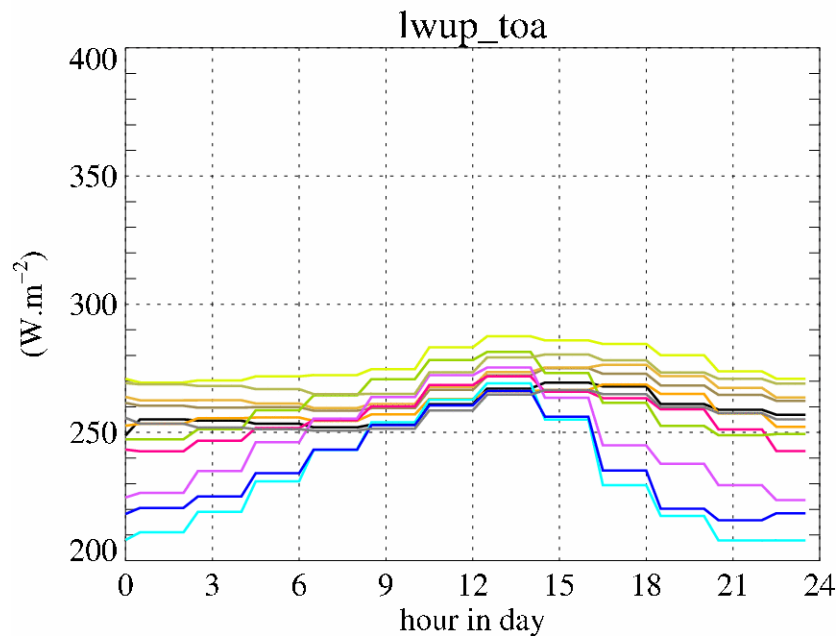
Djouougou, 10°N



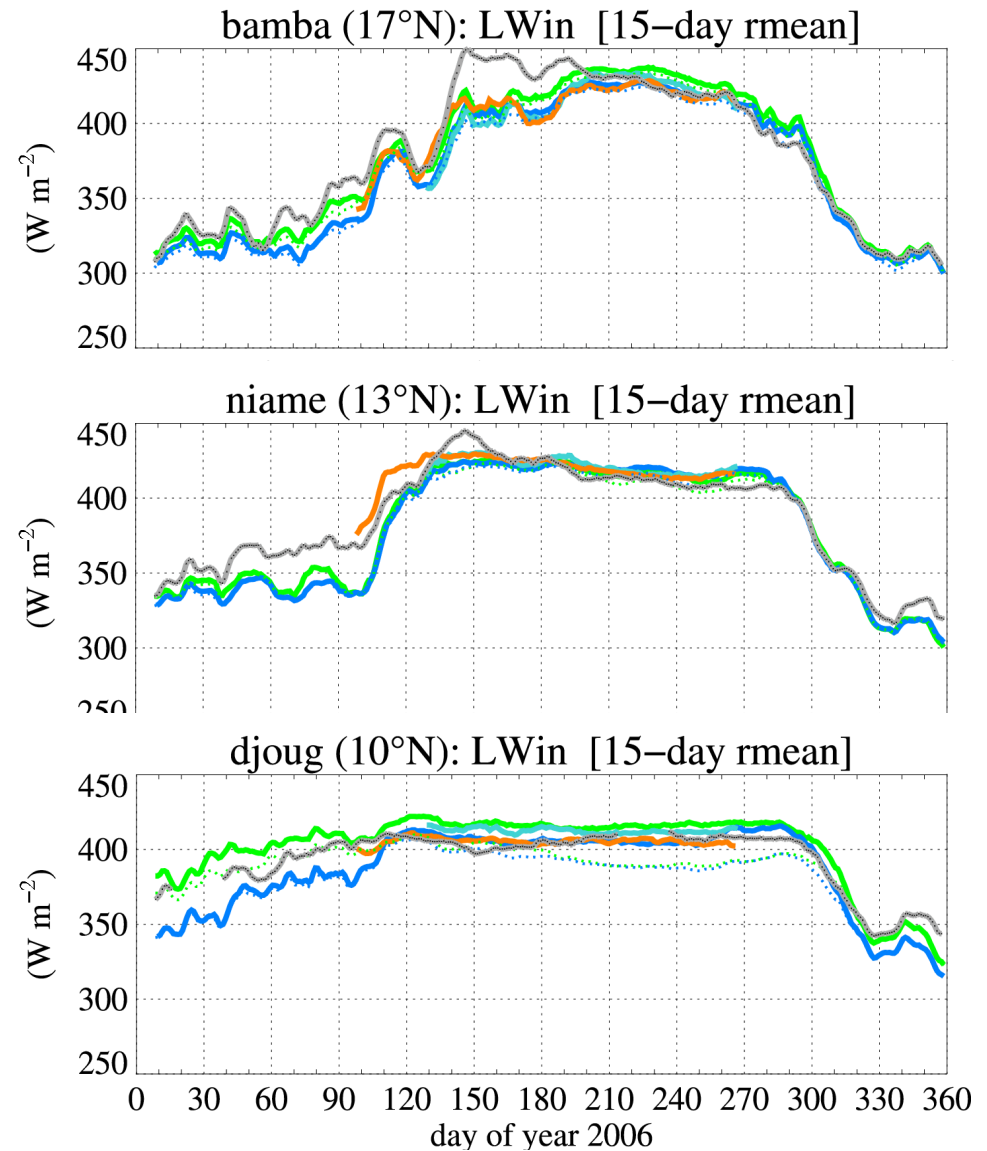
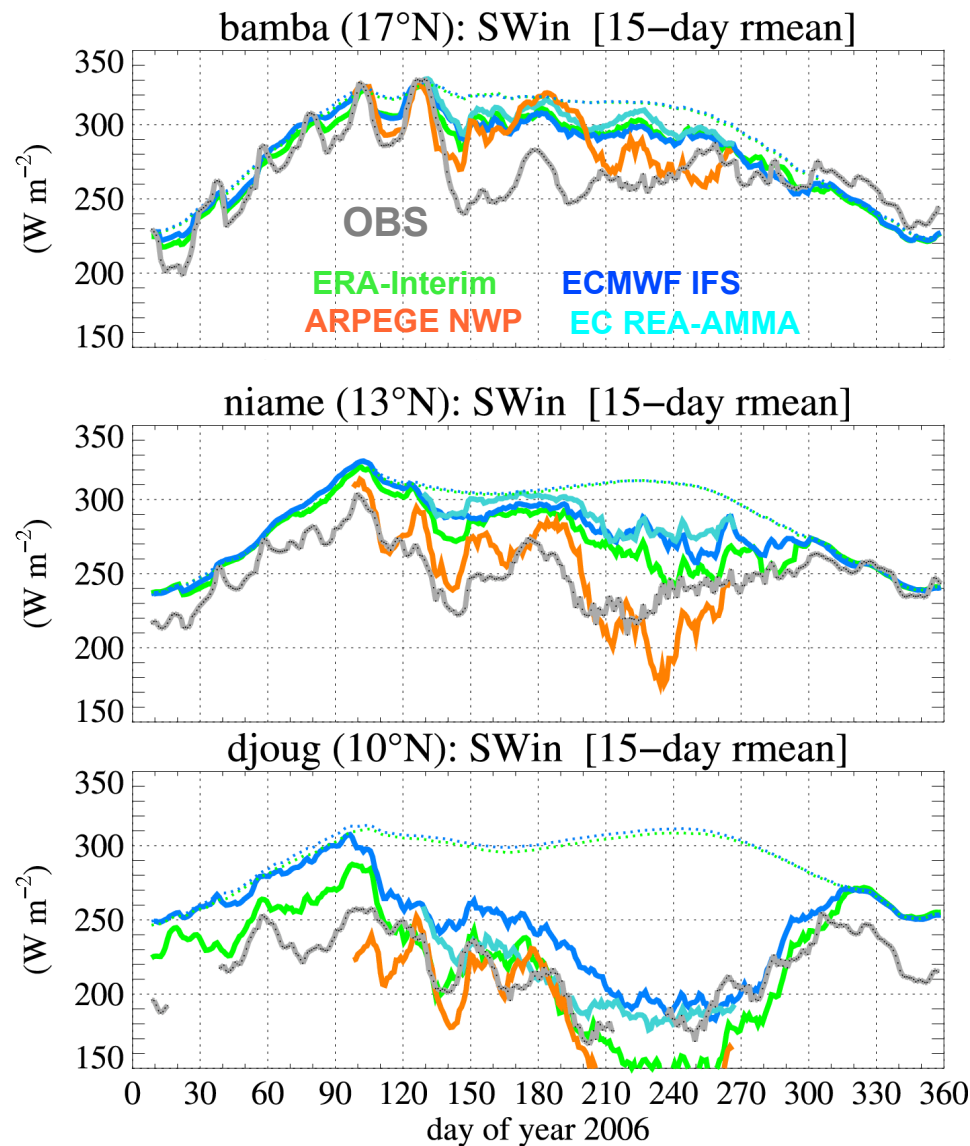
Interannual variability of surface albedo in Spring in MPI: spectral response with a role of aerosols again? (would be consistent with observations, Samain et al. 2008)

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?



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