Surface, boundary layer and cloud couplings over land in climate models: inferences from evaluation of SCM and CMIP5 simulations over West Africa

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Contrasts in surfaces, boundary layers (BL) and clouds (with couplings)

**Surface energy budget** is a critical issue (local & large scale) involves processes which are not all well, nor simple to represent
- incoming SW TOA, water vapour, aerosols and clouds, rainfall
- land surface temperature, soil moisture, albedo, vegetation
  *Especially true in the Sahel (all are important)*

\[ R_{net} = H + LE \sim \Phi_s(\theta_e) \]

**Monsoon establishment**: from drier & higher to cooler, moister & cloudier convective boundary layers, change in the diurnal dynamics
Model evaluation: **AMMA TRANSECT** and **CMIP5 cfSites**

**AMMA transect** 10°W-10°W

**CMIP5 cfSites**

*locations where ground data available (AMMA, ARM MF Niamey, others)*

**MORE** became available recently

**AMMA TRANSECT**: large-scale climatological gradient

**AMMA-MIP**: Hourdin et al. (2010)

**cloud frequency of occurrence**, Aug, CloudSat-Calipso

**Sfc meteo**

$T_{2m}, q_{2m}$: monthly–mean diurnal cycles [Agoufou]

Guichard et al. (2009)

Bouniol et al. (2012)
A common tendency to overestimate $R_{net}$ in Spring

Stronger $R_{net}$ for models with lower rainfall, the opposite in observations (interannual)

Means errors in $H$ and LE
Larger spread in $SW_{in}$ than in $R_{net}$ indicative of distinct balance of processes in each model (compensations of errors) raises model sensitivity issues.
Surface incoming shortwave flux $SW_{in}$ clear sky

Not at all the same clear sky!! why?

clean v clear sky

Some clarifications to arise from Olivier's work
**cfSite Budgets**

*Several reasonable features*

- **Diurnal cycle:** nighttime advection of cooler & moister air during the early monsoon
- **Seasonal transformation of the surface, boundary layer and clouds**
- **Some consistency of the sensitivity of the convective BL to surface evaporative fraction**

But notable difficulties, during the months of establishment of the monsoon (May to August) with large quantitative differences

**Importance of daytime processes for SEB**

1) Dynamics of the diurnal cycle of the atmospheric low levels in ≠ environments sensitivity to rainfall range, cloud radiative impact...

2) Design a few selected cases & design 1D simulations using data and observationally-based datasets as guides, further simplify the setup whenever relevant
Adapted from Gounou et al. (2012)

10-day mean diurnal cycles
lower atmosphere
[0, 500m]
SCM SET-UP

4 cases, 10-day run each: guinean (heavily cloudy), soudanian (convective, wet), sahelian monsoon (deep convection), Sahel in late spring (moist but not wet, no rain, semi-arid)

Simulations performed with MesoNH
10x 1 day or 1 x 10 days

atmos. initialisation

atmos. boundary conditions
larger-scale advection

Early morning
profiles

soundings
or reanalyses

θ

Surface initial &
boundary conditions

Surface properties & state

albedo, emissivity...

soil moisture, soil temperature

Local data
& ALMIP, Boone et al BAMS 2009)

sensible & latent
heat fluxes

ECMWF AMMA reanalysis
(3h) used a broad guide
(sensitivities & corrections)

niame, 20–30 Jun 2006

height (km AGL)

hour in day

r
v

U
larger-scale advection

diagnosed from the ECMWF AMMA reanalysis

limitations: deep convection, low-level monsoon bursts (too weak)... drifts but still usually able to capture synoptic variability in convective activity

high cloud top often coincides with local strong max of omega in ERA-AMMA (omega<0 equiv. to positive vertical velocity)

no high cloud top corresponds to periods with enhanced subsidence in ERA-AMMA (red)
Couvreux et al. (2013)
semi-arid

convective

convective moister

heavily cloudy

Simple setup from which studying coupled processes in model

Couvreux et al. (2013)
difficult to conclude from such a literal comparison
many 'climatic' differences at a given location among models
All (6) sites from The Guinean Gulf to the Sahara (3.5°N to 20.5°N) 30 years

Monthly mean Diurnal cycles sorted by monthly mean precipitation rate

Some consistency but surprisingly distinct behaviour of each model
Summary

Much more CMIP5 cfSites outputs than one year ago, IPSL-CM5s (3), EC-Earth, + 3 others

- broadly speaking, AMIP runs: numerous features of the West African monsoon, even regarding fine-scale phenomena such as the diurnal cycle of the monsoon flow dynamics
- basic issues with the simulation of the annual cycle (location in both space and time), differences among models dominate over interannual variability of each (possibly too weak)
- large differences in clear sky SWin and LWin at the surface (a few tens of W.m$^{-2}$)
- data indicate large biases in SEB with more spread in SWin than in Rnet (not intuitive)

Daytime dynamics of the surface and lower atmosphere (SEB, thermodynamics, clouds)

- characterized from observations, focused on ≠ land regimes, documented SEB, BL & clouds
- set-up of a simple framework to jointly simulate these cases with a model (SCM, LES)
  - biases involve distinct feedbacks between surface, BL & clouds depending on the mean state
  - biases do not appear to be so strongly driven by the large-scale dynamics, emphasizes the importance of local physical processes, and of their couplings

- CMIP5 cfSites:
  differences in the mean thermodynamics of the low levels strongly linked to mean rainfall but daytime evolution still displays important model-specificities

Next step: use cfSites profiles and budgets to analyse these differences (surface, BL & clouds), analyse of feedback loops, similarities with finding from SCM?
ordered by monthly precipitation (mm): 50 100 150 200 250 300 350 400 450 500
(b) CONVECTIVE WET