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

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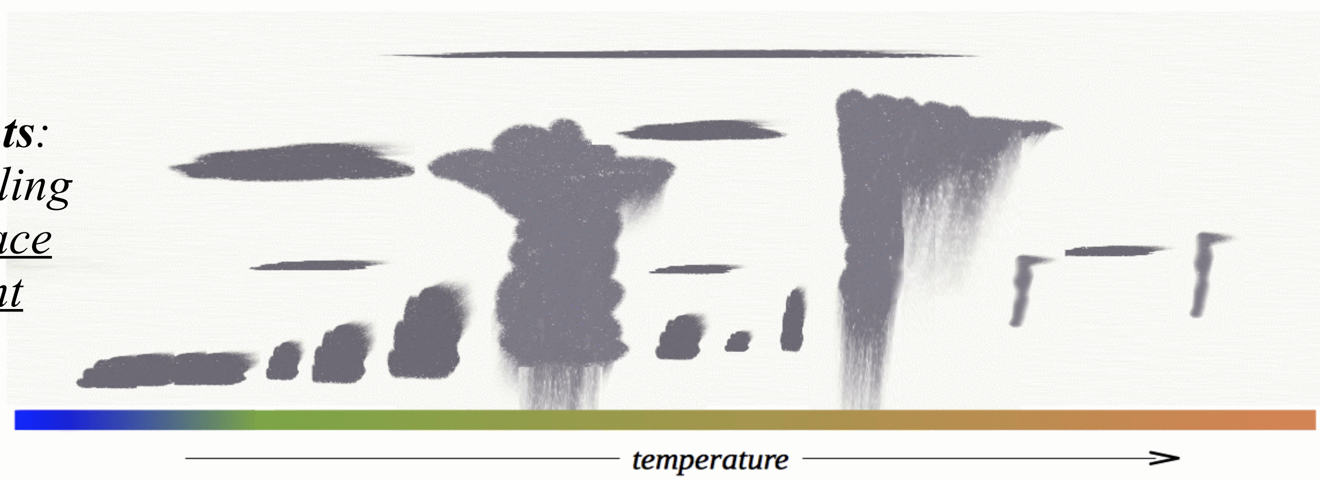
Thanks to H. Douville, F. Favot, S. Tyteca, A. Voldoire & CMIP5

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* *<u>surface temperature gradient over land</u>*



- 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, Δt ~ 30 min

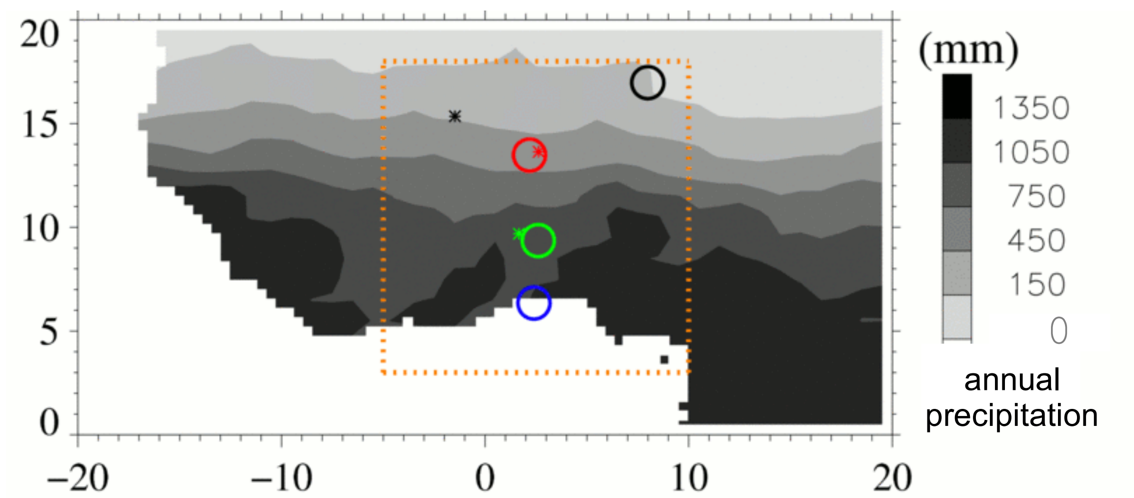
- ARM Mobile Facility of Niamey [used by Bouniol et al. (2012) for clouds]

- Thousands of high-resolution soundings (Δt = 3 h, 6 h, 12 h or more) [Parker et al. 2008] - a wide variety of boundary layers in space and time

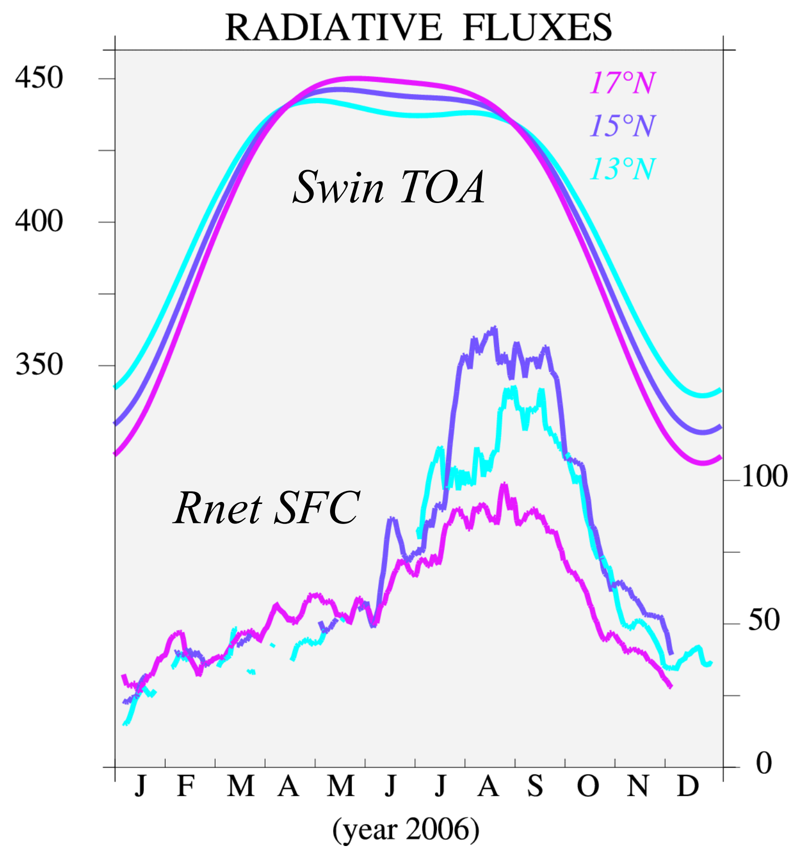
- Precipitable water (GPS, Δt = 1h) [Bock et al. 2008]

- SYNOP data (Δt = 3h to daily)
- low-resolution GTS soundings

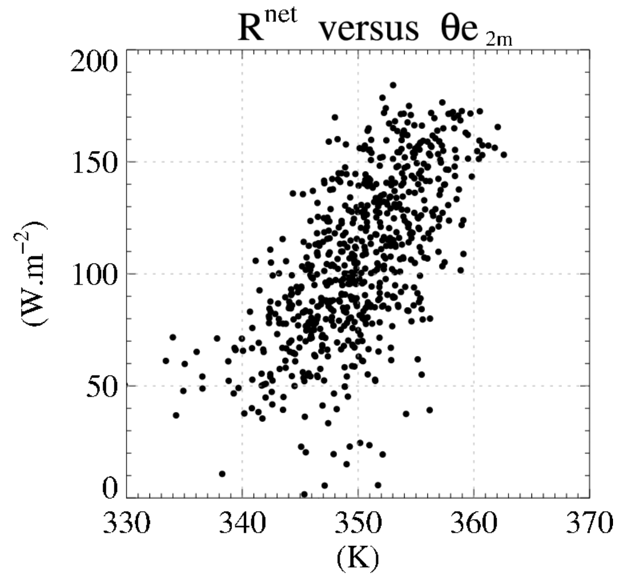
....



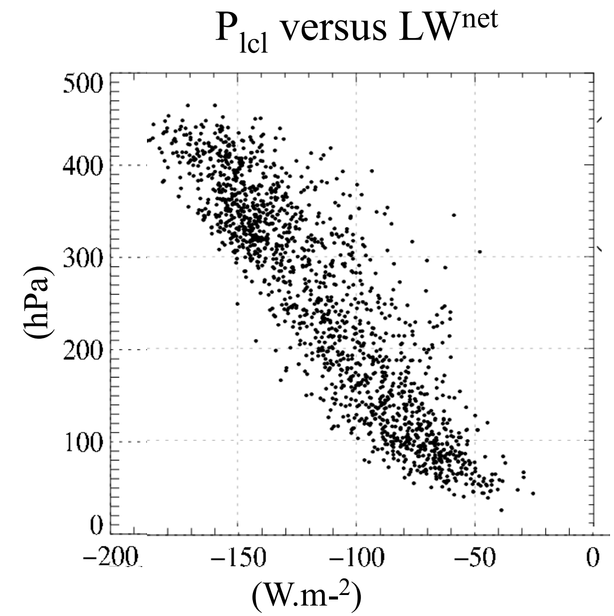
Surface energy budget: specificities of the Sahel



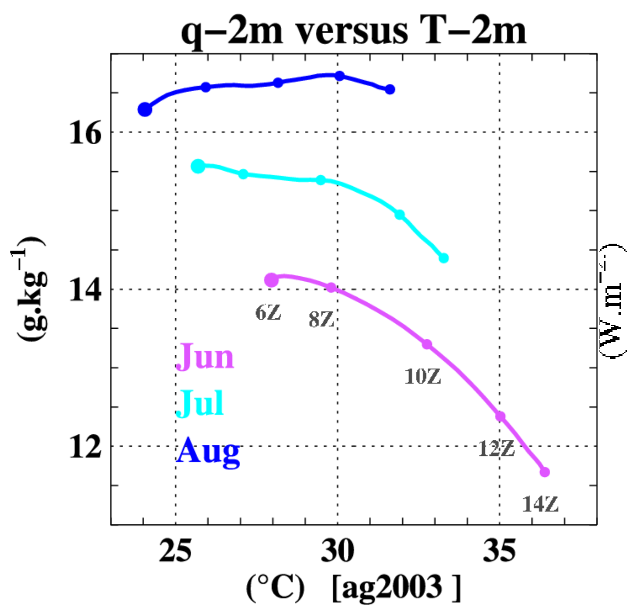
JJAS, daily values



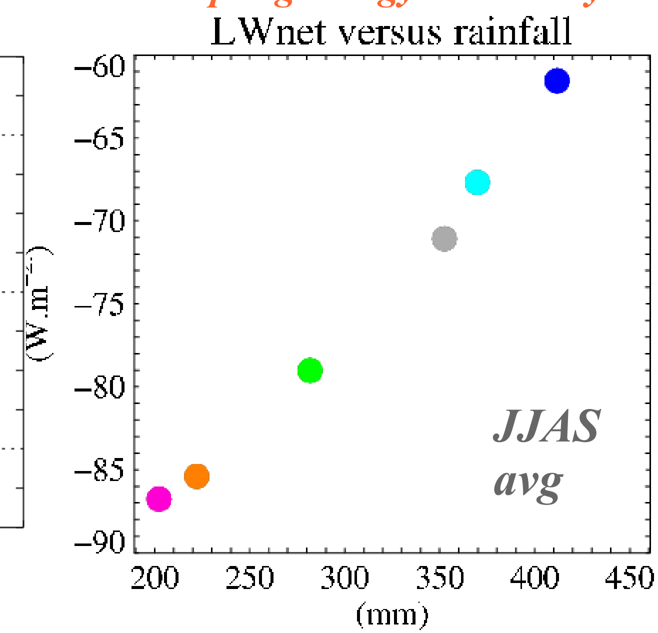
All year, daily values



BL depth & diurnal cycle



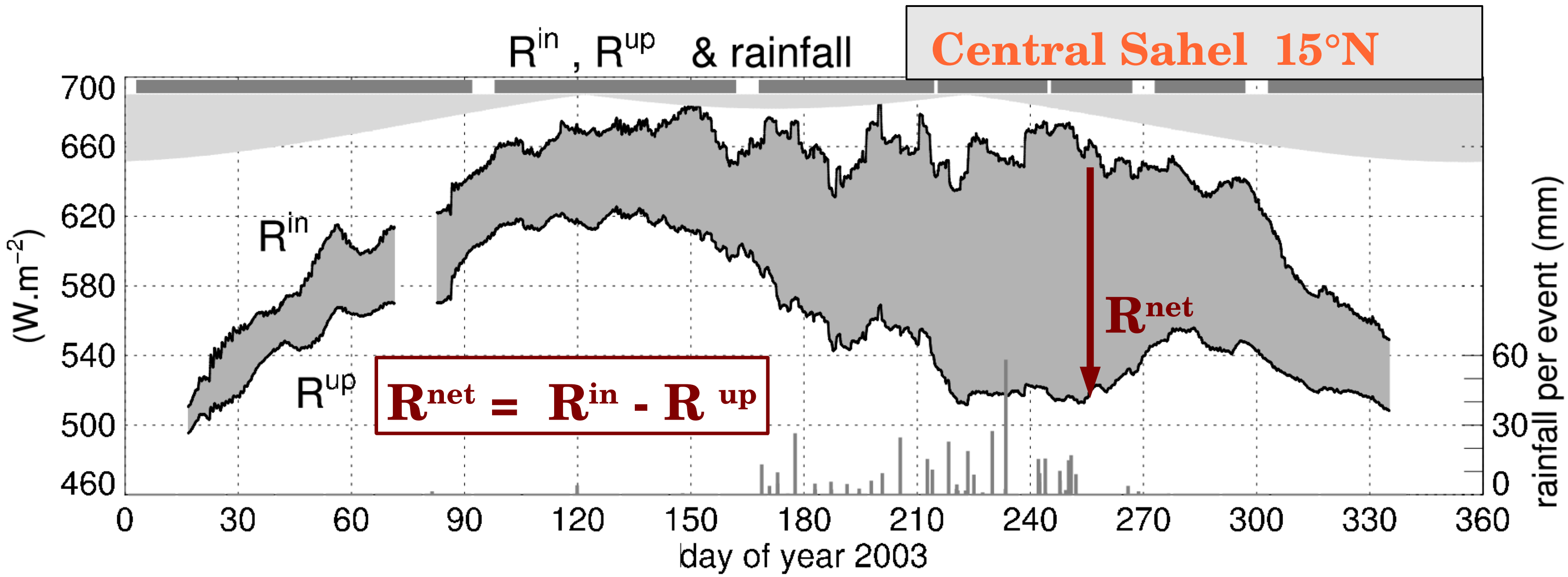
Interannual variability
coupling energy & water cycle



Guichard et al. (2009,2012)

From May 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)

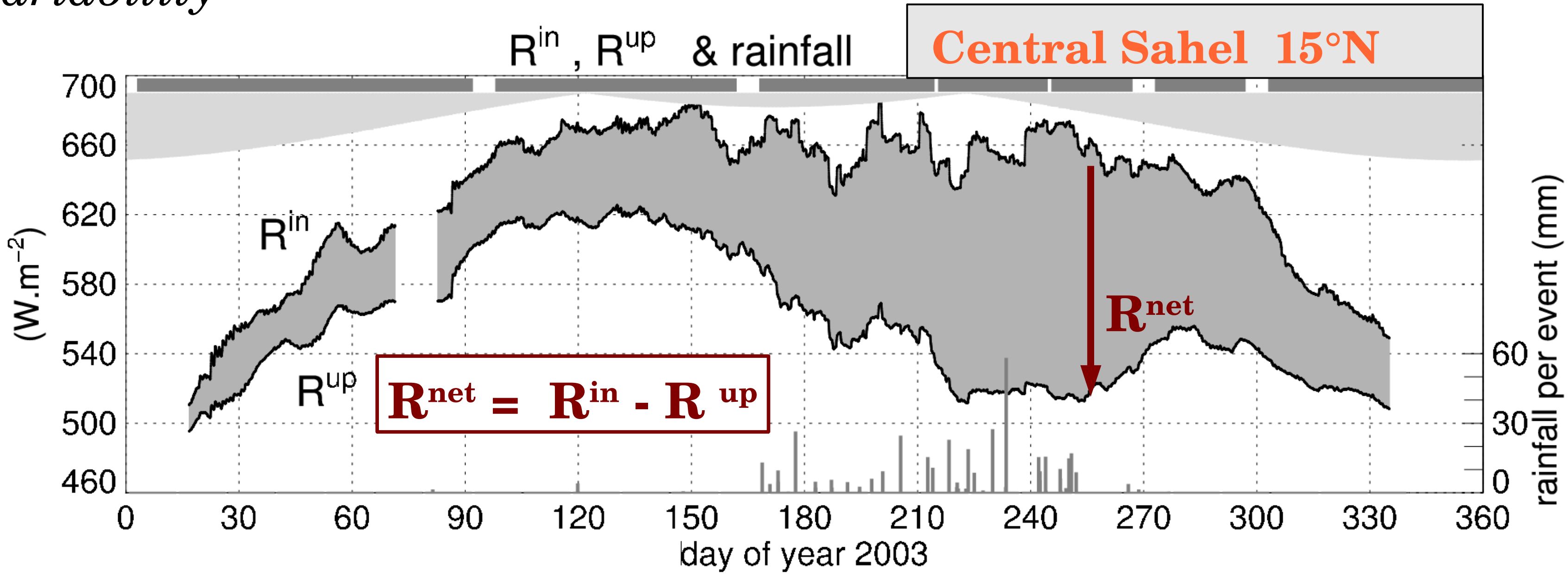
surface cooling

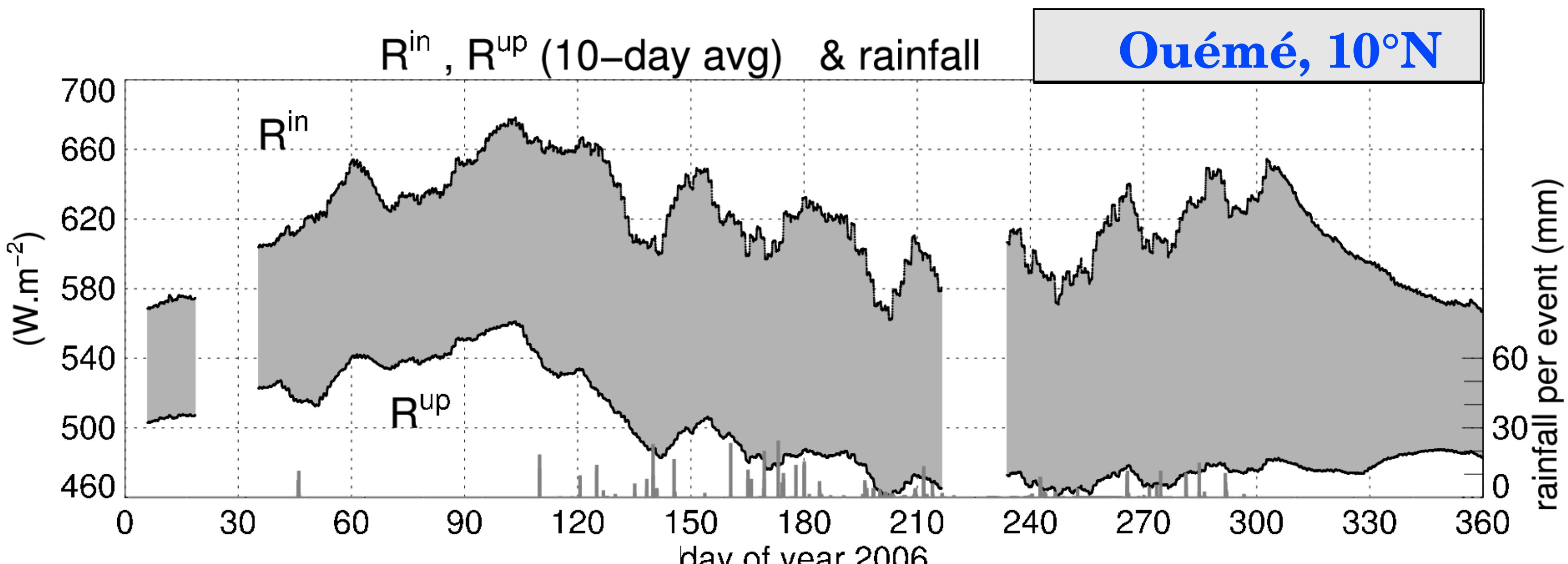
surface albedo (vegetation, Samain et al. JGR 2008)

(consistent with 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



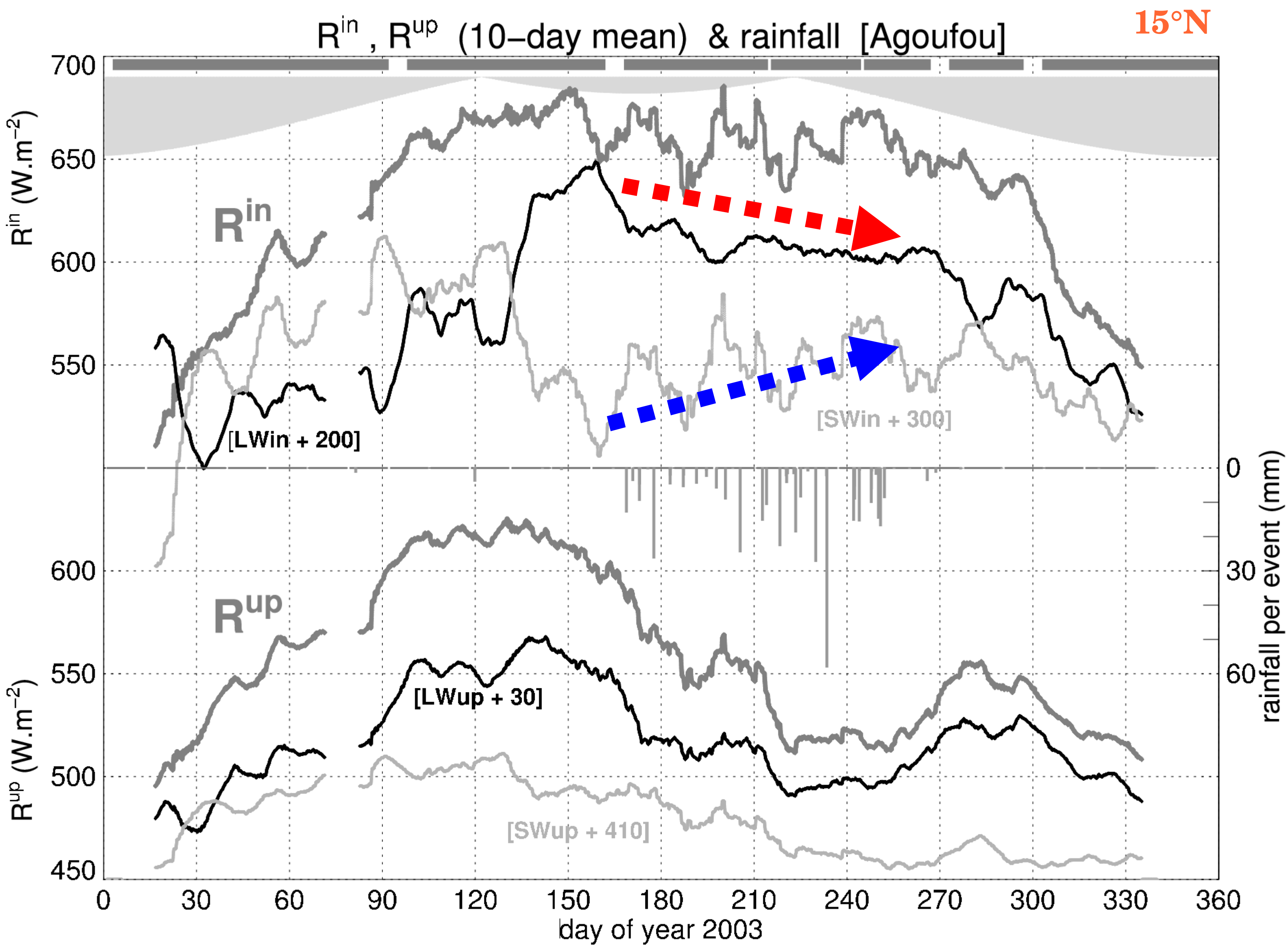


* Rin, Rup more strongly coupled at this scale

* significance of cloud SW radiative forcing

seasonal cycle of surface radiative fluxes

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

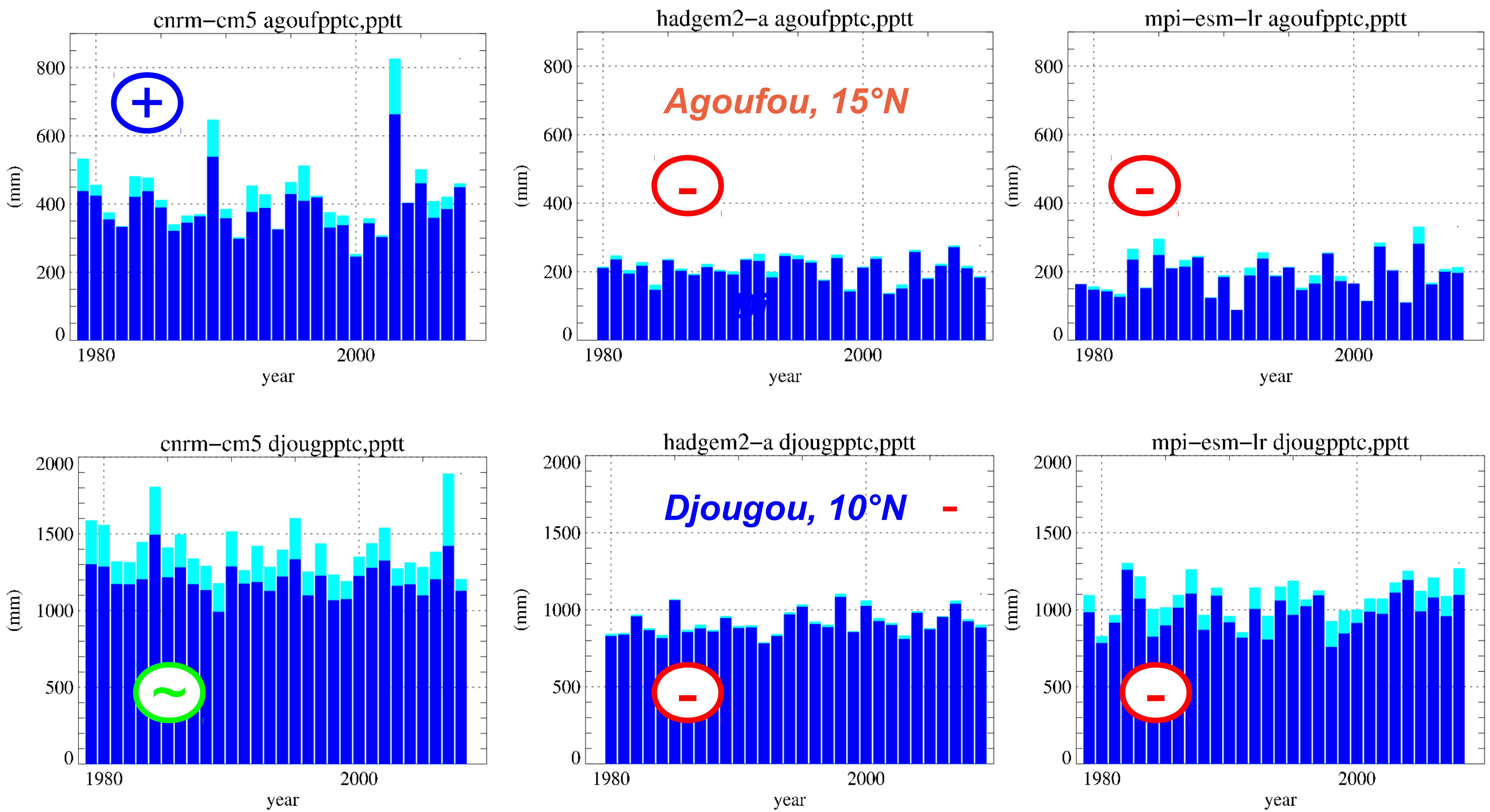


A preliminary broad overview of the cfSites outputs, AMIP runs

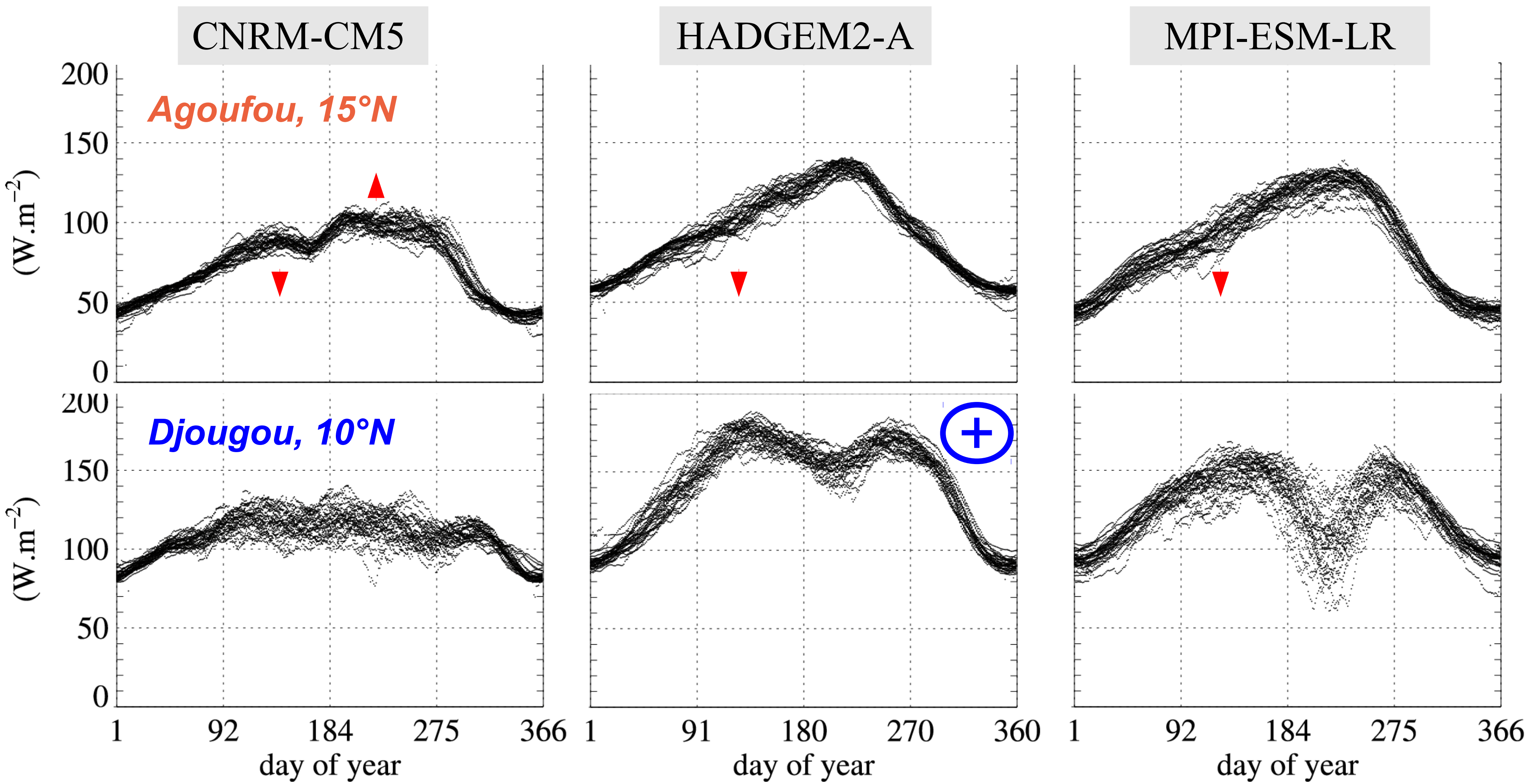
2 points: 10°N et 15°N

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

Annual precipitation



Rnet sfc , 31-day running mean

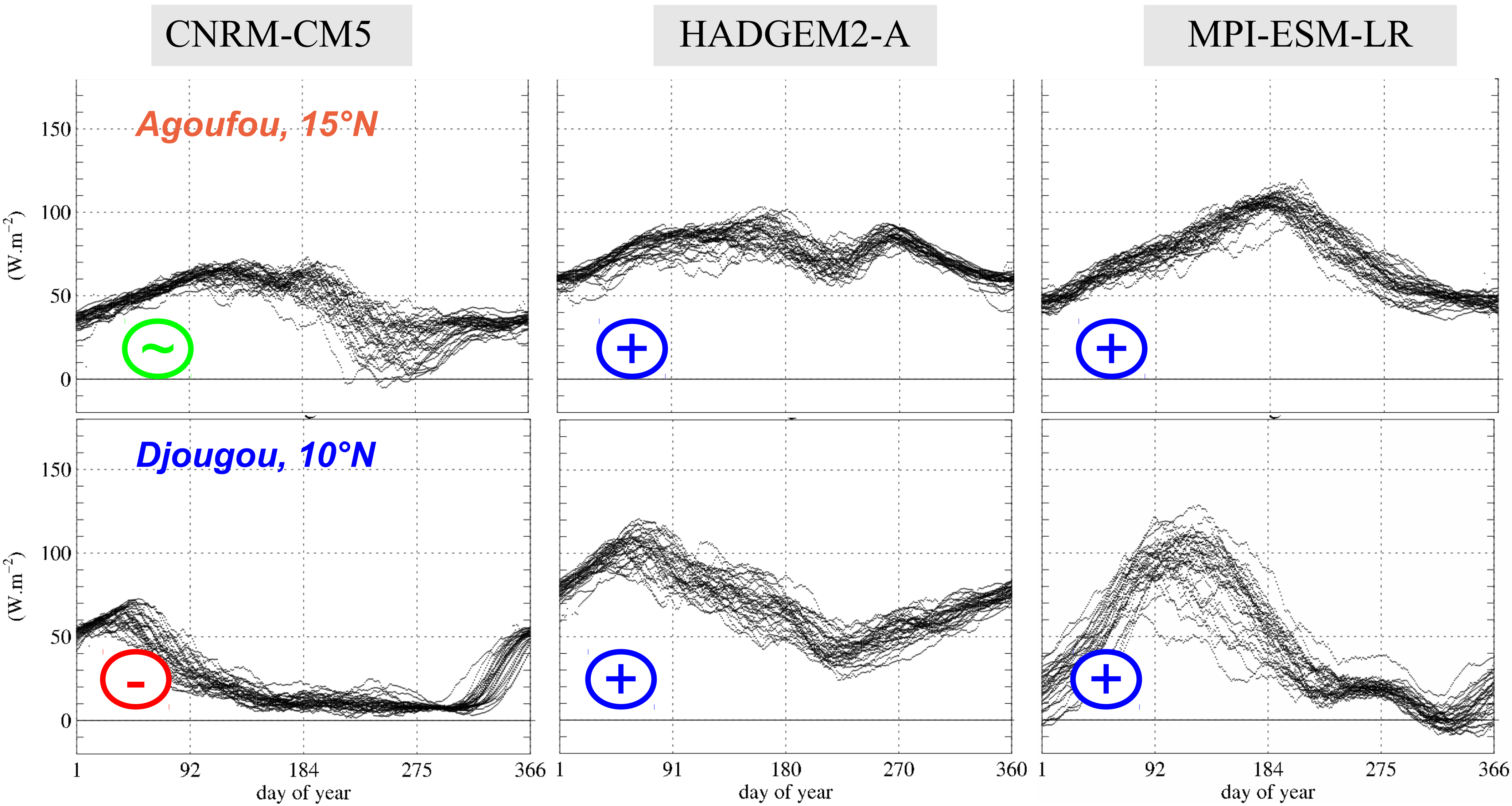


15°N: a common tendency to overestimate Rnet in Spring (consistent with Traore 2011)

Stronger Rnet for models with lower rainfall, the opposite in observations

Translates into errors in H and LE

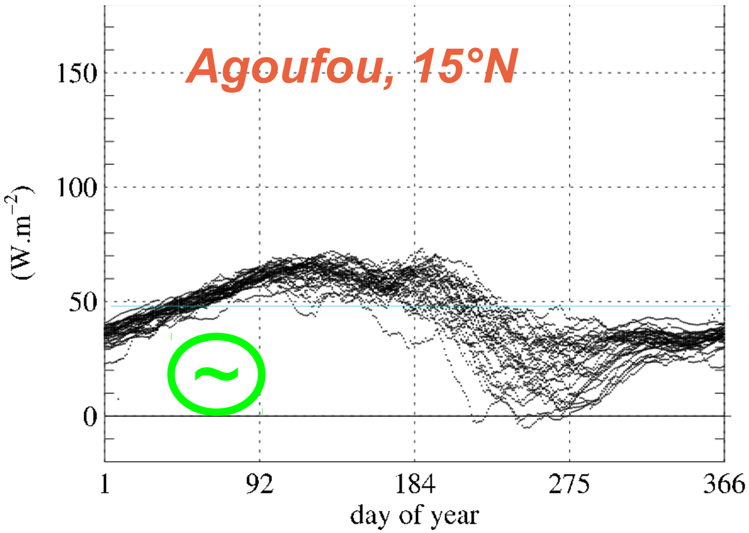
Surface sensible heat flux H , 31-day running mean



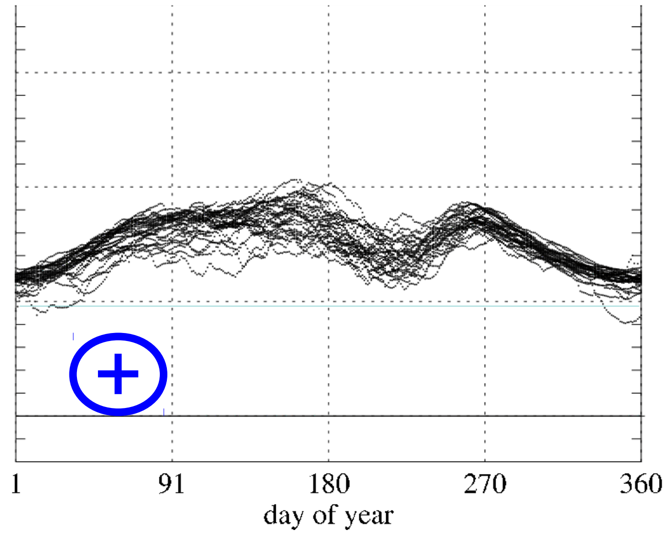
large differences among models, dominate over interannual differences

Surface sensible heat flux H , 31-day running mean

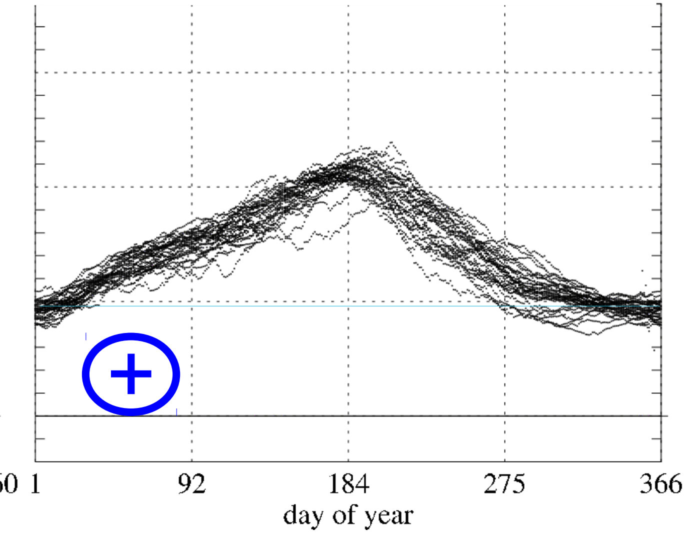
CNRM-CM5



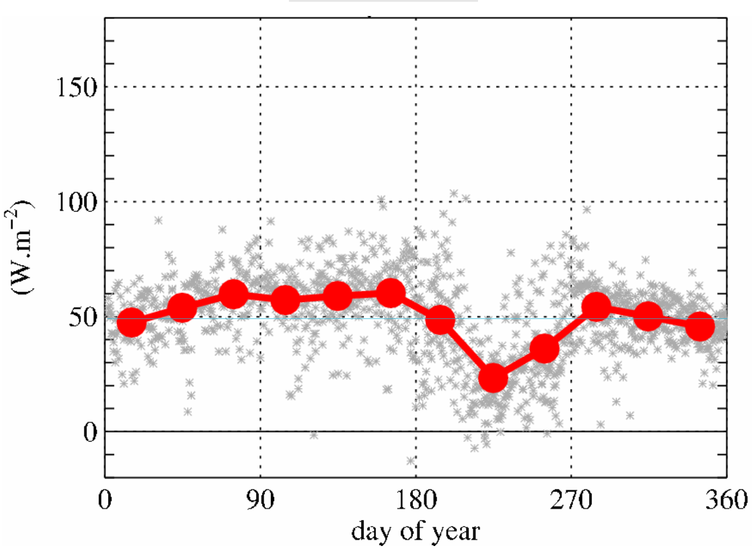
HADGEM2-A



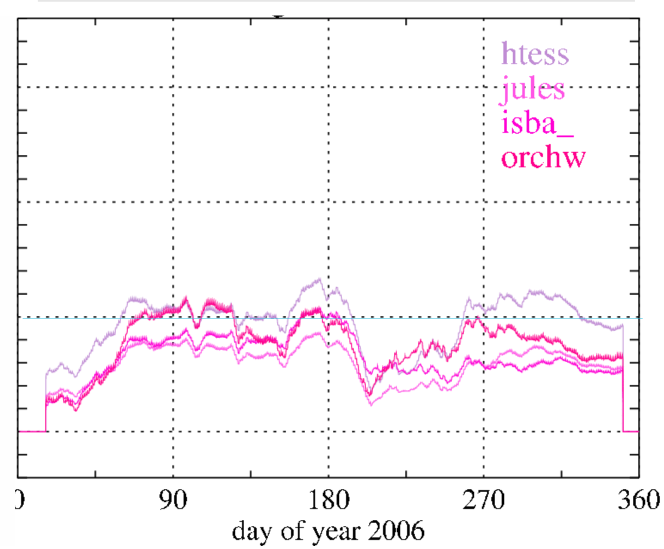
MPI-ESM-LR



DATA



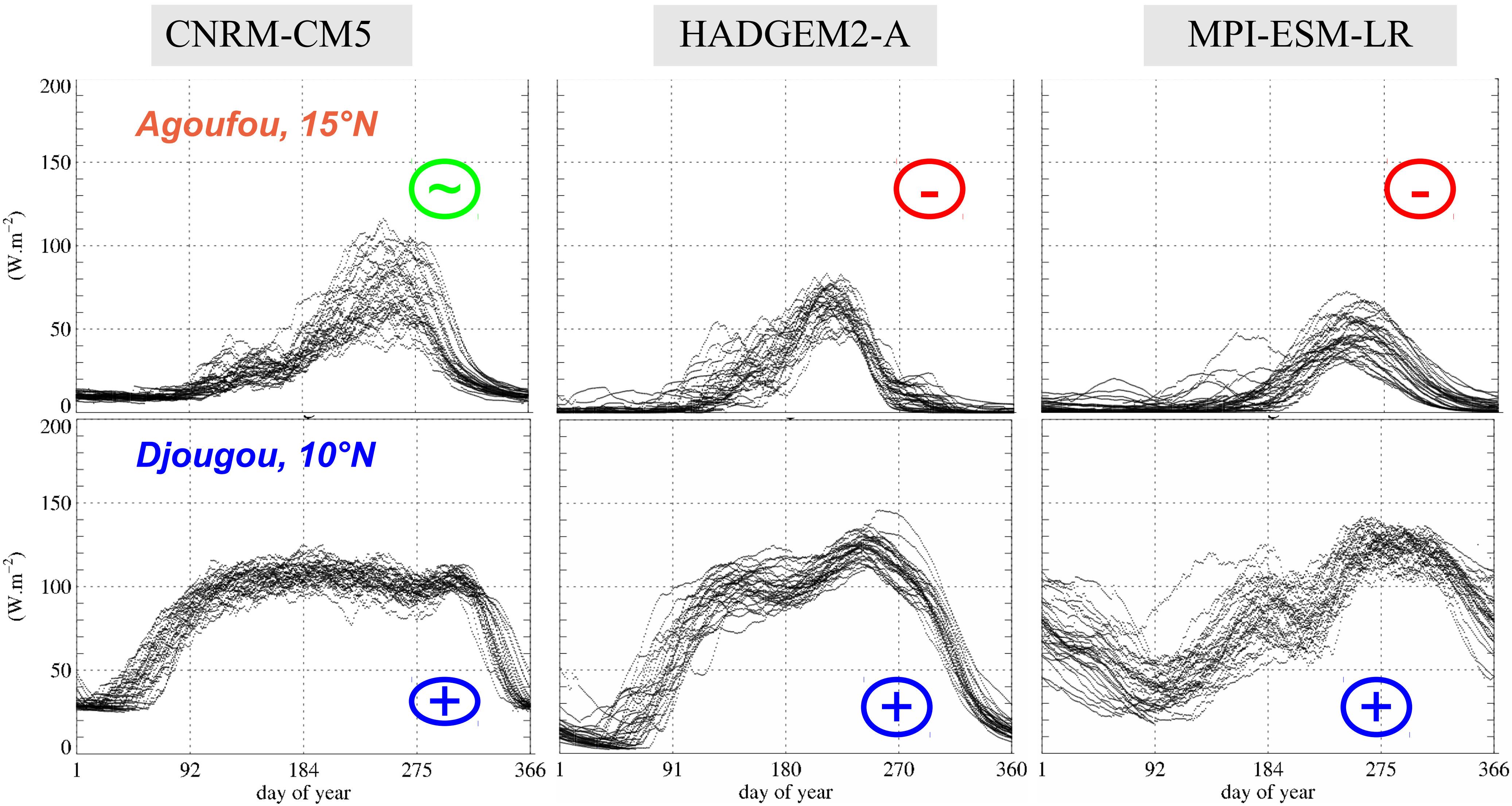
LSM modelling (ALMIP)



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

explain some of the differences, not all

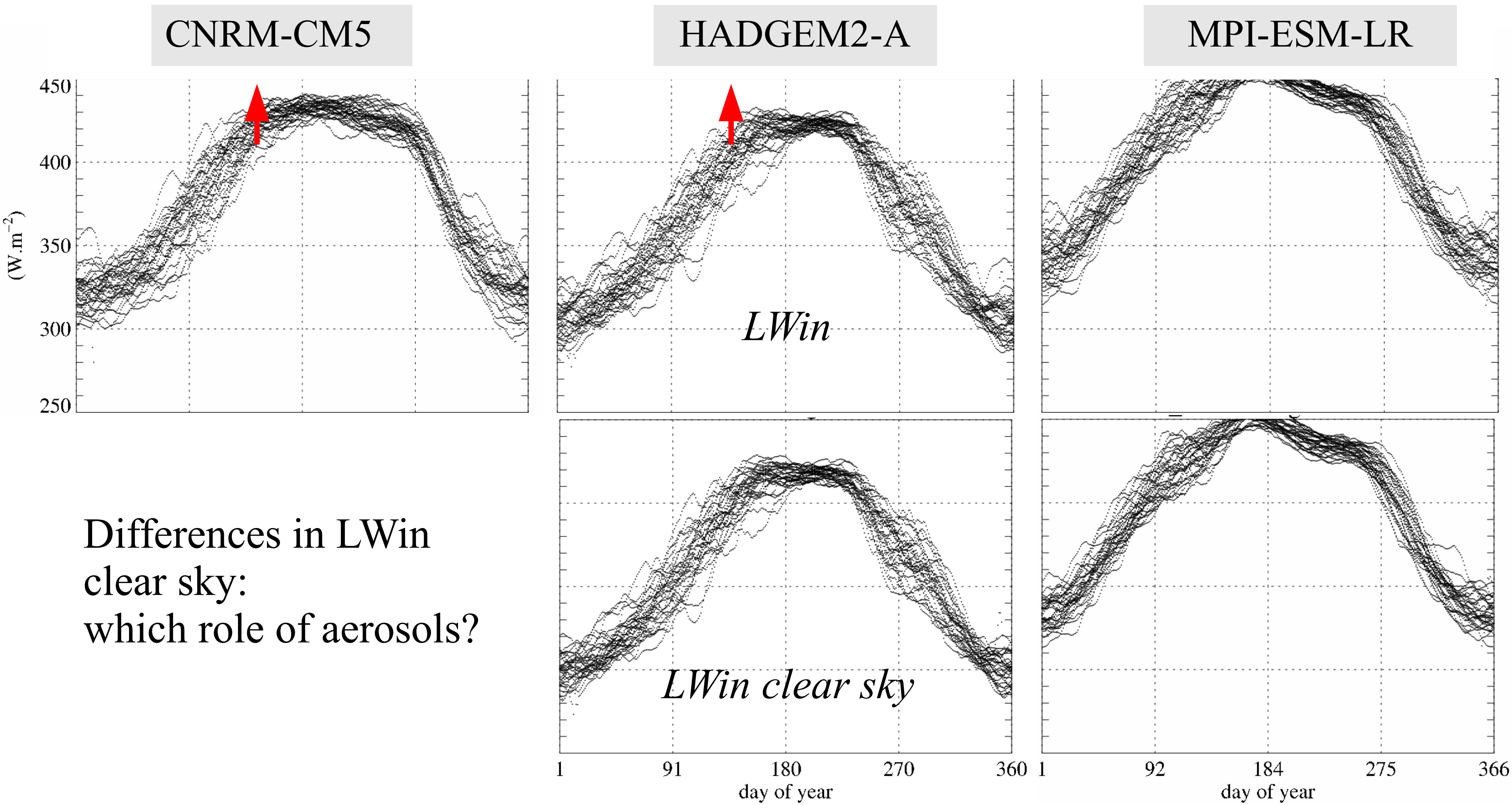
Surface latent heat flux LE , 31-day running mean



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)*

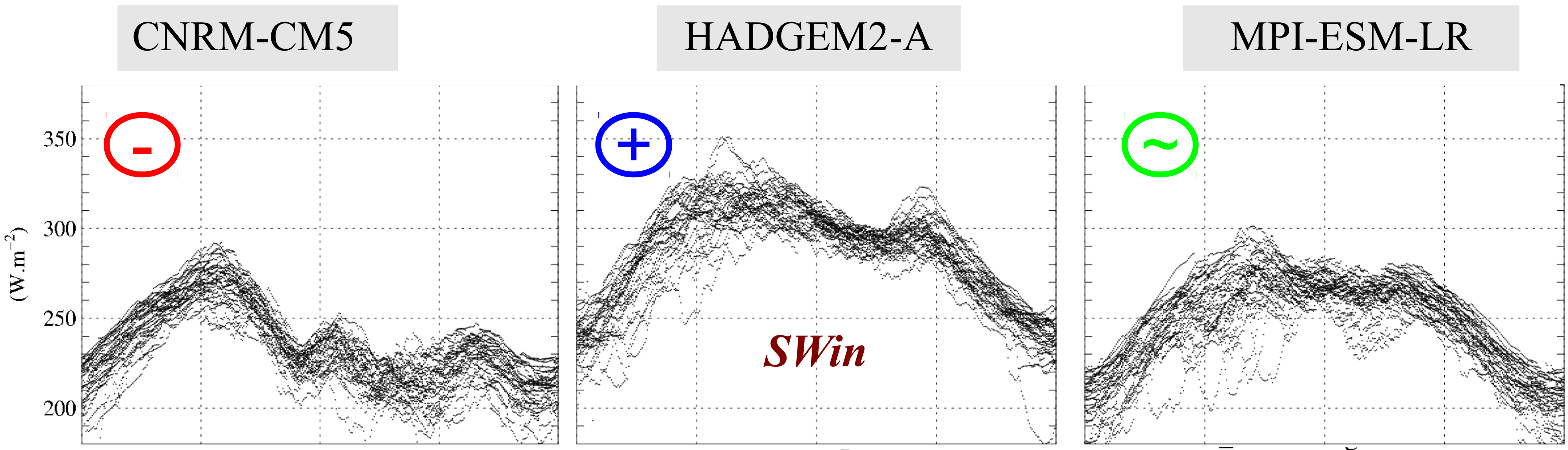
LWin , 31-day running mean

Agoufou, 15°N



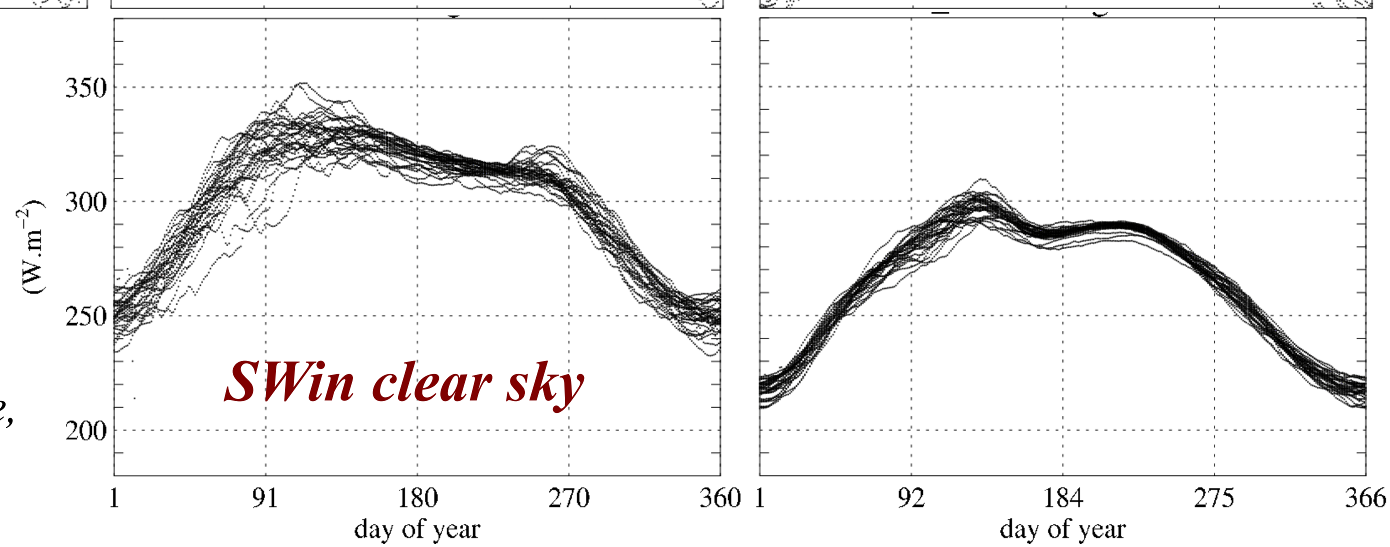
Differences in LWin clear sky:
which role of aerosols?

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



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

Reanalyses are not error free, nor satellite products either!

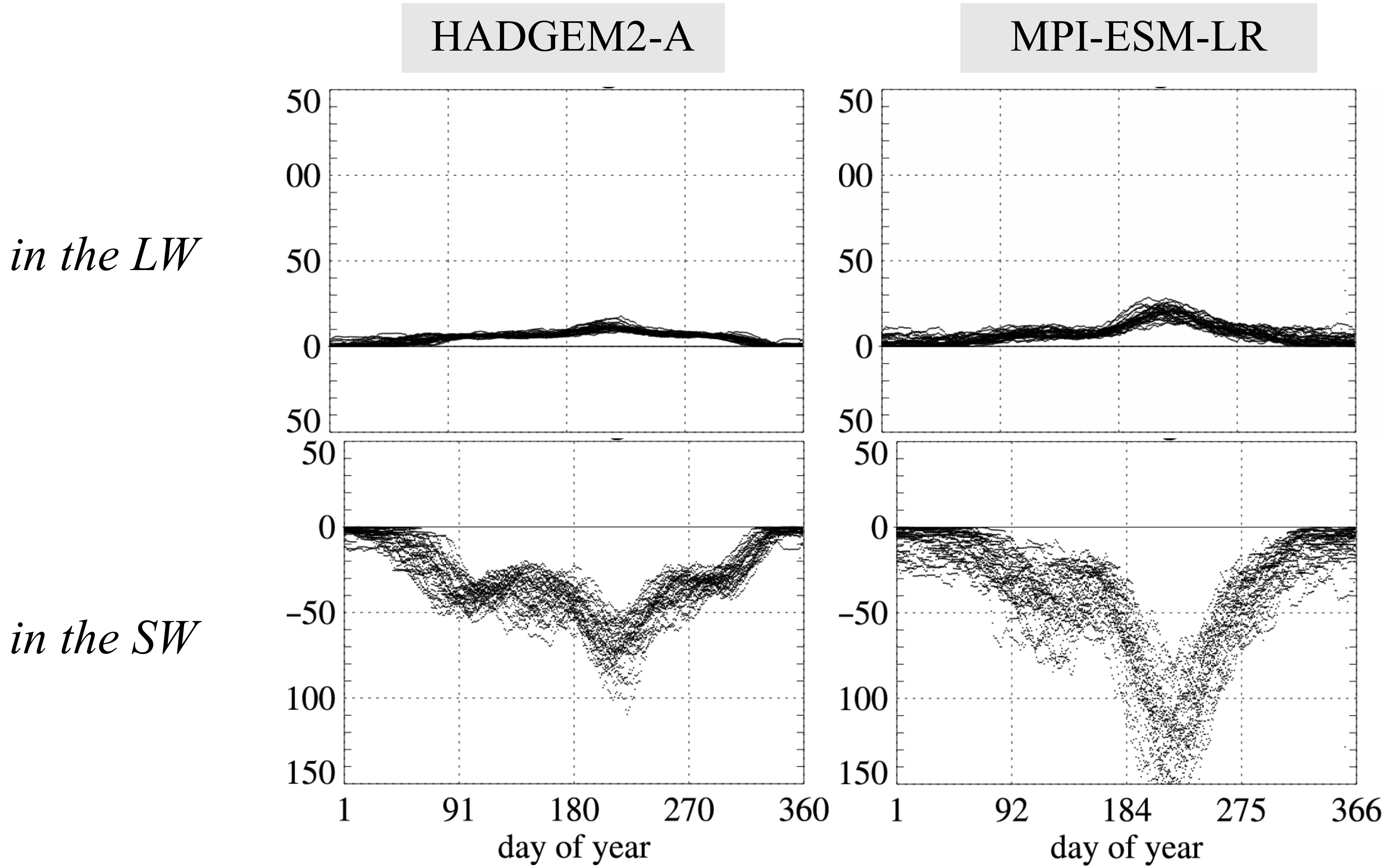


Differences in SWin clear sky: impact of T & q structures, a role for aerosols?

interest of 1D radiative transfert model for further investigation (O. Geoffroy Poster)

Djougou, 10°N

Cloud radiative forcing



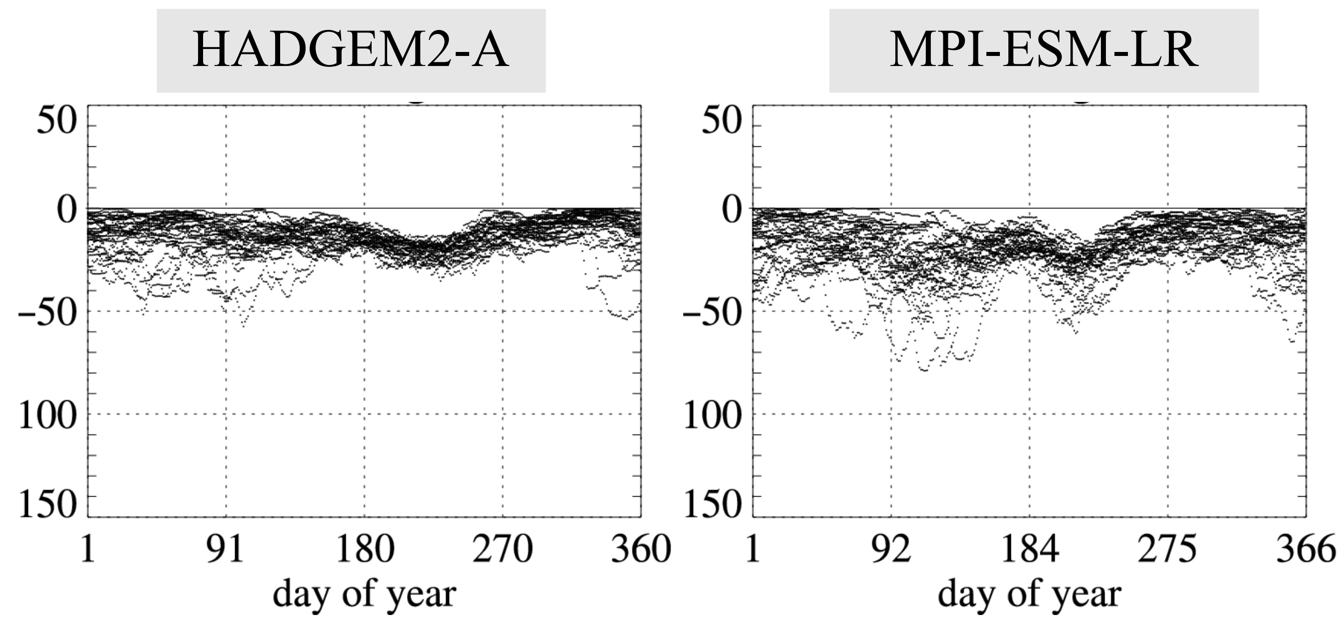
SW cloud forcing dominates (distinct behaviour compared to TOA)

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

Cloud radiative forcing

Agoufou, 15°N

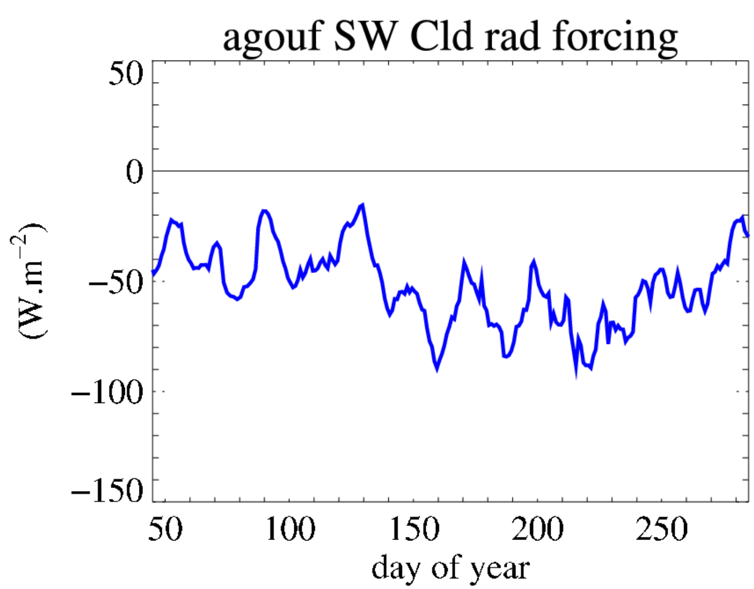
in the SW

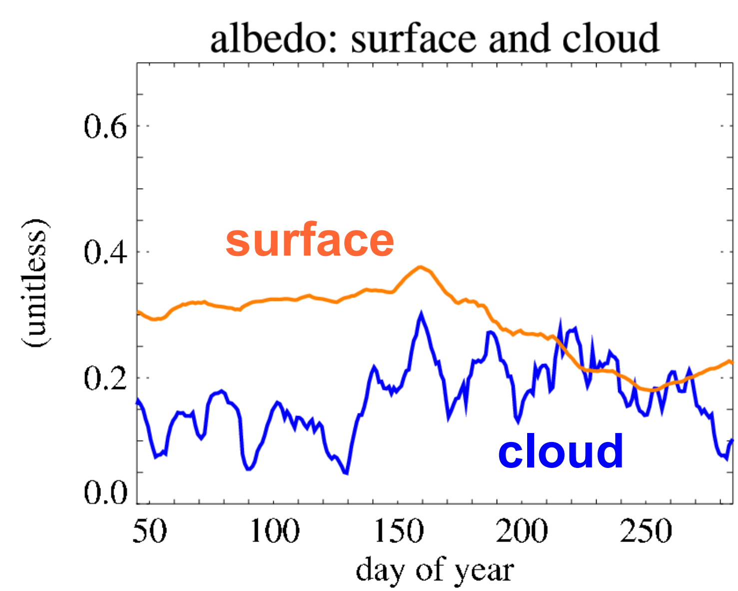


SWnet = (1 – a_sfc) Swin

(1 – a_sfc) (1 – a_cld) SWin_clear_sky

Data
very rough
estimation

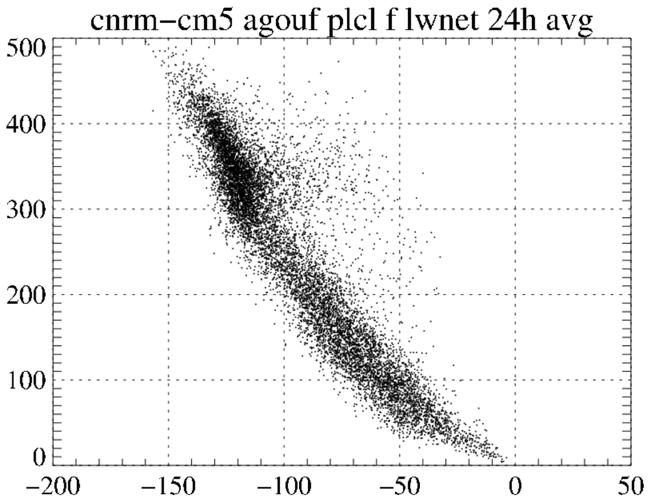




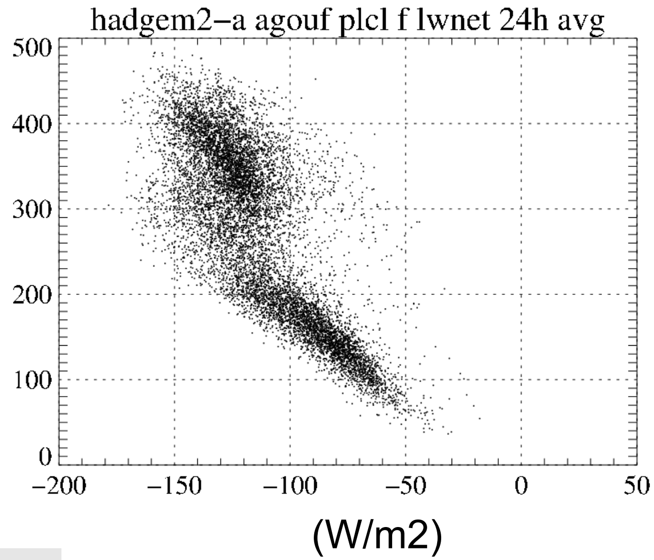
couplings LWnet, Plcl (~ RH)

15°N

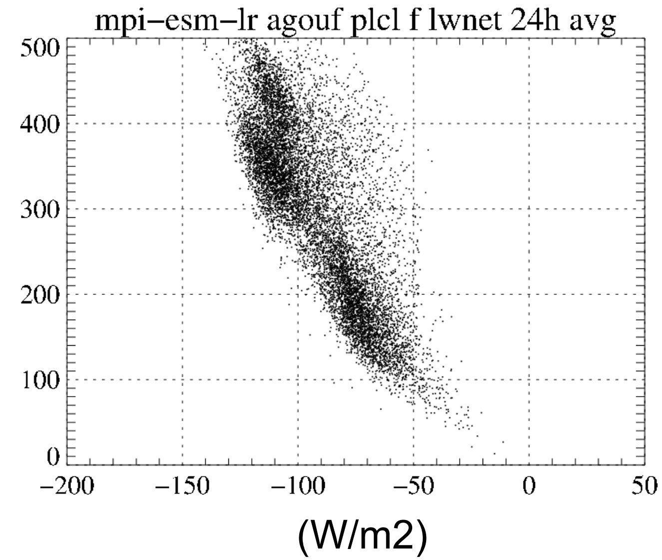
CNRM-CM5



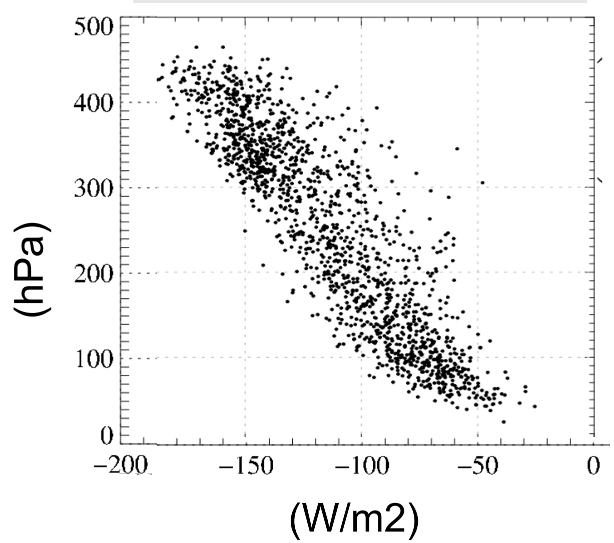
HADGEM2-A



MPI-ESM-LR



OBSERVATIONS

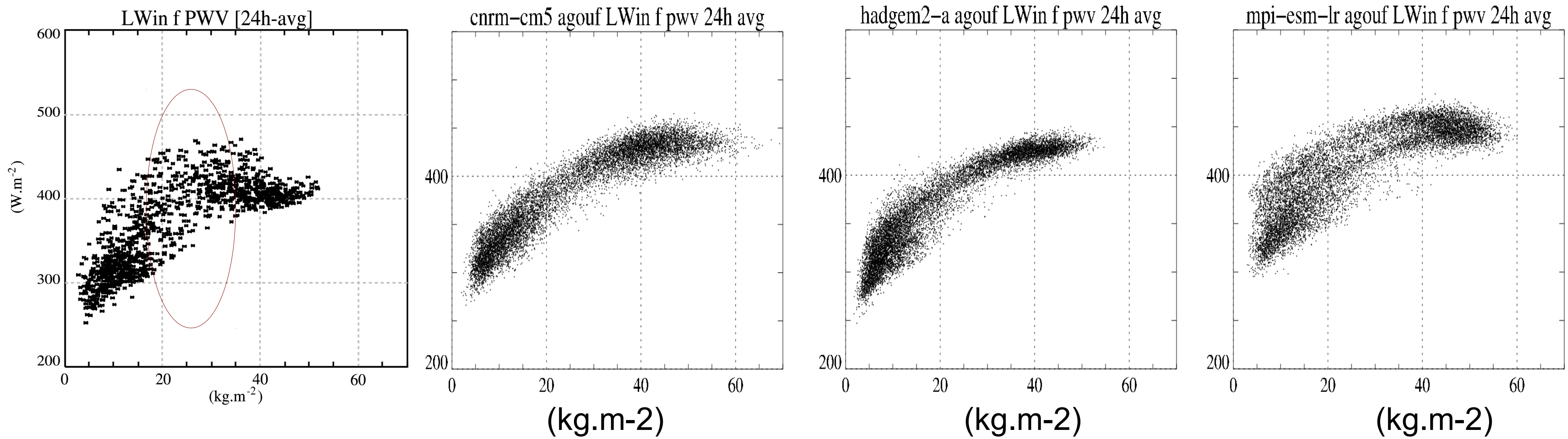


Need to understand better the cloud-related sources of differences

Link between Plcl and actual cloud base

Couplings LWin, precipitable water (PWV)

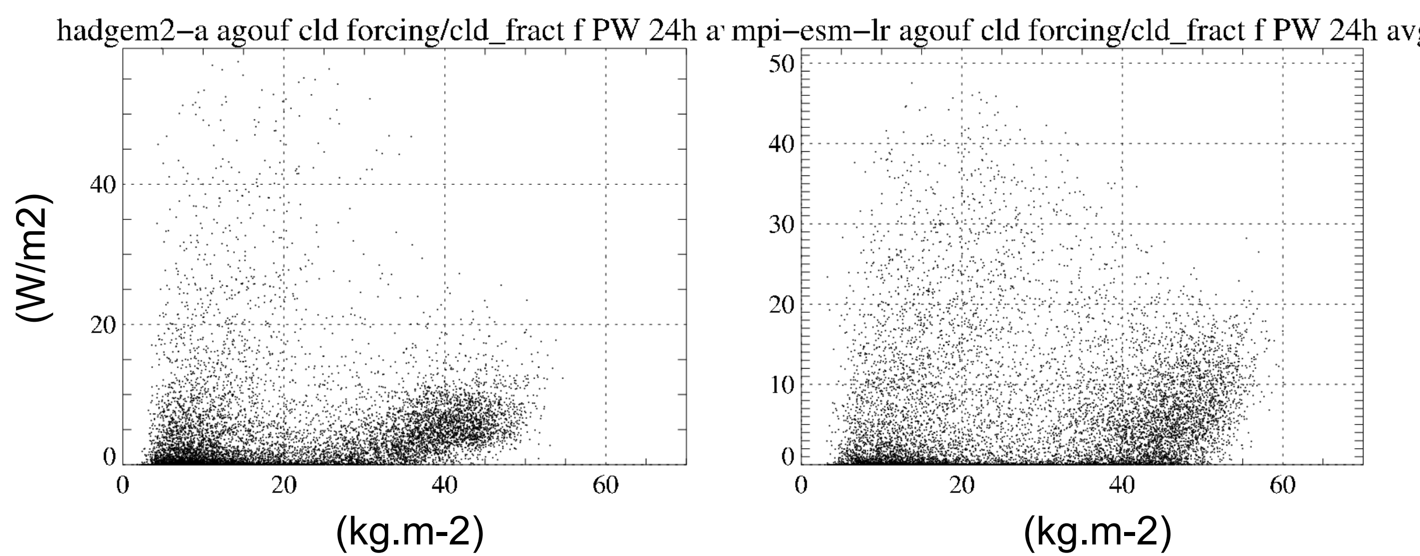
DATA	CNRM-CM5	HADGEM2-A	MPI-ESM-LR



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

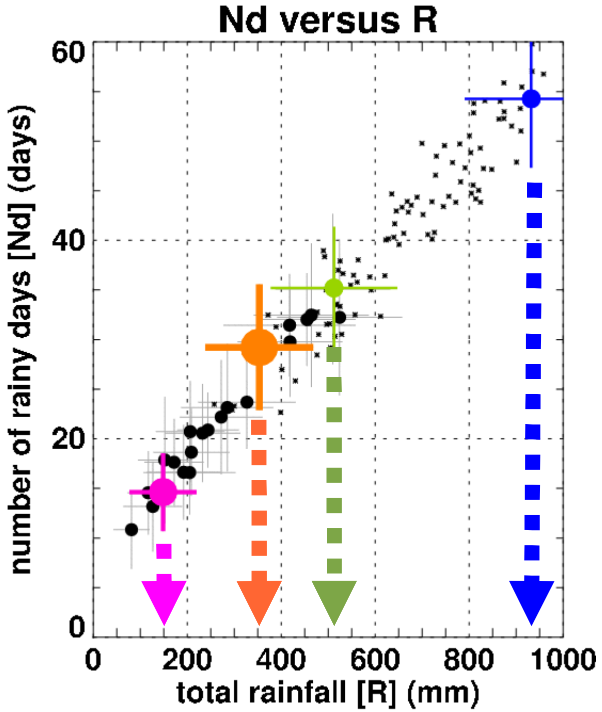
THE MEASUREMENT SITES AMMA-CATCH

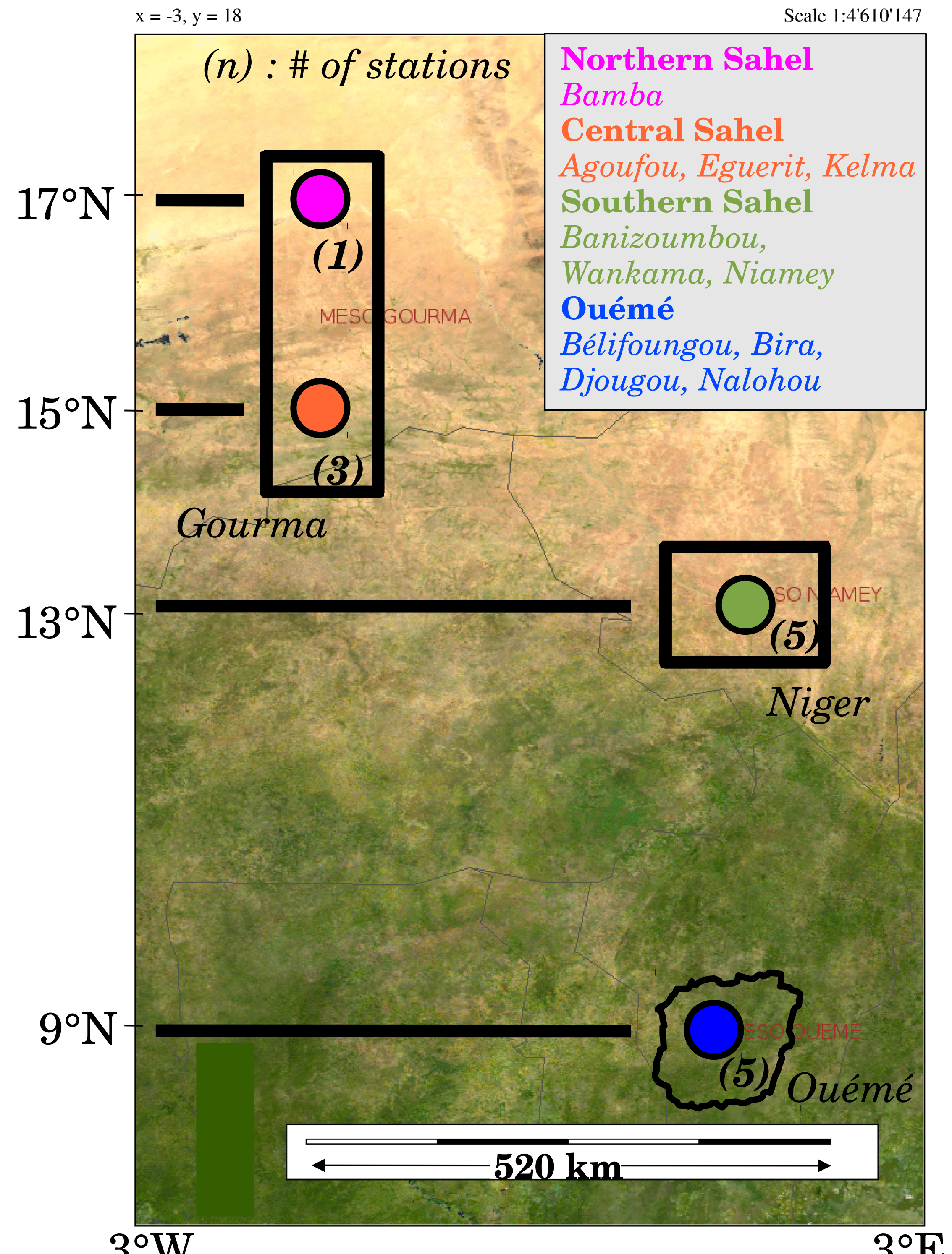
Located along a meridional climatological gradient

Over ≠ surface/vegetation types

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

PRECIPITATION





From AMMA-CATCH GIS web mapping

thermodynamic-radiative coupling during the monsoon

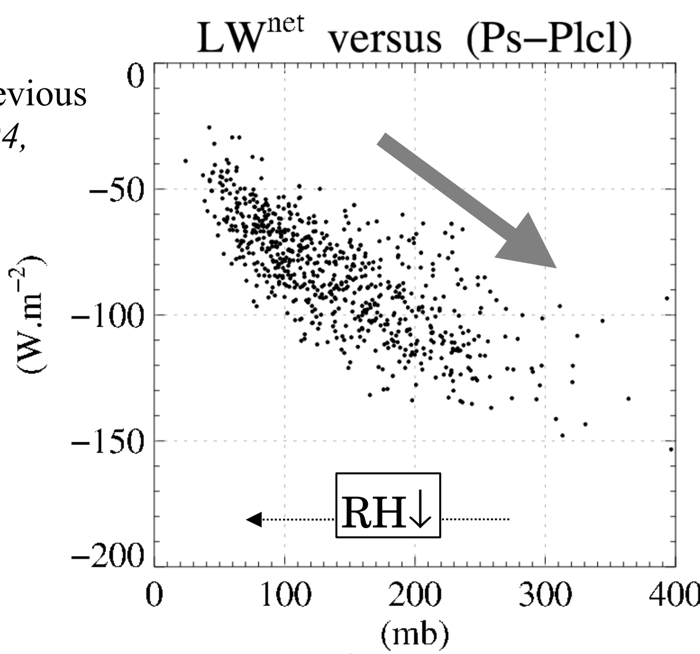
24-h mean values, JJAS 2002 to 2007, Central Sahel 15°N

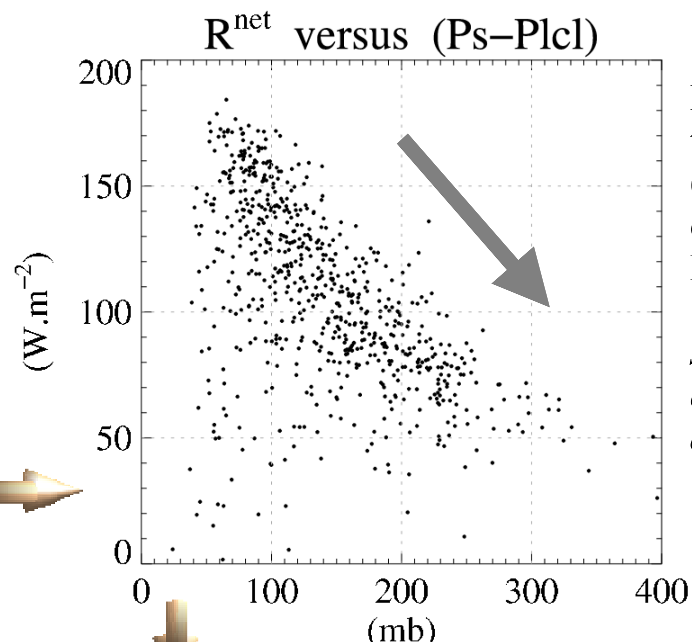
(1)

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

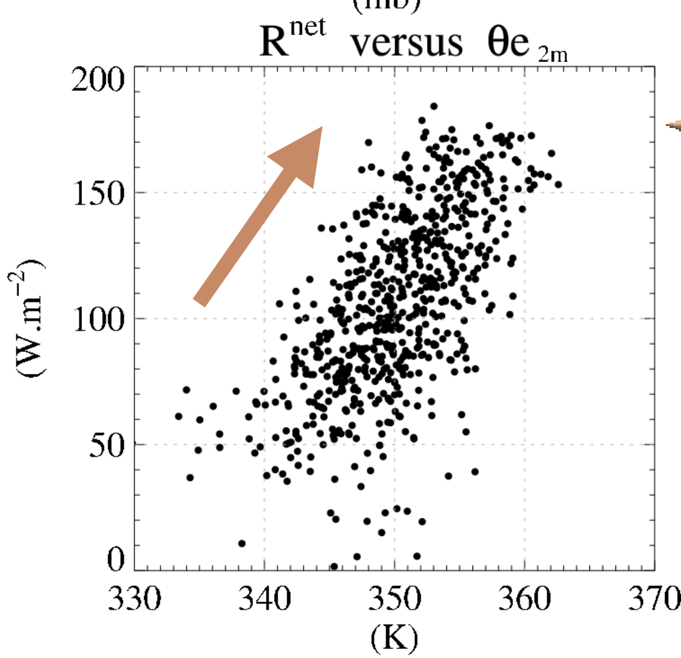
semi-arid region cloud impact does not dominate

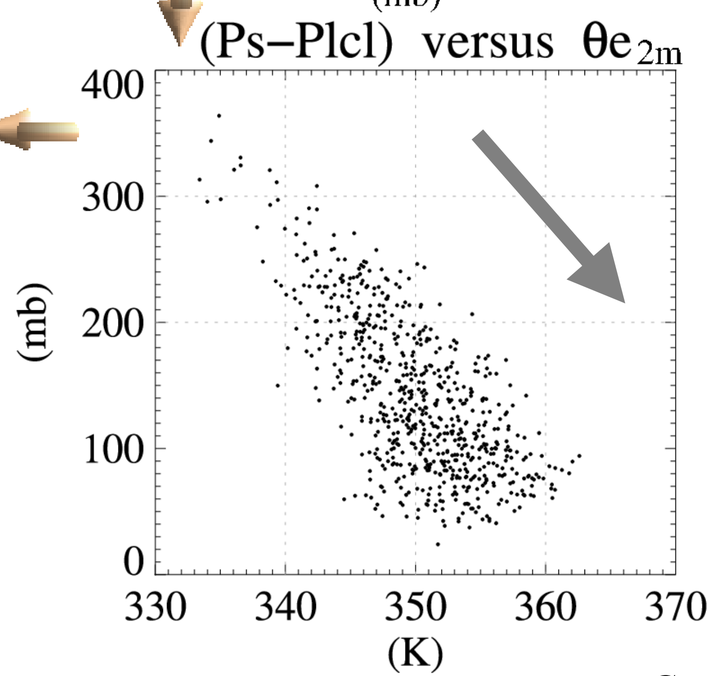
(4)

R^{net} and θe correl > 0

involves seasonal transformations

not well simulated



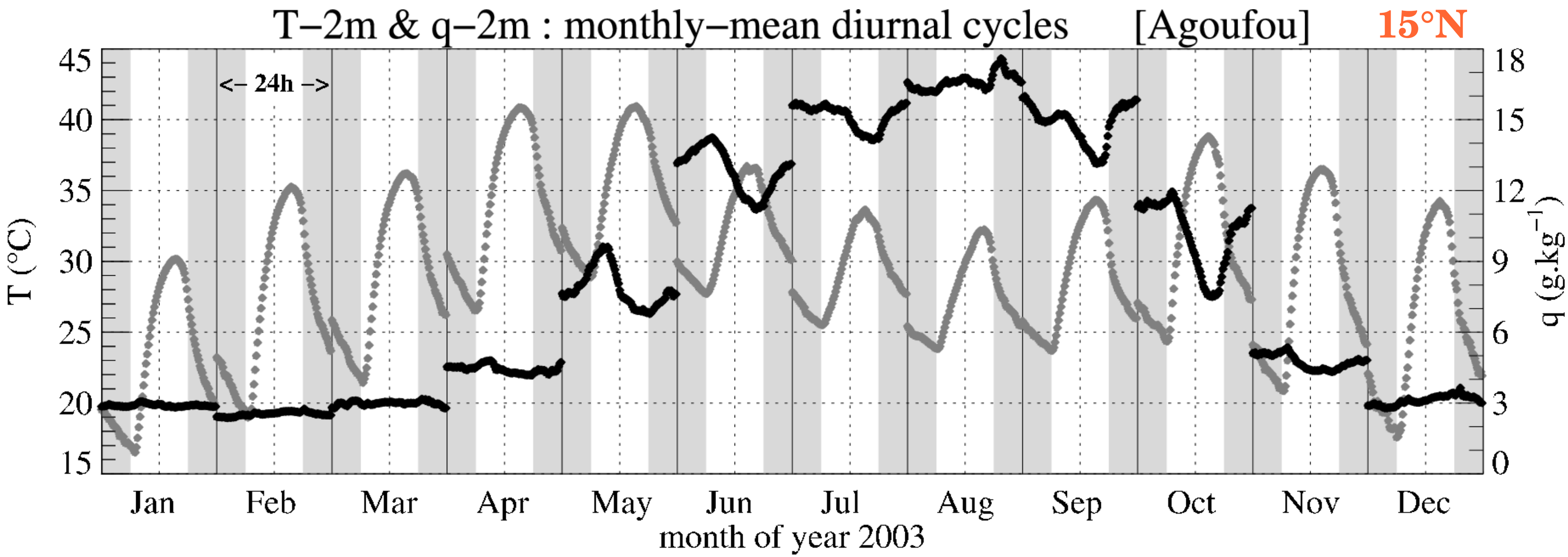


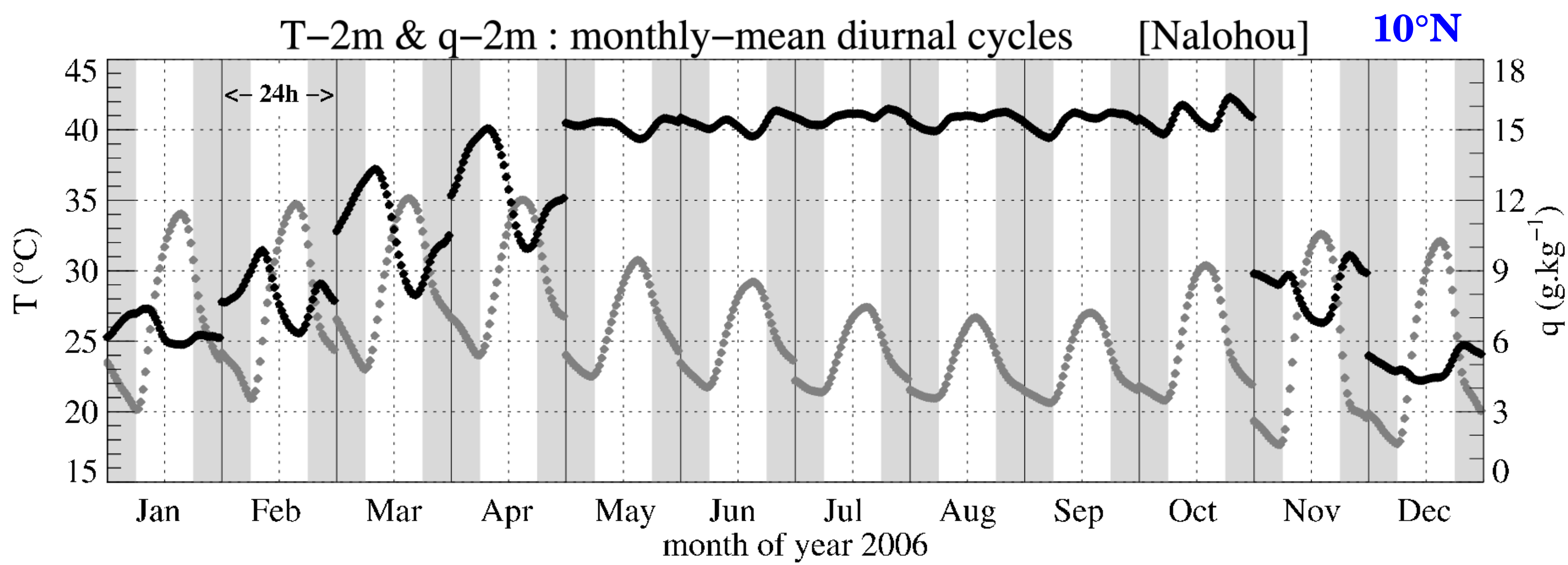
(3)

Increase of θe coupled to increase of Plcl, RH

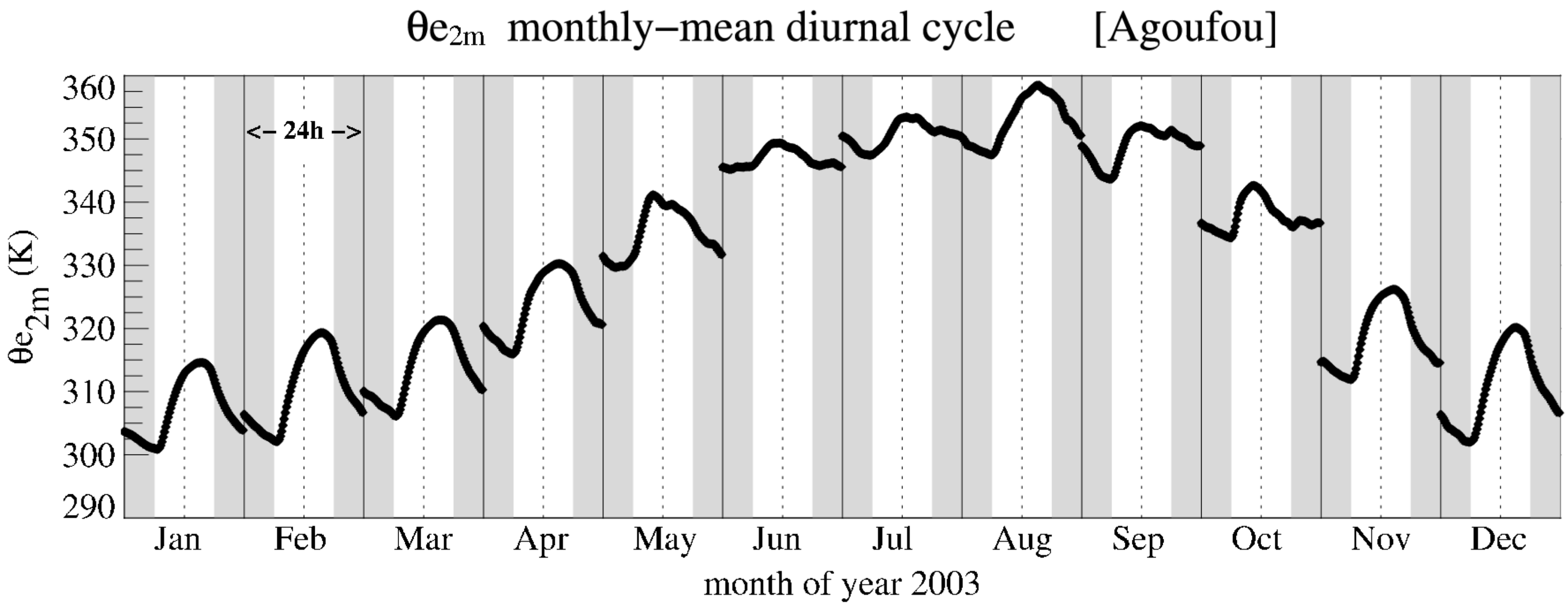
Guichard et al. (2009)

seasonal changes of the diurnal cycles



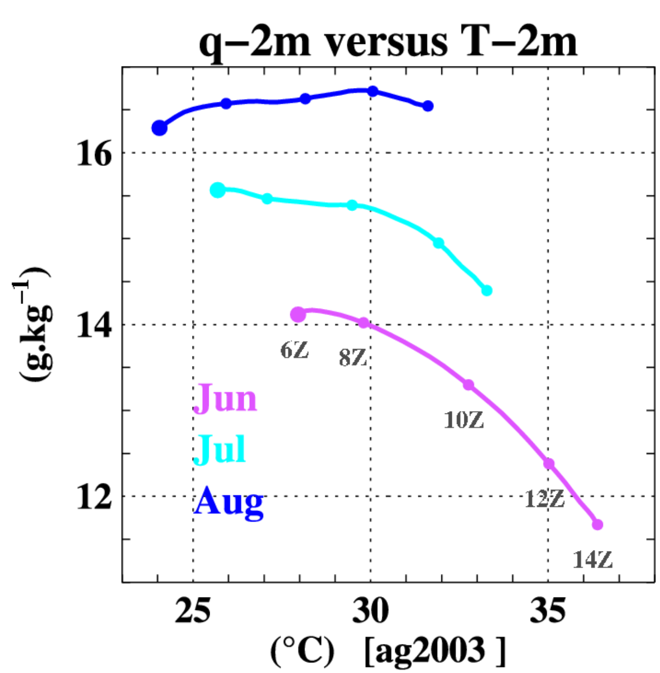


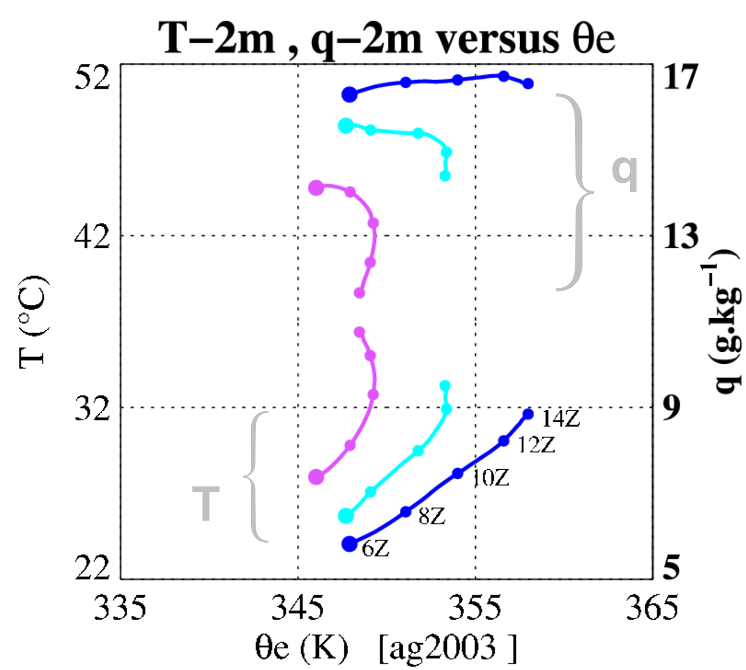
seasonal changes of the diurnal cycles



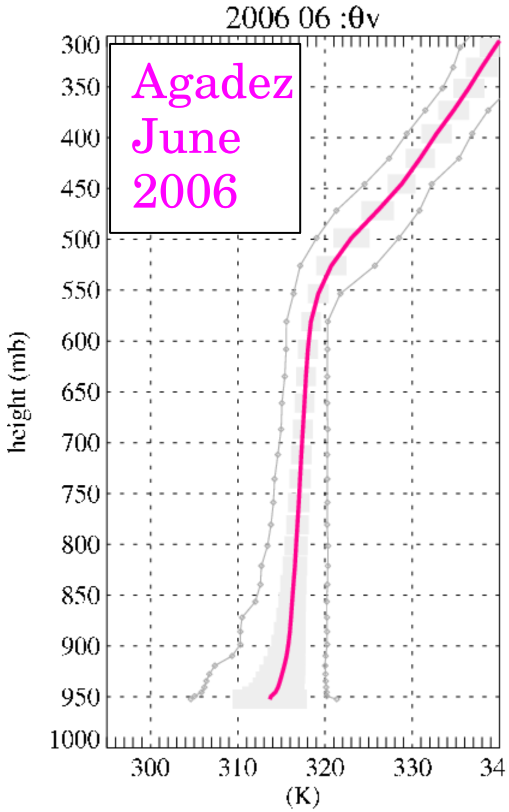
daytime drying:
strong impact on the diurnal cycle of θe

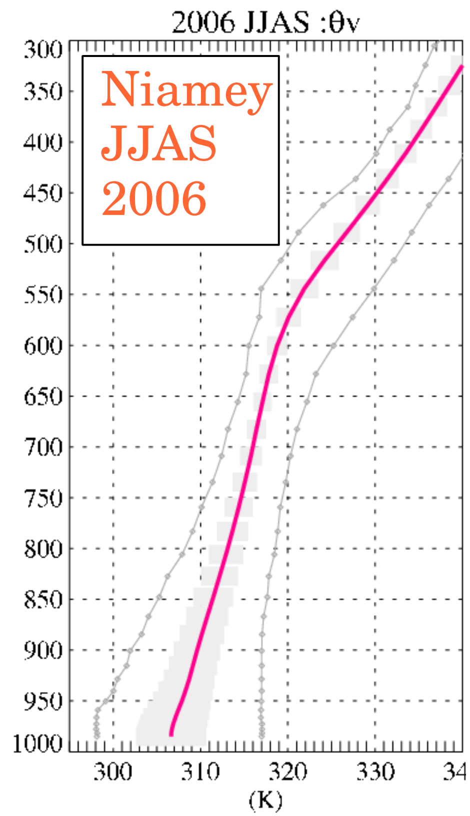
during the monsoon, significant diurnal cycle of θe in August only (flatter in Jun, Jul, Sep)

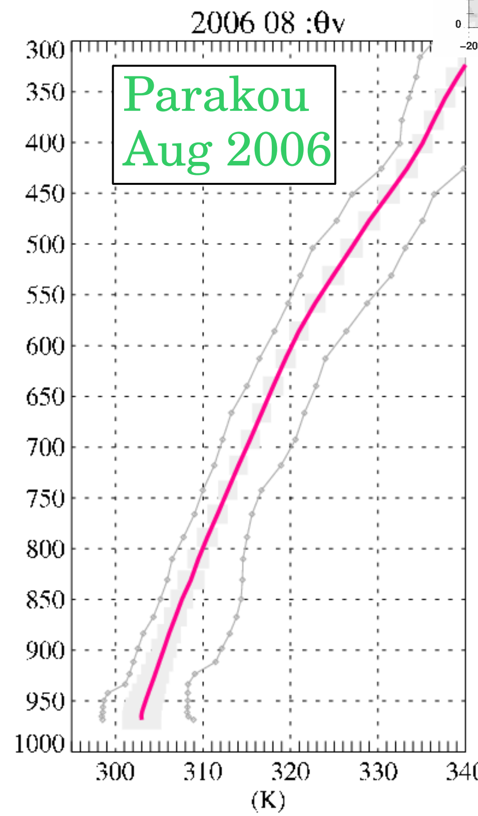


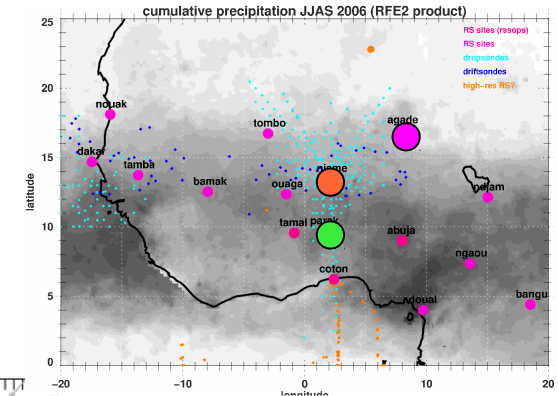


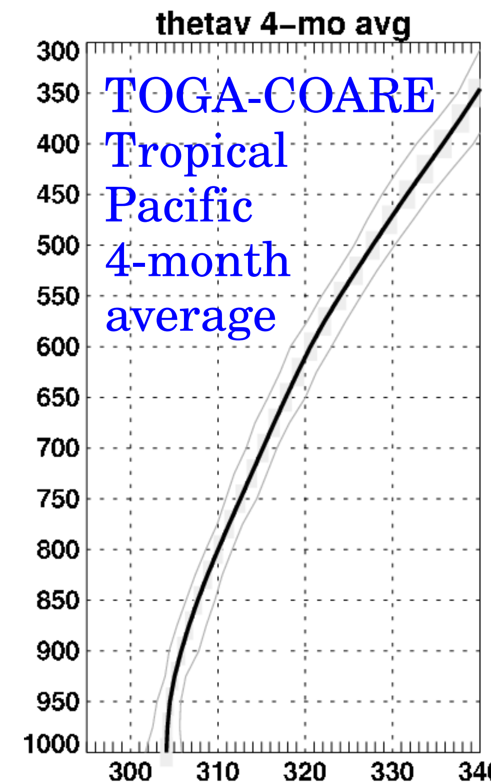
SOUNDINGS







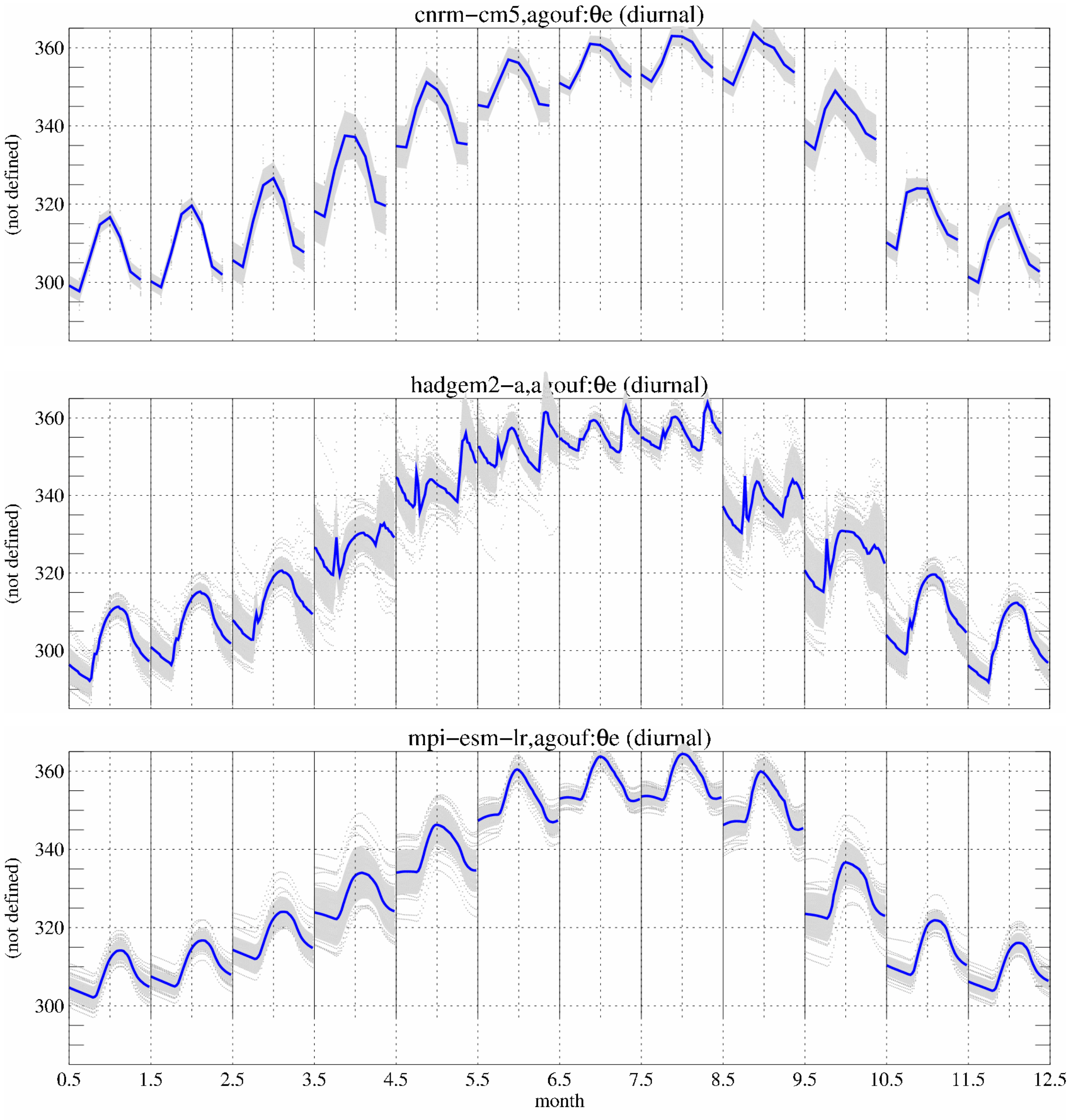




θv at different sites

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

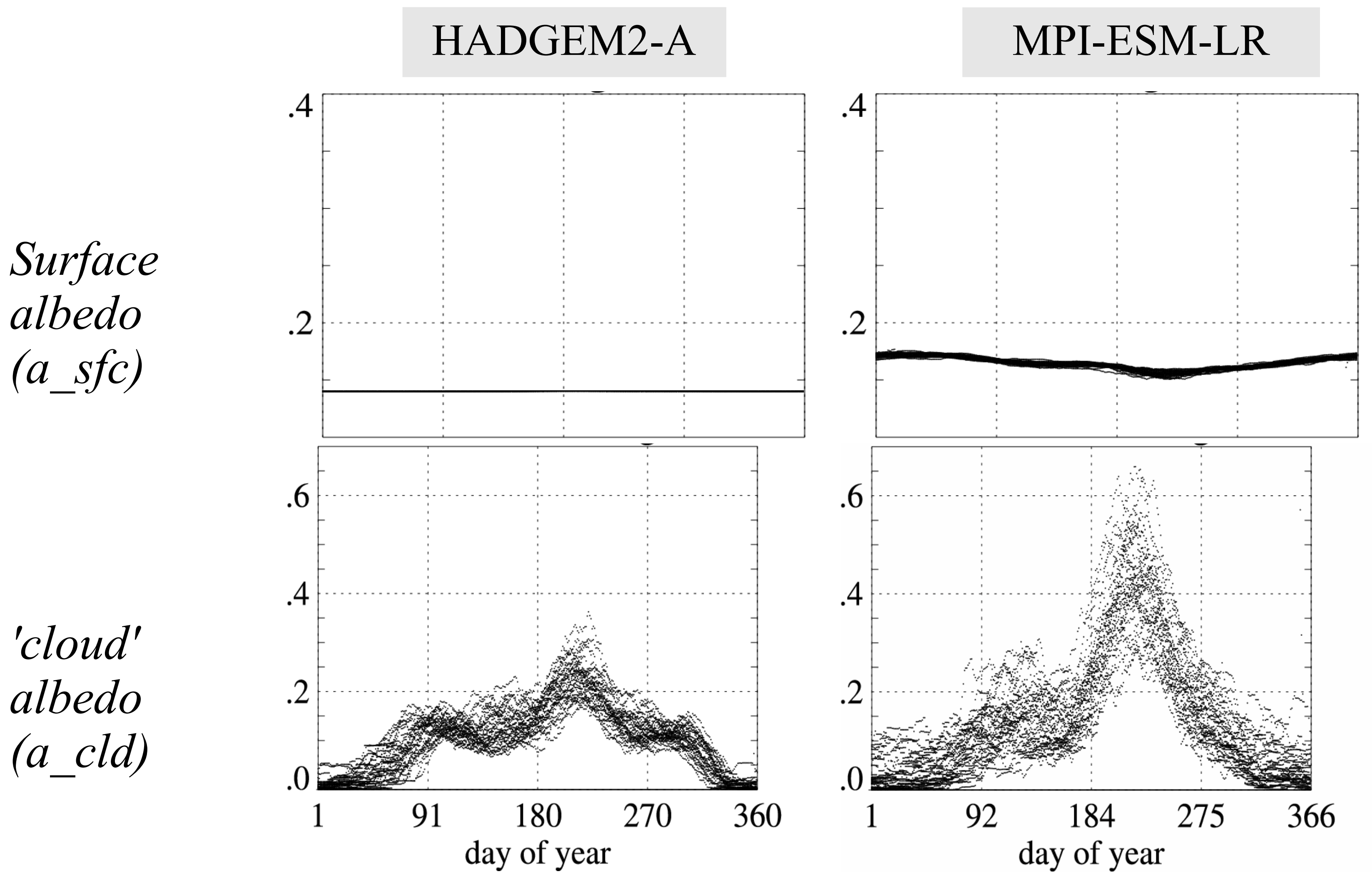
seasonal changes of the diurnal cycles



ALBEDOS SWnet = (1 – a_sfc) Swin

(1 – a_sfc) (1 – a_cld) SWin_clear_sky

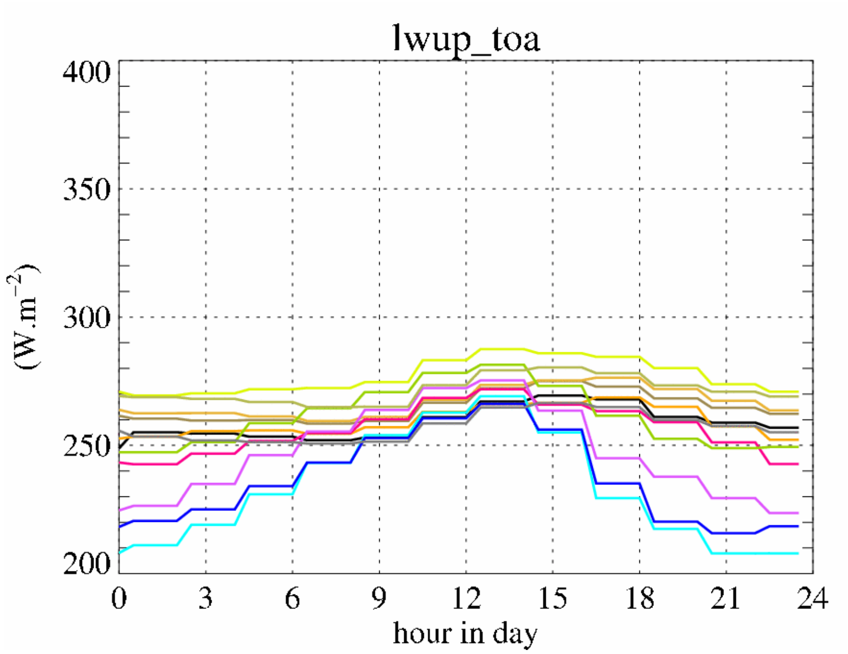
Djougou, 10°N

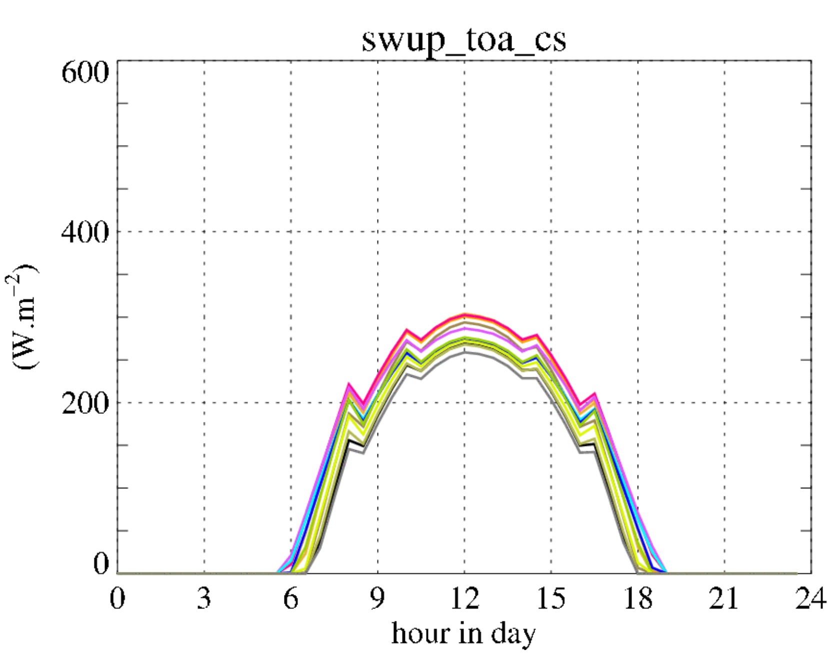


Interannual variability of surface albedo in Spring in MPI: spectral response with a role of aerosols again? (would be consistent with observations, Samain et al. 2008)

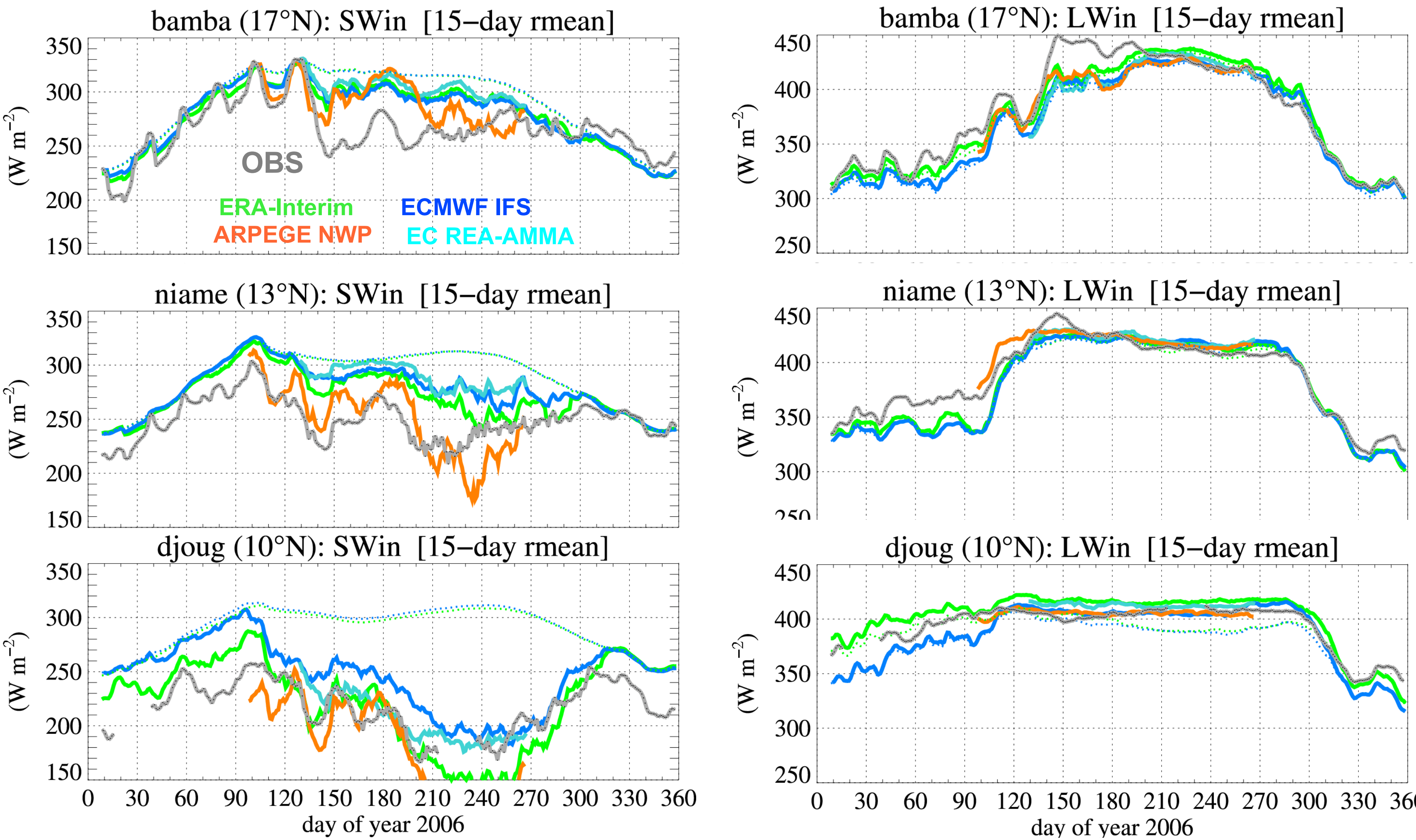
A few technical issues and questions

- 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