Clouds over West Africa

process-based studies and evaluation of models

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thanks to AMMA-Catch colleagues (S. Galle, LTHE & L. Kergoat, GET), ARM and F. Hourdin, IPSL

Context

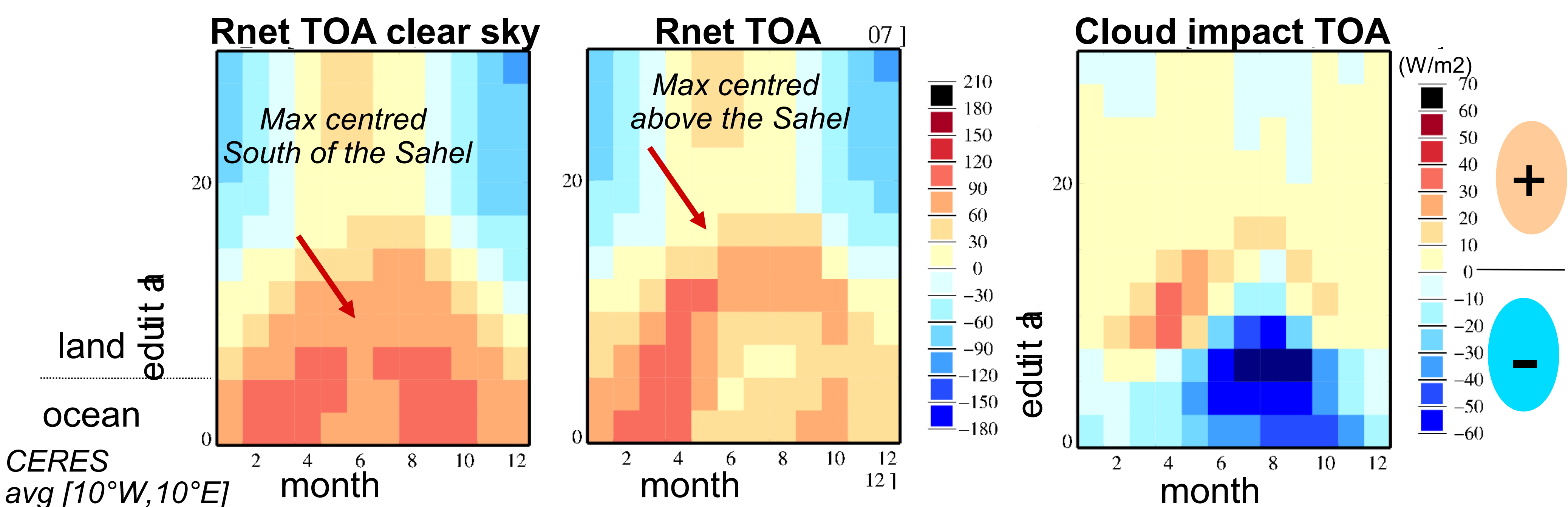
not much consideration of clouds until the recent past years, for instance:

Zheng and Eltahir (1998) developed a zonally symmetric model designed to describe the seasonal evolution of the West African monsoon rainfall. An insightful study at that time.

> *"for simplicity **we assume clear sky conditions** for radiation calculations." … "**the qualitative effect of cloud radiation is not hard to assess**."*

However observations indicates:

- large cloud radiative impacts (several tens of W.m-2)
- A potentially important role on the dynamics of the West African monsoon
  - *thermodynamic factor: more Rnet TOA favours more convection (Chou & Neelin 2002)*
  - Here: a more northward migration of the ITCZ, distinct cloud impact with latitude



Approach to study Clouds in West Africa

Context: not much consideration of clouds until the recent past years, for instance...

From Zheng and Eltahir (1998) who developed a zonally symmetric model designed to describe the seasonal evolution of the West African monsoon rainfall (An insightful study at that time): *"for simplicity* ***we assume clear sky conditions*** *for radiation calculations."* ... *"**the qualitative effect of cloud radiation is not hard to assess**."*

1) Observationally-based process studies

cloud macro-physical properties: occurrence, size, type... *(Bouniol et al. 2012)*

radiative effects: surface & TOA fluxes

Bouniol et al. (2012), Geoffroy et al. (2014), Guichard et al. (2009)

2) Evaluation of CMIP5 climate models

Clouds: part of a broader evaluation of CMIP5 models *(Roehrig et al. 2013)*

COOKIE experiment with the zonally symmetric model of *Peyrillé et al. (2007)*

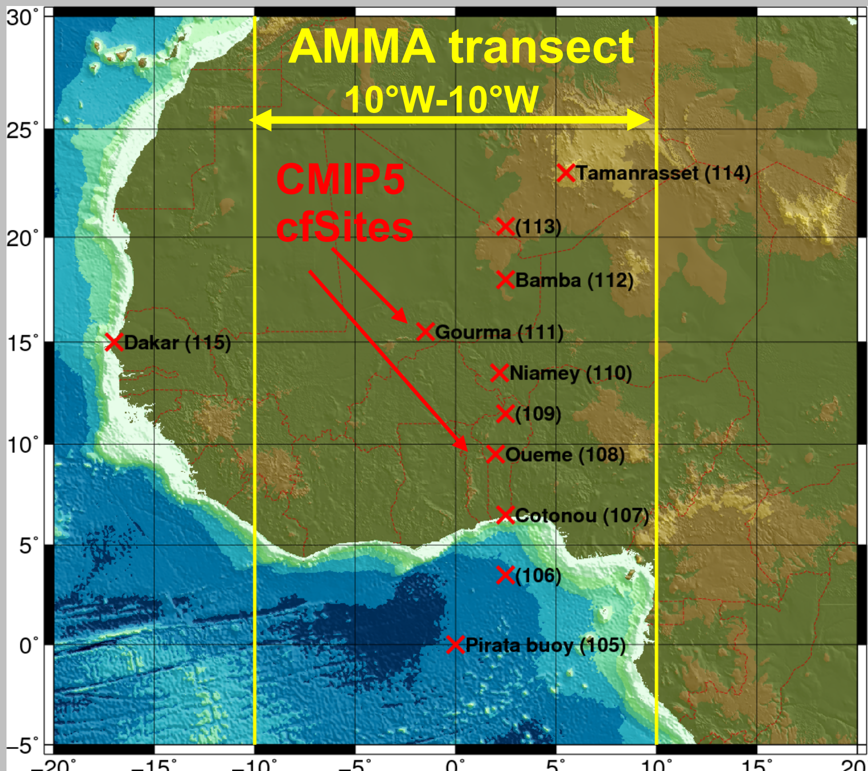
3) Design of two modelling case-studies framed by observations

case studies suitable for LES process studies & SCM tests of parametrizations

daytime deep convection in the sub-tropics (Lothon et al. 2011, Couvreux et al. 2012)

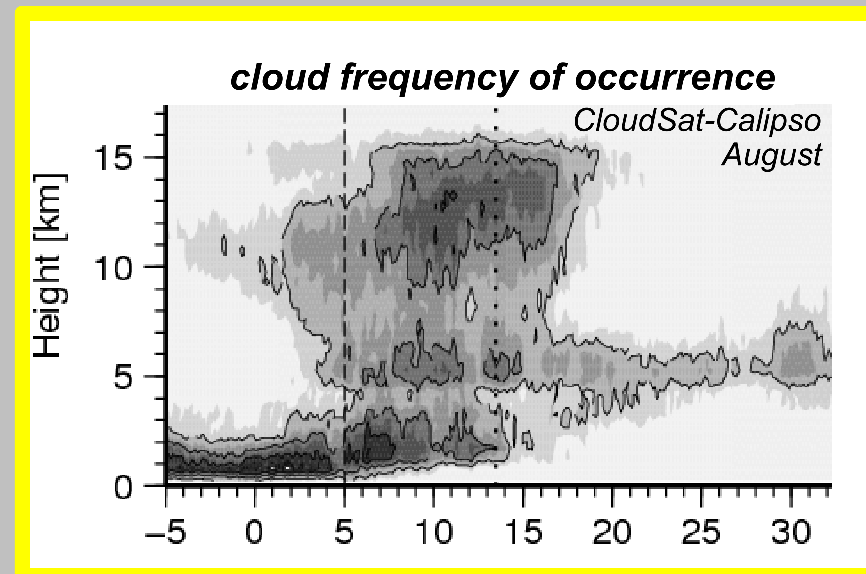
surface-boundary layer-clouds coupled system, from the wet Tropics to the Northern Sahel (Gounou et al. 2012, Couvreux et al. 2014)

Complementarity of AMMA TRANSECT and CMIP5 cfSites



AMMA TRANSECT: take advantage of the large-scale climatological gradient

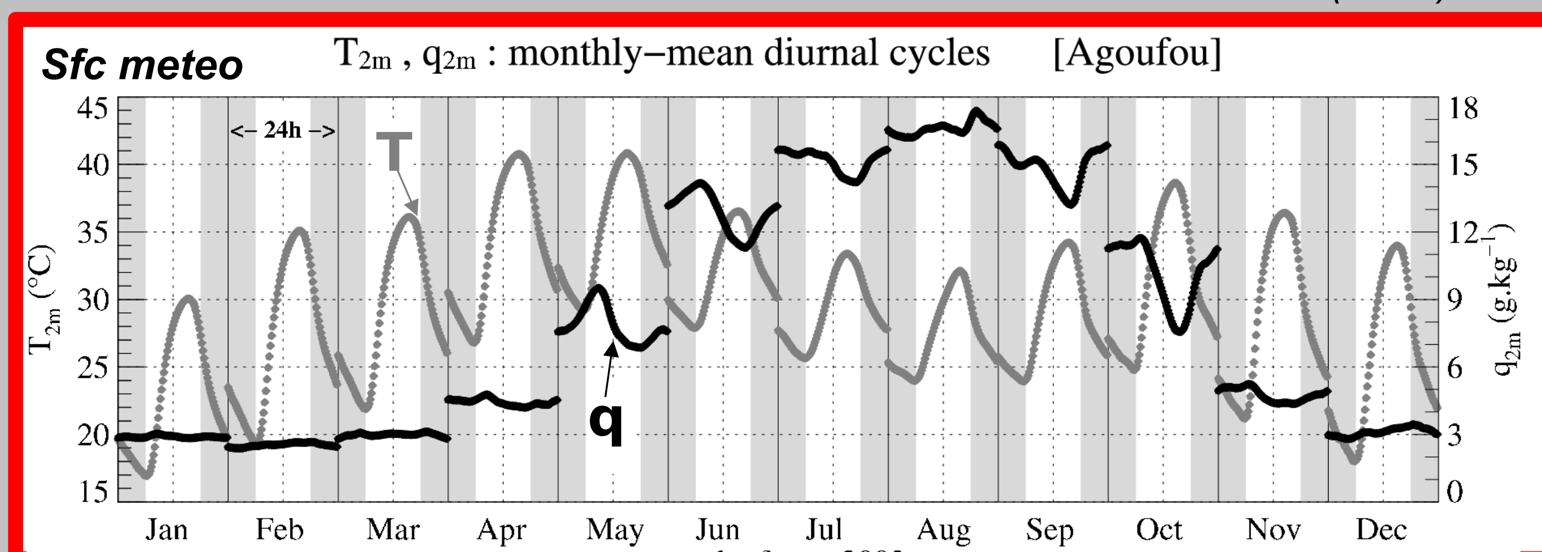
AMMA-MIP: Hourdin et al. (2010)



Bouniol et al. (2012)

CMIP5 cfSites

- *locations where ground data available*
- *sample the gradient*
- *high frequency long term observations (valuable e.g. for diurnal cycle)*

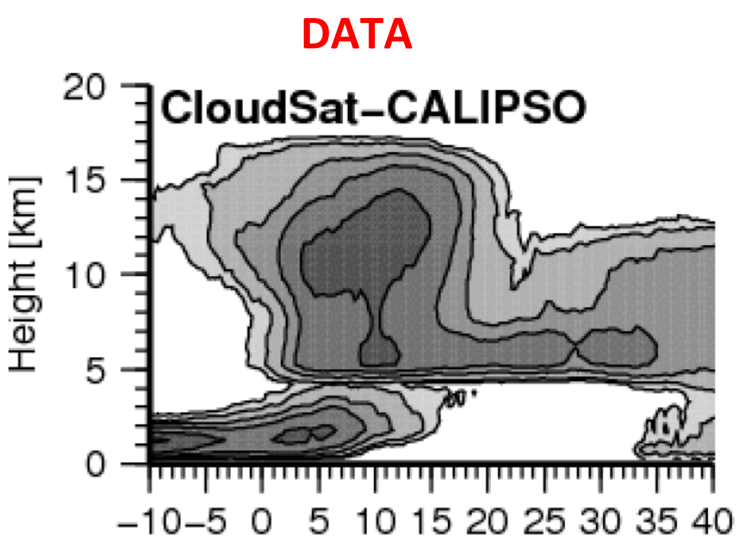


Guichard et al. (2009)

Evaluation of clouds in CMIP5 AMIP runs

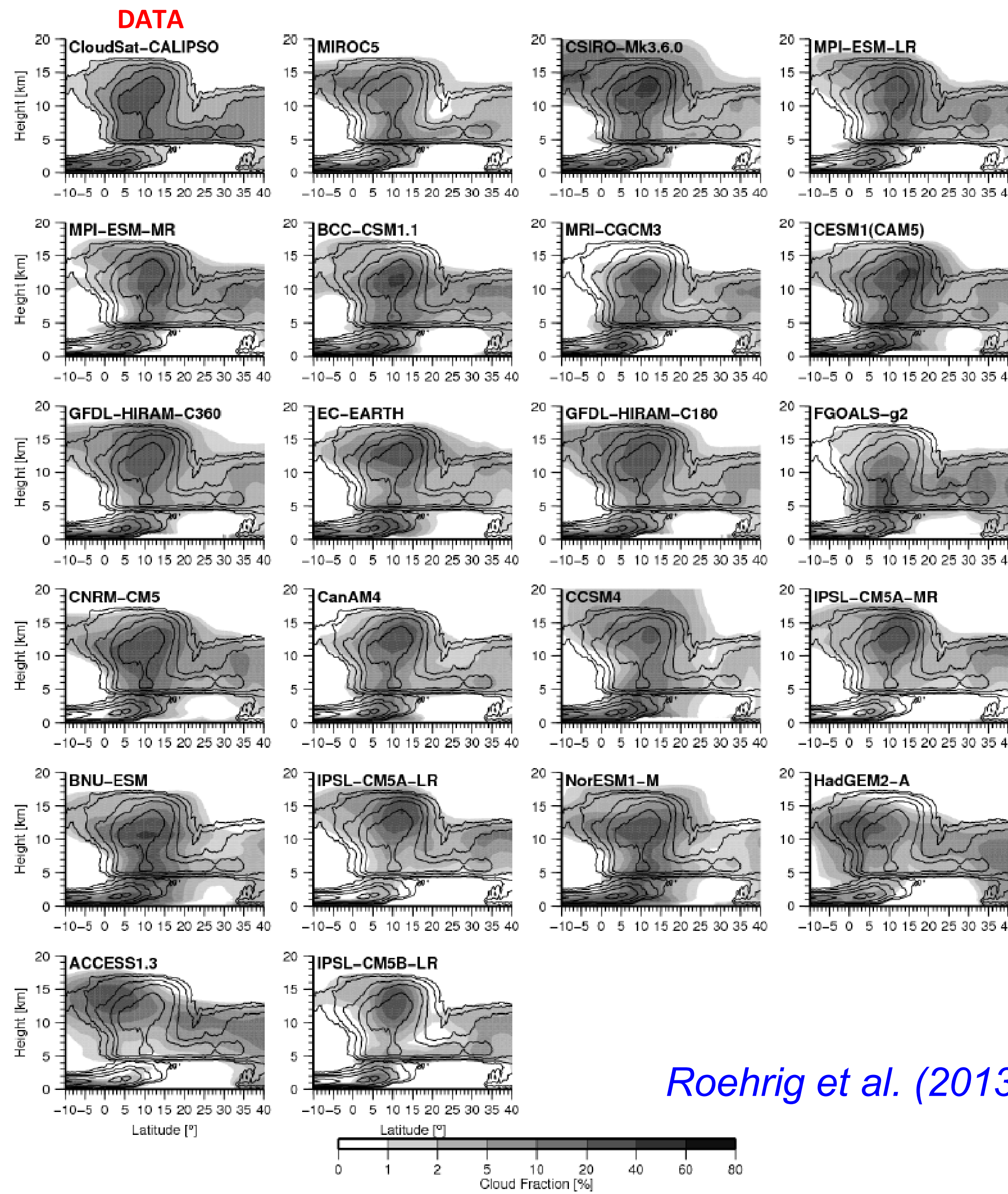
Large-scale features

Cloud fraction (latitude, height)
JAS (10°W,10°E) average



Broad structure captured by most models

Lack of mid-level clouds still present above the Sahara in observation



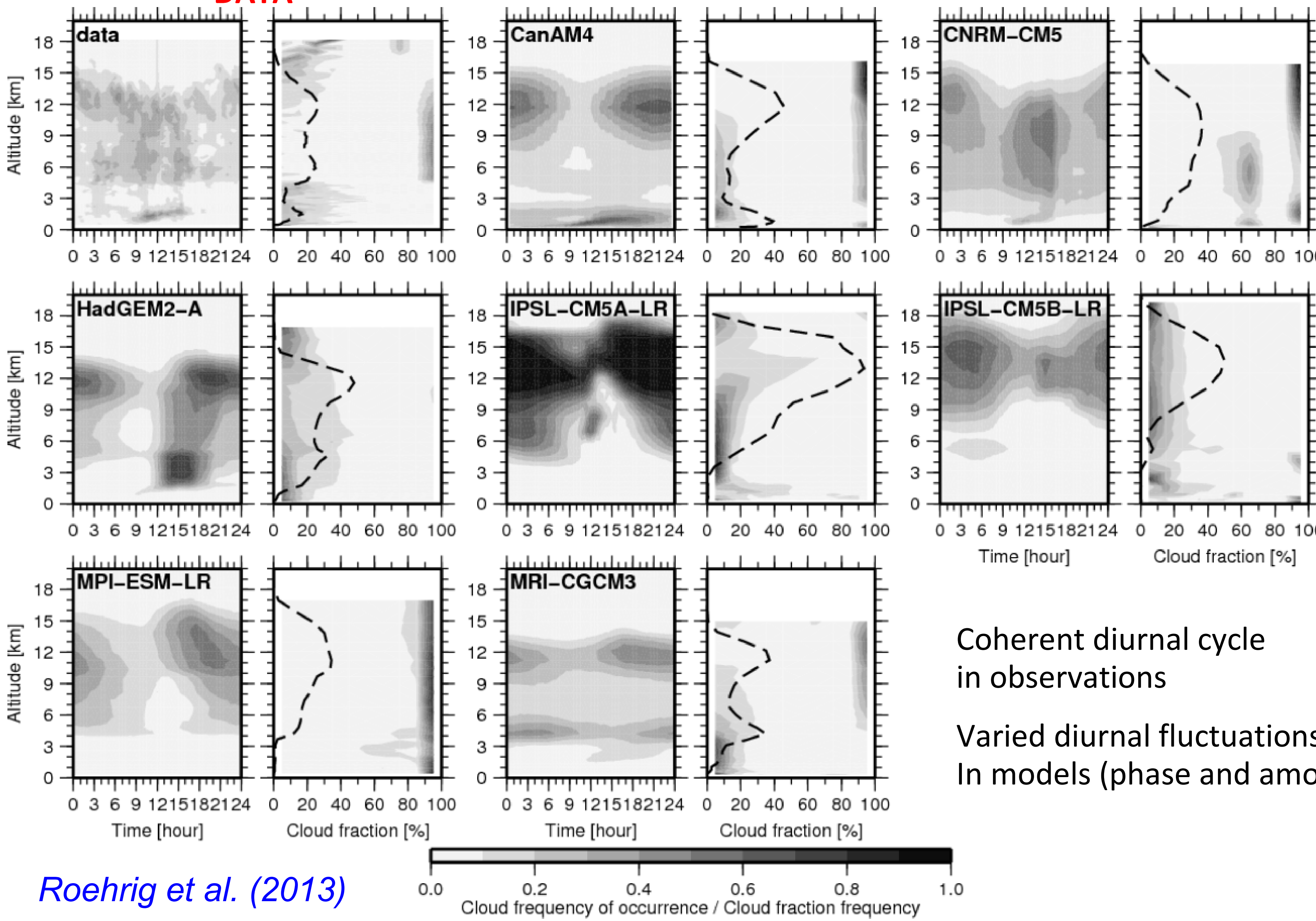
Roehrig et al. (2013)

Evaluation of clouds in CMIP5 AMIP runs

Finer scales: diurnal cycle

ARM mobile facility in Niamey (Sahel)
August 2006 mean diurnal cycle of cloud fraction

DATA



Coherent diurnal cycle
in observations

Varied diurnal fluctuations
In models (phase and amount)

Roehrig et al. (2013)

Evaluation of clouds in CMIP5 AMIP runs

Cloud radiative impact TOA and surface, fct (latitude)

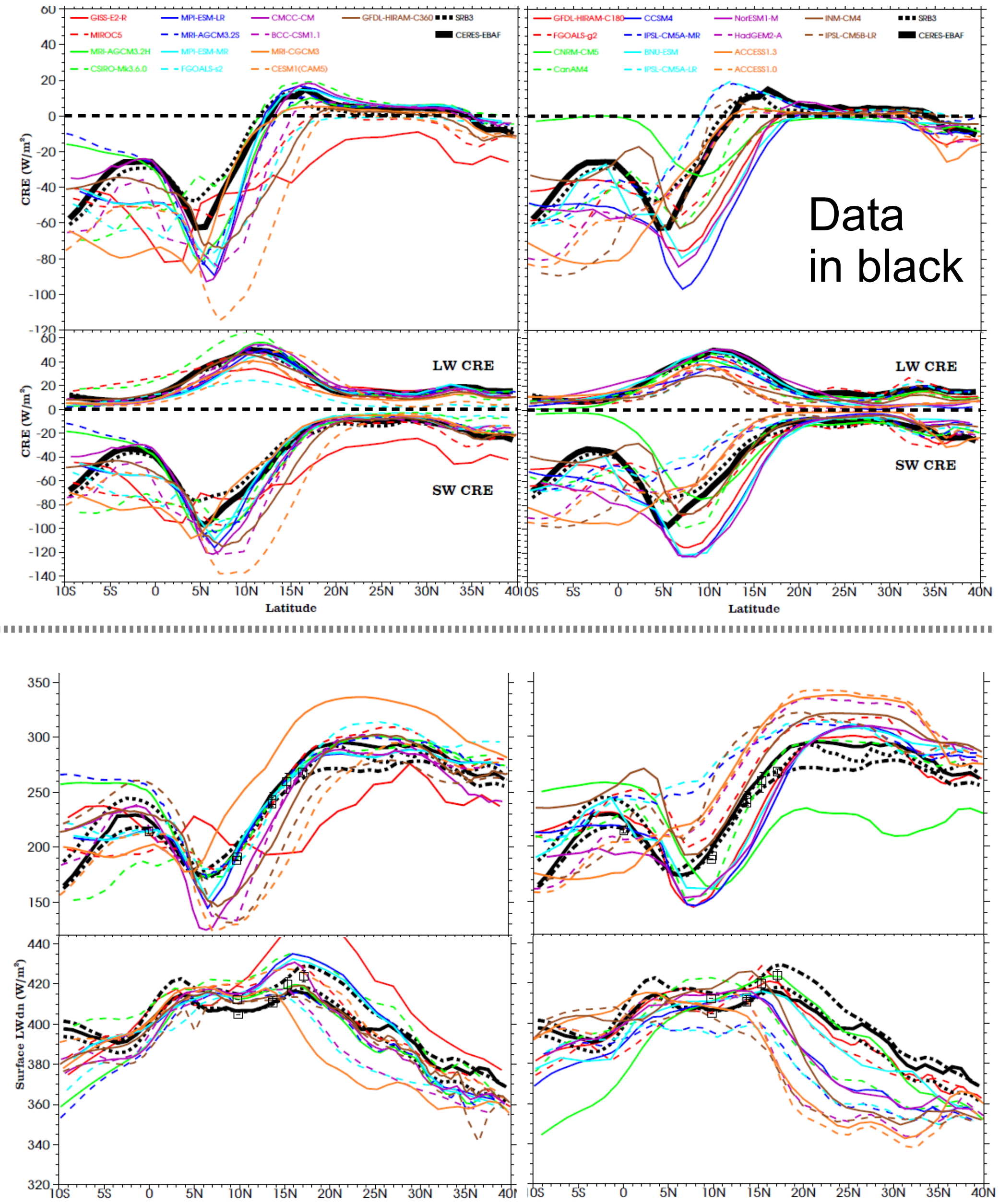
on R_{net} TOA

on OLR

on SW TOA

on SW_{in} sfc

on LW_{in} sfc



Again, broad features generally captured by models

But

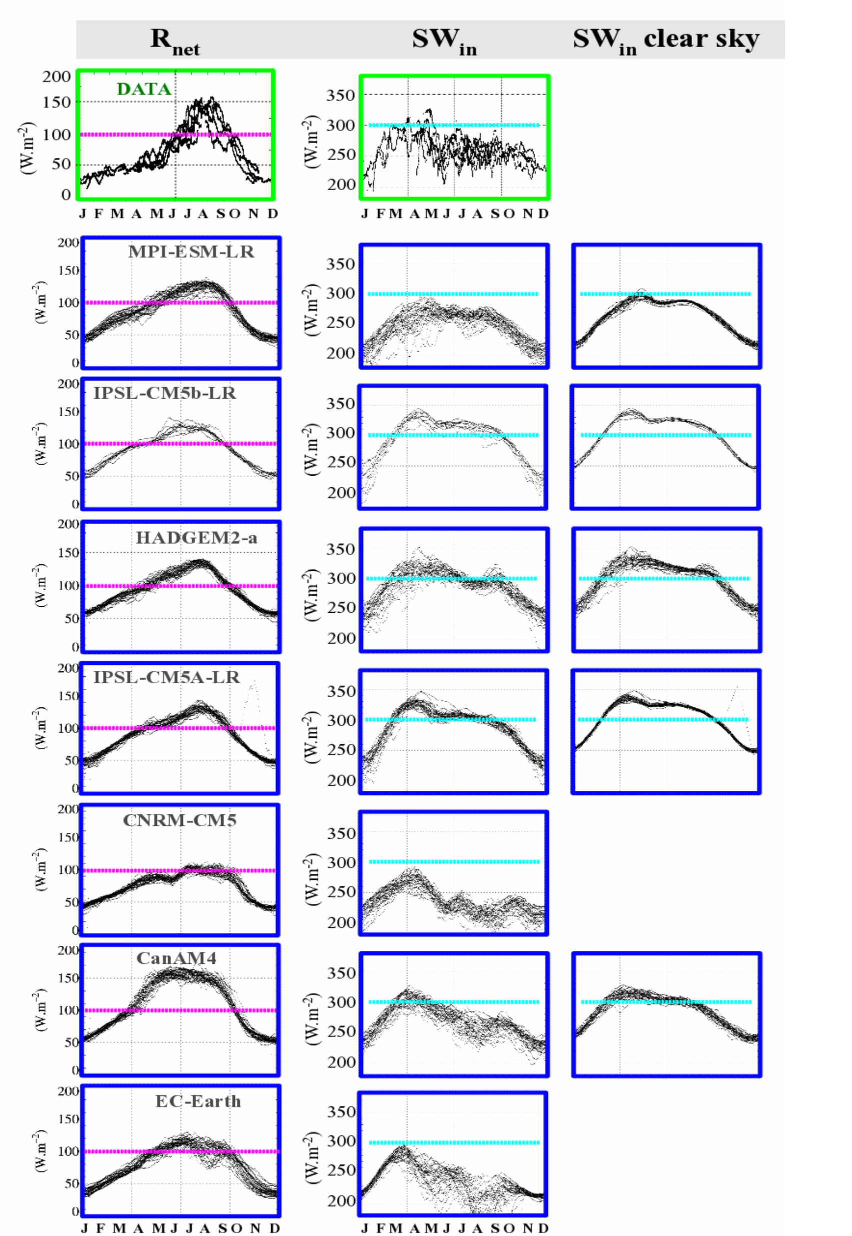
The differences in the latitudinal position of the ITCZ cannot account alone for the large biases in TOA and surface radiative fluxes (several tens on $W.m^{-2}$)

large compensating errors

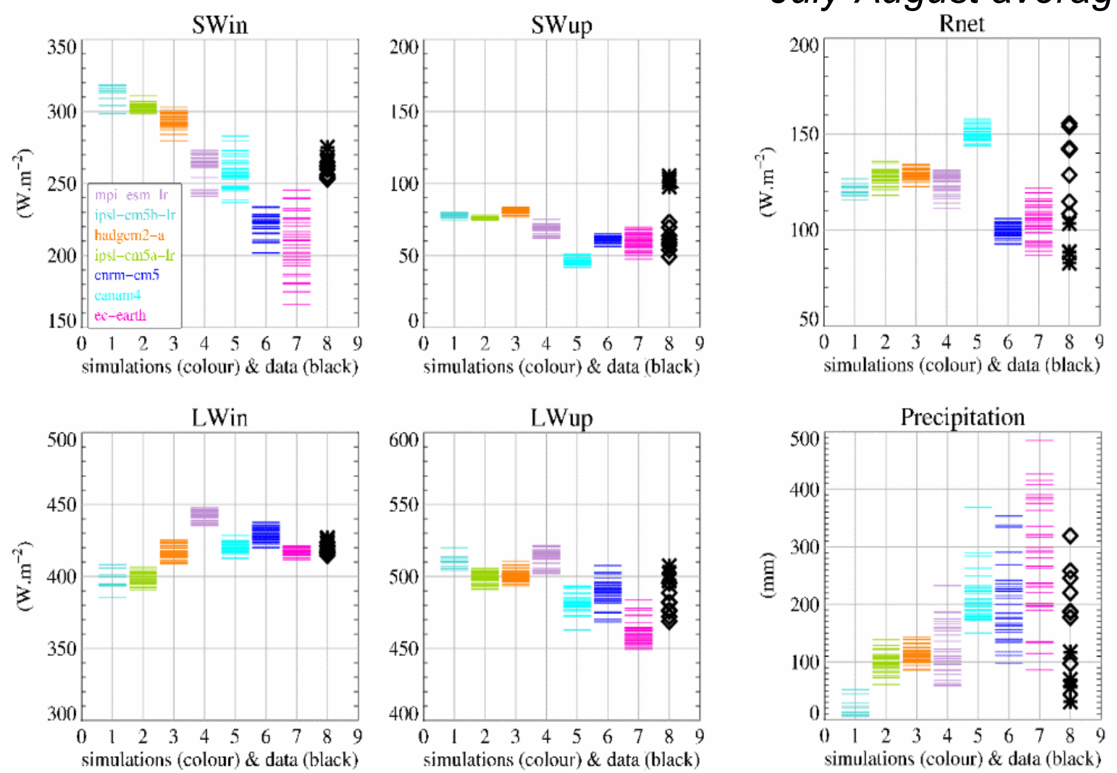
Roehrig et al. (2013)

Evaluation of clouds in CMIP5 AMIP runs

Cloud radiative impact at the surface *example in the Sahel: annual cycle*



July-August average



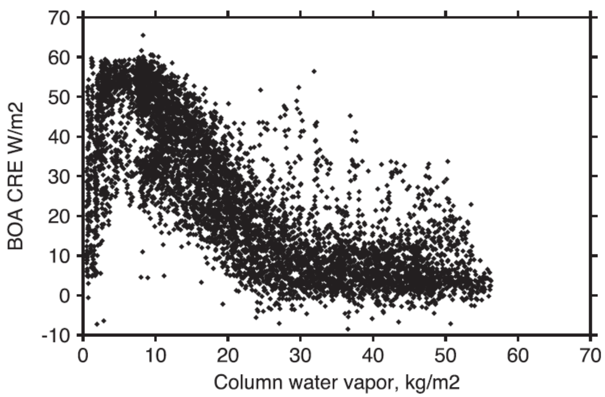
(one tick=1 year, one color= one model, obs in black, 2 sites)

Much larger spread (and errors) among models in surface incoming radiation SWin than in surface net radiation Rnet

Sfc Rnet ~OK does not mean at all that H & LE are !!!

Still very large difference even without clouds, for clear-sky SWin ! (aerosols ?)

Evaluation of clouds in CMIP5 AMIP runs

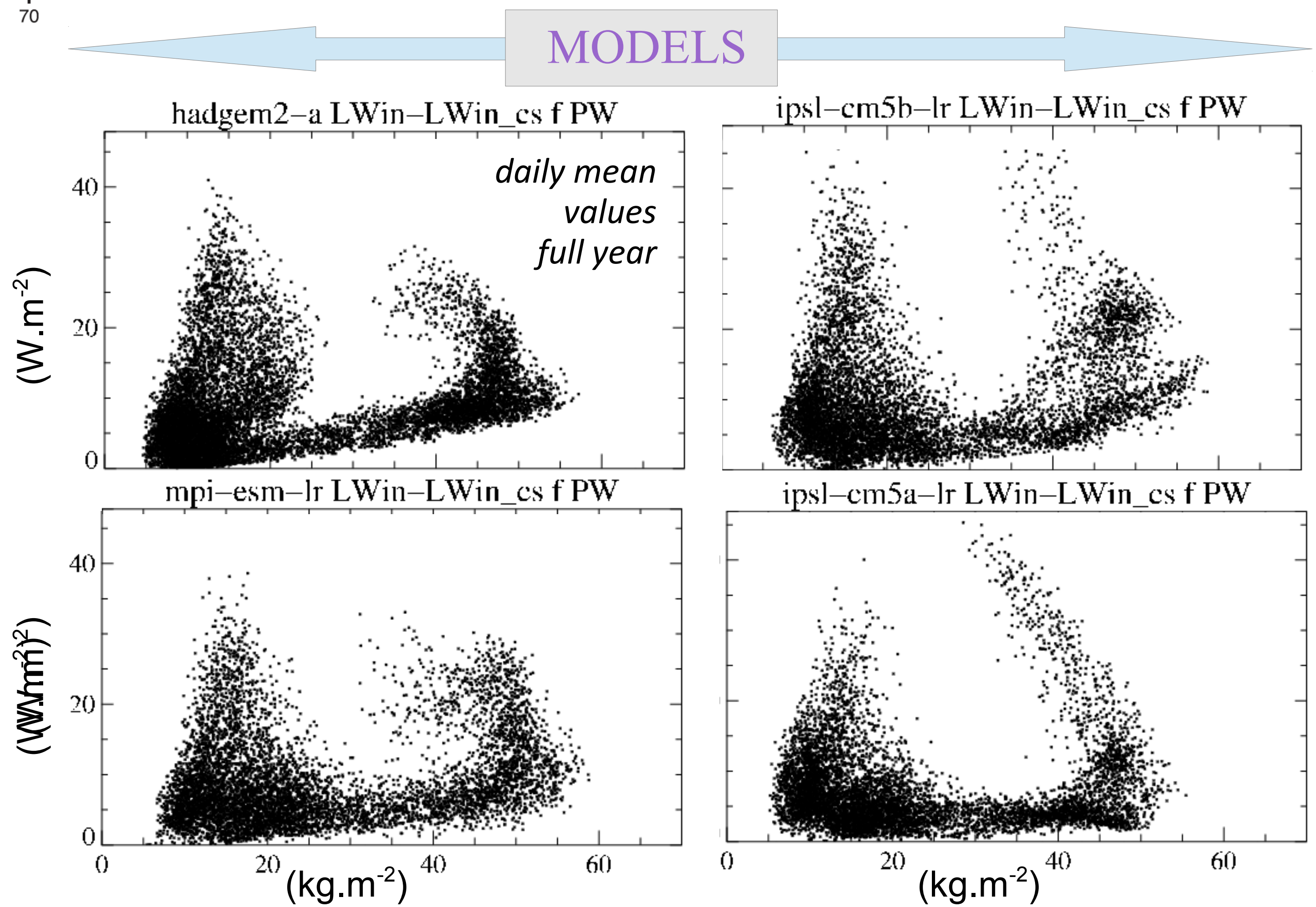


Stephens et al. (2012)
over Ocean

couplings of LW fluxes, water vapour and clouds

cloud radiative impact in the LW at the surface:
sensitivity of to precipitable water

Over The Sahel



A peculiar signature in models.

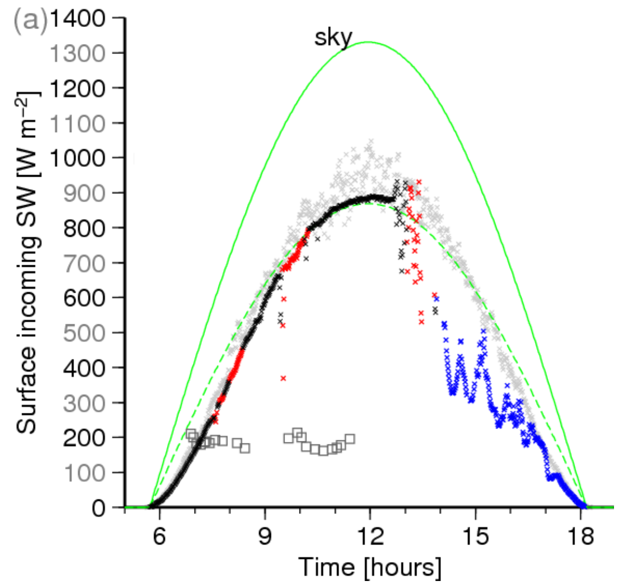
And in observations?

Connection with cloud types?
or with changes in diurnal cycles (cofluctuations clouds-LWin)?

(Work in progress)

Estimation of cloud radiative impact from observations

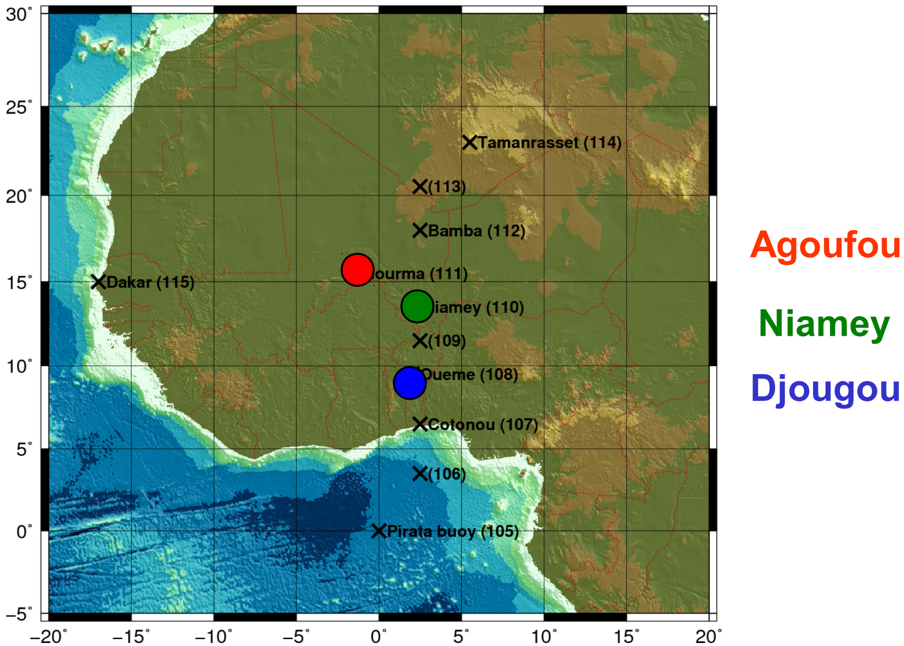
1) First estimates from empirical methods
Bouniol et al. (2012), Guichard et al. (2009)



2) Use a radiative transfert model (RRTM) together with observations to provide physically-based estimates

done for 3 sites along the gradient

(Geoffroy et al. 2014)



Data and method

Slide Courtesy O. Geoffroy

RRTM Inputs

→ Greenhouse gazes : RRTM climatology
→ **Humidity** & **temperature profiles:**
radiosondes & ECMWF analysis (stratosphere)
radiosonde: 4 to 8 per day
ECWMF (re)analysis : 4 per day
→ **Aerosols** : Aeronet, AOD,SSA, ... dt < 1h
→ **Albedo** : surface data, LSA-SAF products
(*D. Carrer, C. Meurey*)
→ surface temperature from LW surface flux

data from AMMA, ARM, AMMA-CATCH

INPUTS

Radiative transfert model

- RRTM LW and SW (AER)

(*Iacono et al, 2008; Morcrette et al, 2008*).

- Resolution: 100 levels

Radiative fluxes : ARM, AMMA-CATCH & RADAGAST

Slingo et al.,2006; 2009, Spec. Issue JGR
AMMA Catch Spec. Issue 2009 J. Hydrology

Surface : ARM Mobile Facility, dt = 1 min, others : 15 min
TOA : GERB data , dt = 15 min

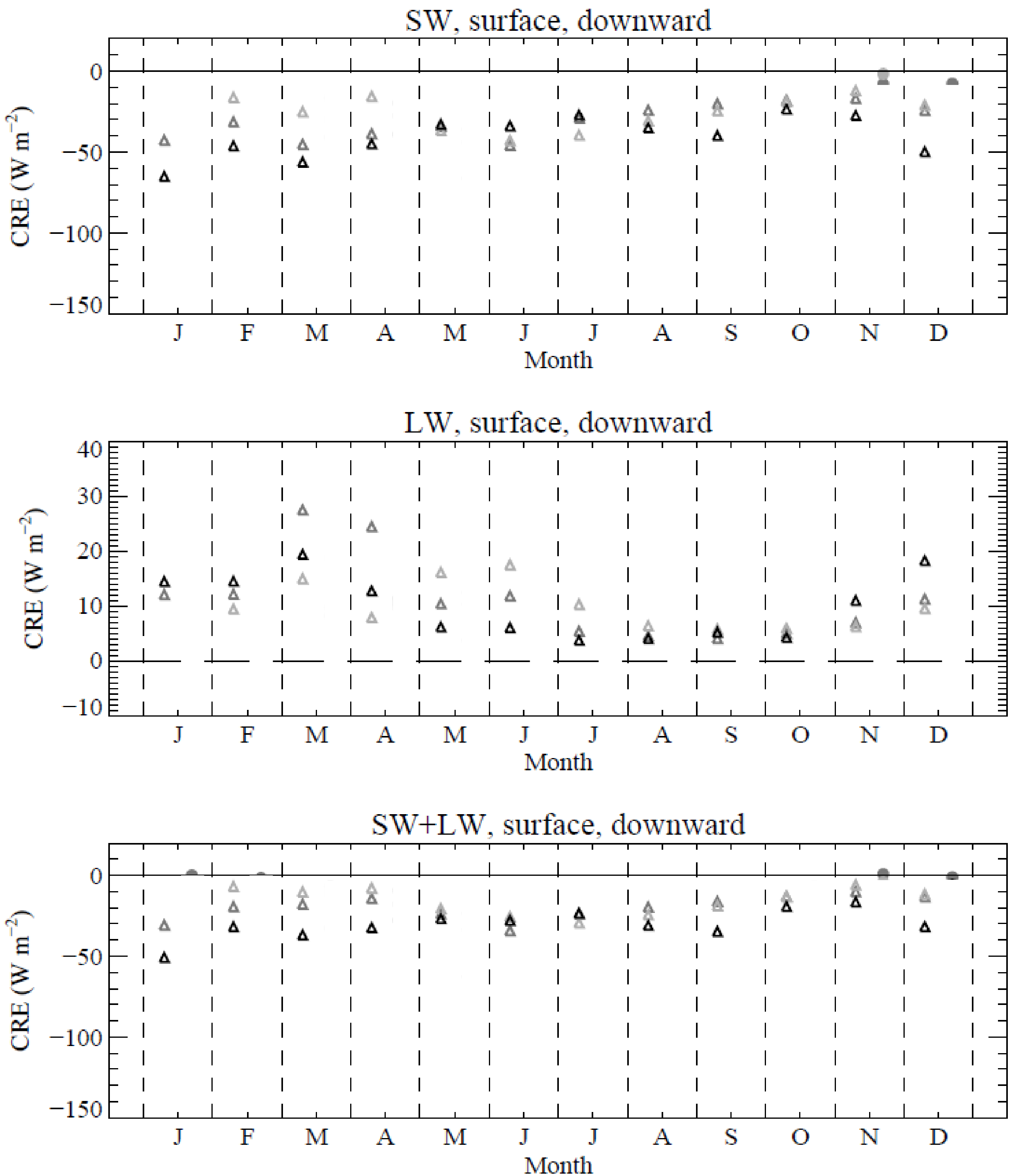
Radiatives fluxes estimates
Clear sky and Clean sky
LW / SW
TOA / Surface

ADDITIONAL DATA FOR ANALYSIS

Cloud masks *(Illingworth et al., 2007)* from AMF radar, lidar
Precipitable water, GPS *(Bock et al., 2008)* dt = 1 h
Precipitation

CRE (dt ~ 30 min)

radiative Impact of ***aérosols*** ***at the surface***



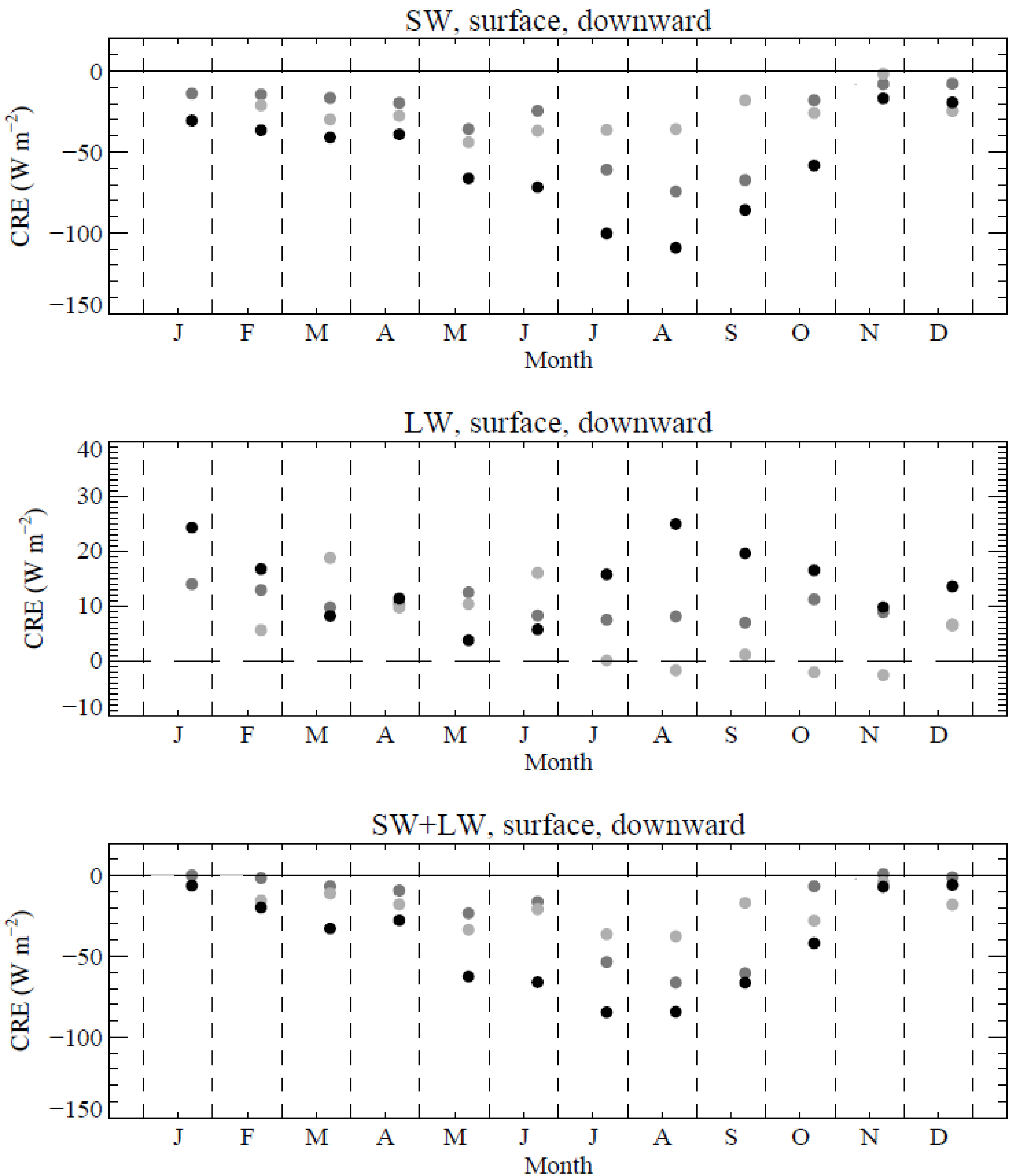
Agoufou
Sahel Central
(15.5°N)

Niamey
Sahel Sud
(13°N)

Nalohou
Soudanien
(9.5°N)

Geoffroy et al.

Radiative Impact of clouds at the surface



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Radiative Impact

clouds (disk)

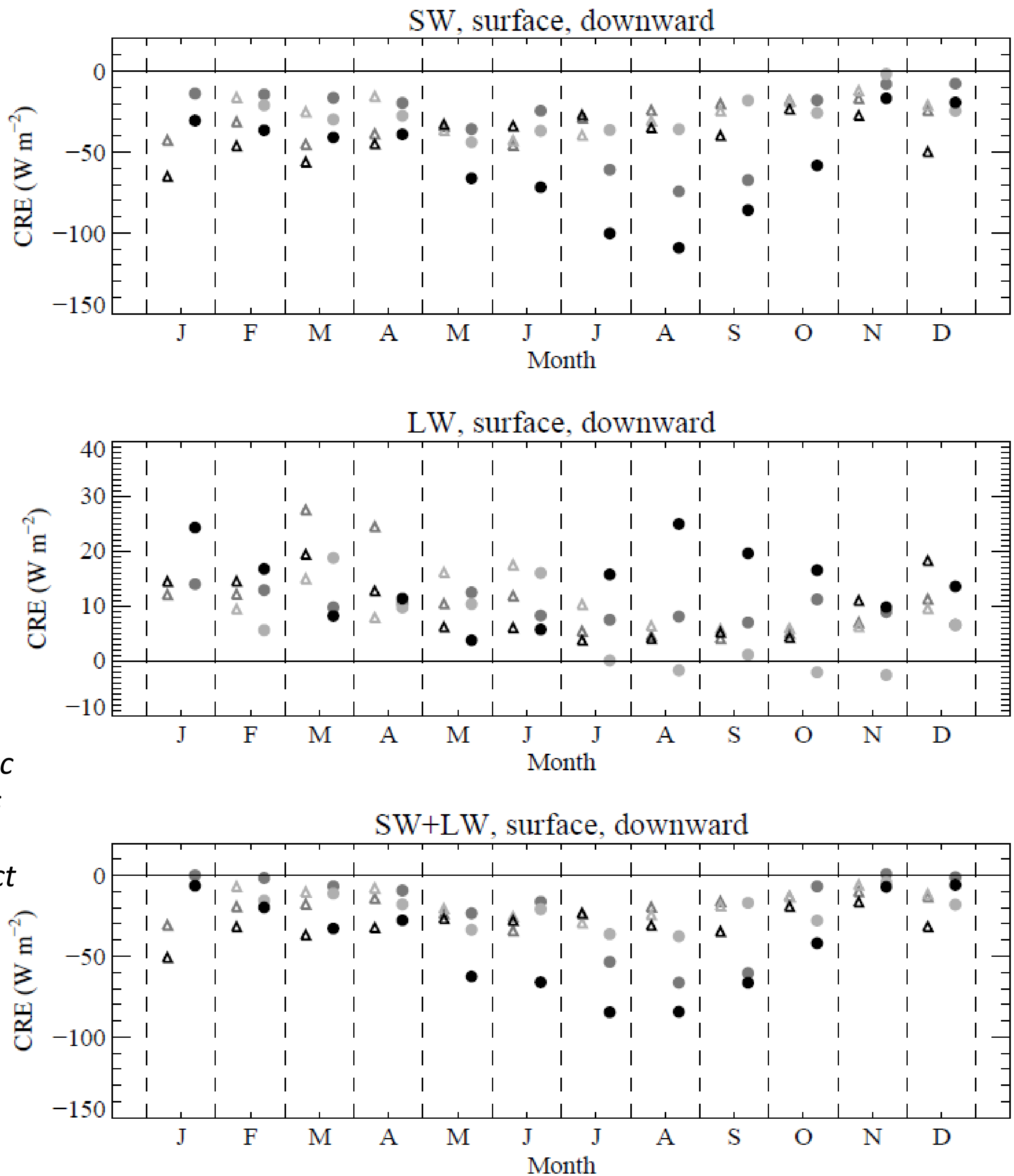
aerosols (triangles)

Quantification of both cloud and aerosols effects

A small word of caution for the interpretation:

by design, such method is asymmetric 1st estimate aerosols and from there the cloud radiative impact

With this in mind: further useful to analyse CMIP5 models



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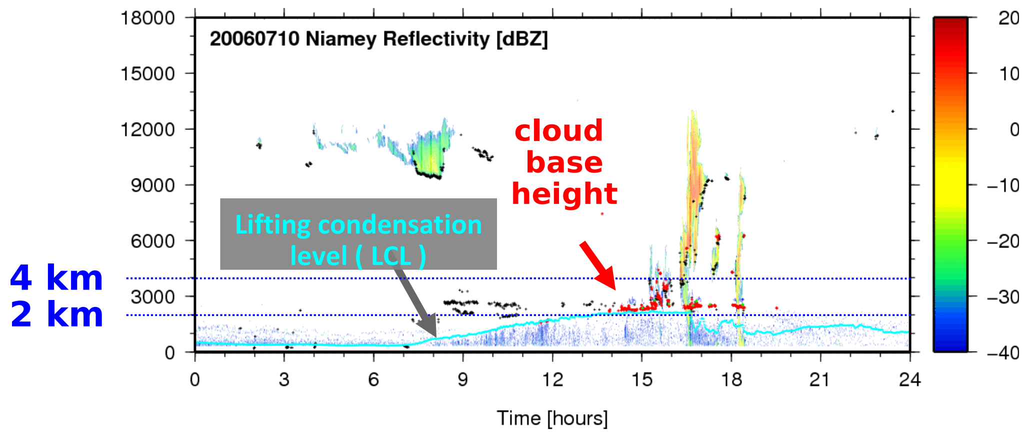
Geoffroy et al.

Design of 2 modelling case-studies framed by observations

Both cases designed to be run by LES/CRM and SCM
process understanding and guidance for parametrizations

Case 1 aim study daytime convection in semi-arid environments *(Couvreux et al. QJ 2012)*

latent heat flux close to 0, not very moist, deep CBL, large CIN, long duration of transition (distinct from existing case-studies)



used for parametrization development by Rochetin et al. (2014 a,b) and Andrea et al. (2014)
also Couvreux et al. in prep.
(EMBRACE project)

Case 2 aim analyze how interactions between clouds, convection, boundary-layer and surface processes vary among different climates/regimes (meridional gradient)

Use observations/AMMA ECMWF reanalysis to first build a set of 4 'realistic' 10-day cases (with diurnal cycle, synoptic fluctuations...)

Simplify the set up in a way that preserve robust features of the model behaviour

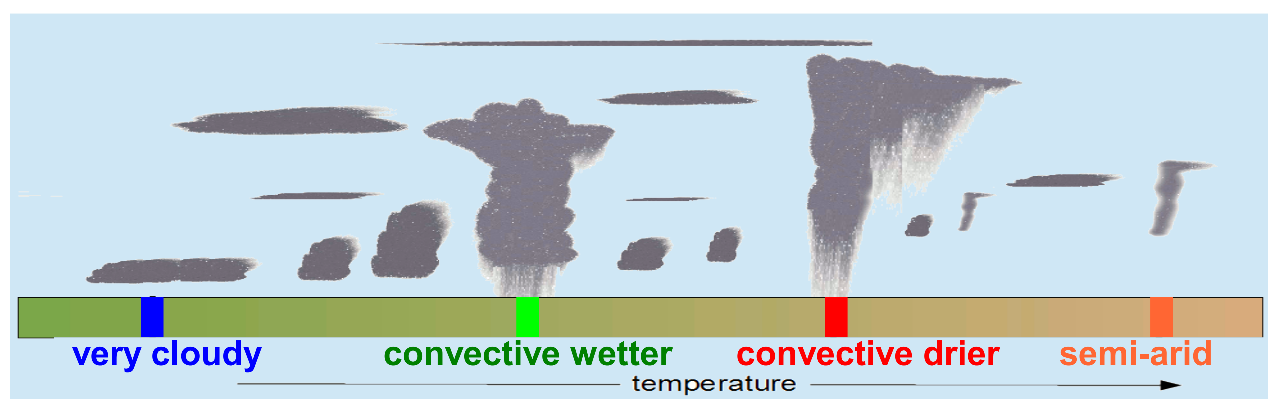
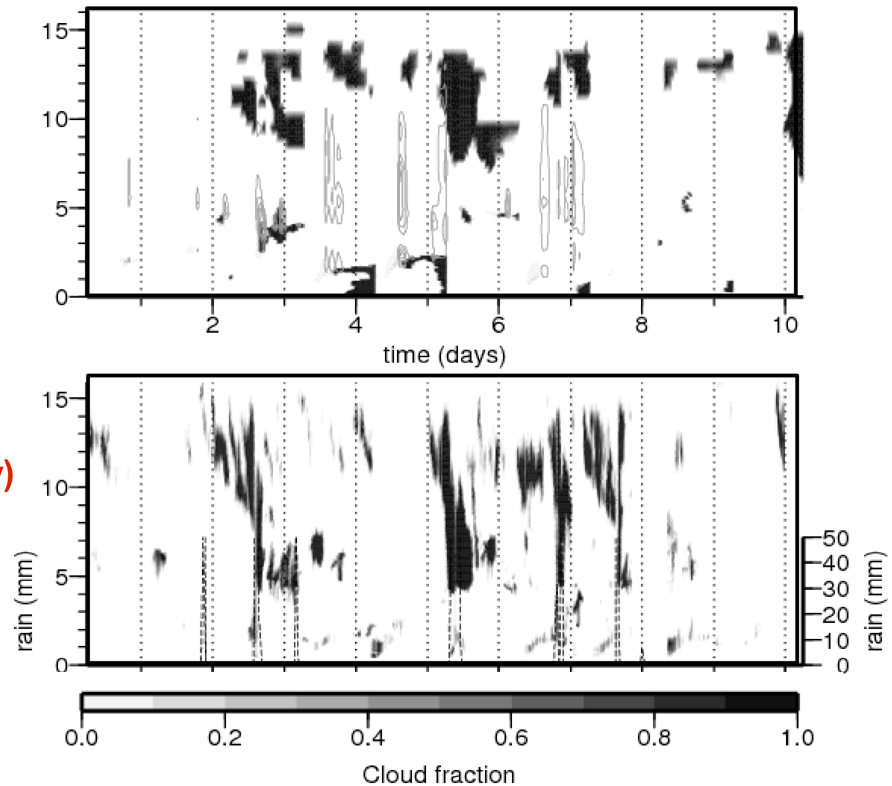


Illustration of CASE2 modelling results

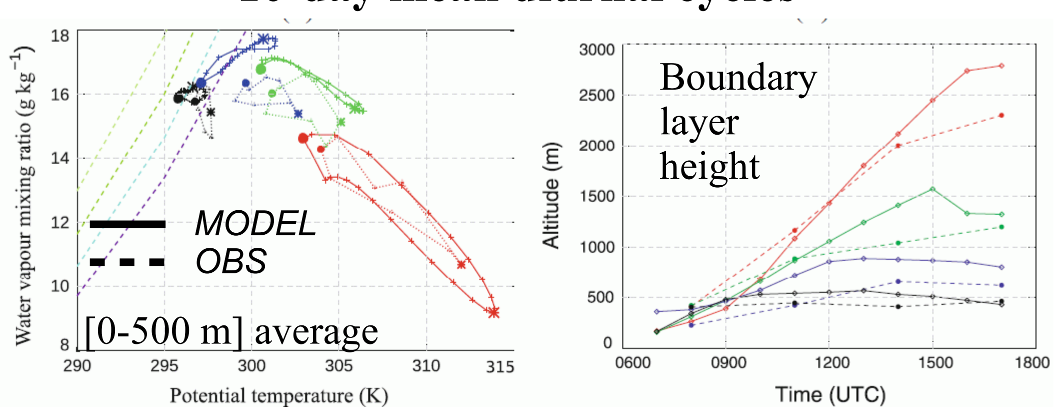
Evaluation of simulations

MODEL SCM MesoNH

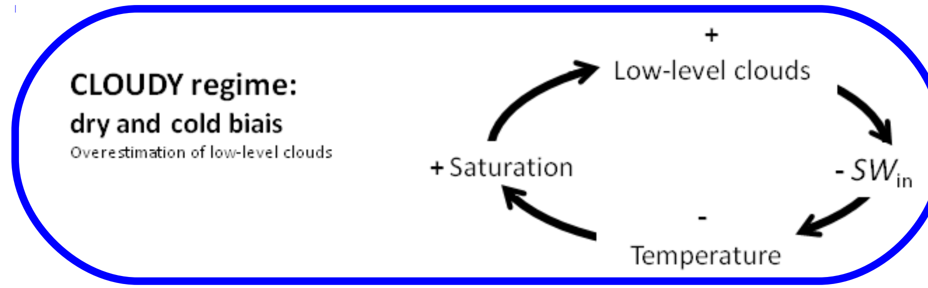
OBS (Niamey)

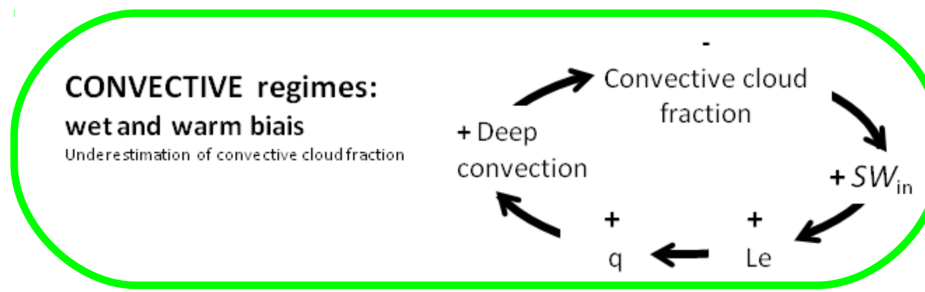


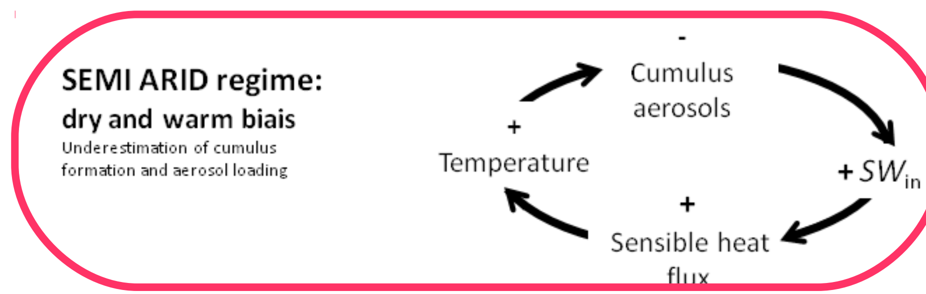
10-day mean diurnal cycles



Mechanisms behind simulation biases







Couvreux et al. (BLM 2014)

Summary

West Africa **:** *a major tropical land mass displaying a large climatic gradient from South to North also expressed in the cloud types and covers*

Use of AMMA data:

to analyse physical processes over West Africa
to provide ground truth for model evaluation
to help assessing cloud radiative impact
to frame simple (LES/CRM/SCM) case-studies

Observations highlight the importance and variety of clouds over West Africa

- *At large scale, structure of the monsoon (notably latitudinal position)*
- *On short time scales (during daytime in particular, via large cloud impact on surface fluxes)*
- *For they role in the strong couplings identified between water vapour and radiative fluxes*
- ***Cloud radiative impact*** *estimated with a radiative transfert model & data (valuable 'ground truth')*

Evaluation of CMIP5 climate models

- *Clouds and cloud radiative impact: 'Qualitatively' reasonable (but qualitative only!)*
- *Large biases in radiative fluxes not simply explained by differences in the large-scale structures (which implies the relevance of local studies)*
- *Analysis of couplings should also help understanding better model sensitivities and biases (clouds are 'playing' together with other processes, complex interactions)*

Design and analyse of **modelling case-studies** framed by observations (CRM/LES/SCM)

- *Daytime convection in semi-arid conditions (surface and BL processes particularly important, long duration of transitions, strong cold pools) – still in use for process understanding & param.*
- *Interactions between surface-boundary layer-clouds and convection from cooler-moister to warmer-drier conditions. Highlights simply how distinct mechanisms explain varied model biases Provides a simple and robust test of the model behaviour in different representative environments*

Illustration of CASE2 modelling results

Tendency of liquid potential temperature