Towards a regional climate modeling system for West Africa: sensitivity studies, input bias correction and hydrological coupling

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OBJECTIVE: Provide a regional climate modeling system able to reproduce the observed West African climate, in preparation to land use change and climate change impact studies that will be done in the context of WASCAL

SENSITIVITY STUDY

Weather Research and Forecasting (WRF) Model Set-up

The regional climate model (RCM) used for this study (**WRF**) provides a large choice of physical parameterizations. Results sensitivity to some commonly used schemes is investigated here:

3x Cumulus Schemes (CU): Betts-Miller-Janjic (BMJ), Grell-Freitas (GF), Kain-Fritsch (KF)

3x Planetary Boundary Layer Schemes (PBL): Asymmetric Convective Model, V.2 (ACM2), Mellor-Yamada-Janjic (MYJ), Yonsei University (YSU)

3x Microphysics Schemes (MP): Lin Purdue (LIN), Thompson (TH), WRF Single Moment 3 (WSM3)

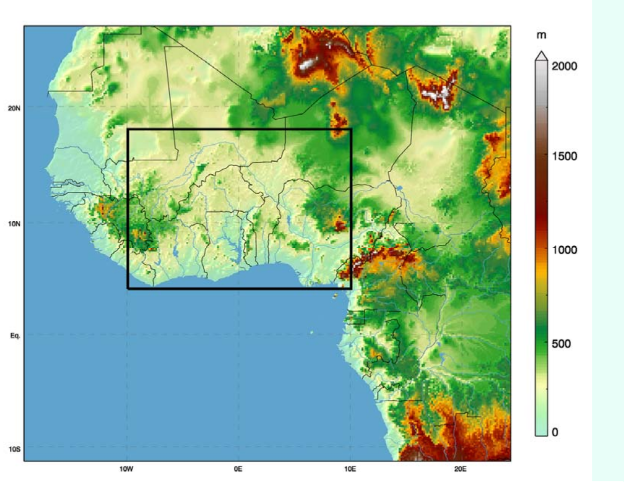

Fig. 1: WRF model domain and topography. Regions of interest are outlined.

→ all combinations totaling in **27 simulations**

Fixed model parameters:

Forcing Data: ERA-Interim[1] (ERA-I)
SST Data: NCDC
Resolution: 24km
Vert. levels/model top: 36 / 50hPa

Model physics: Noah land surface model, RRTMG long-wave radiation, Dudhia short-wave radiation

Time period: Apr-Oct 1999

Precipitation

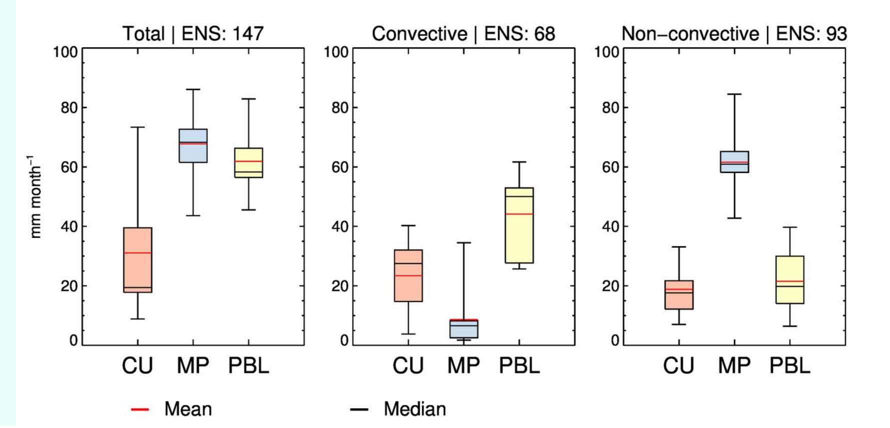

Fig. 2: Jun-Sep 1999 total (left), convective (middle) and non-convective (right) precipitation spreads with the total ensemble spread (ENS). Each box consists of nine spreads computed between the three members that differ in one parameterization scheme only.

Non-convective: MP schemes have a major influence with a spread of ~ 60 mm month^{-1}

Convective: PBL shows the largest spread but the large interquartile-spreads of PBL and CU illustrate their non-linear interplay

Total: Sensitivity to PBL and MP is almost equal with reduced but highly variable importance of CU

Monsoon dynamics

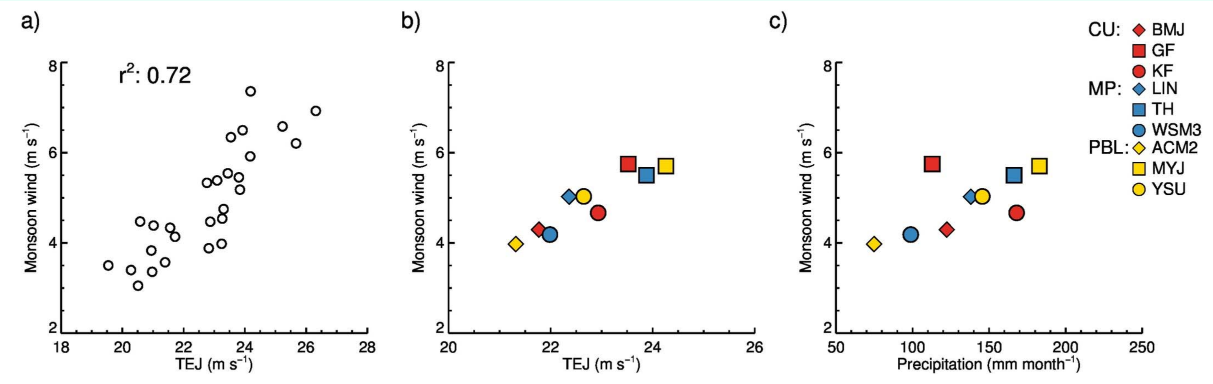

Fig. 3: Aug 1999 monsoon wind versus (a) TEJ velocity for all ensemble members, (b) TEJ velocity for each parameterization group, (c) Sahel precipitation (Fig. 1) for each parameterization group. Each group consists of the mean of nine members that use the indicated parameterization scheme.

a) Correlation of monsoon wind and Tropical Easterly Jet (TEJ)
→ inter-member differences result from differing intensities of the moist Hadley-type overturning

b) Parameterization schemes can be ranked according to the intensity they induce (weak<strong):
CU: BMJ<KF<GF ; **MP:** WSM3<LIN<TH; **PBL:** ACM2<YSU<MYJ

c) The ranking for Sahel precipitation (indicates northward extent of monsoon) is accordingly for MP and PBL. Convective precipitation produced by CU is not linearly related to the monsoon dynamics

INPUT BIAS CORRECTION

Comparison of input bias correction methods

- Global circulation models (GCMs) are commonly used to initialize and force regional climate models (RCMs), but large GCM biases can deteriorate the regional models
- Here, we compare two bias correction methods for GCM data prior to ingesting them into the regional climate model (Fig.4)
- We conduct 10-year long simulations at 18km grid spacing with WRF using MPI-ESM (GCM) / ERA-Interim re-analysis (REA)

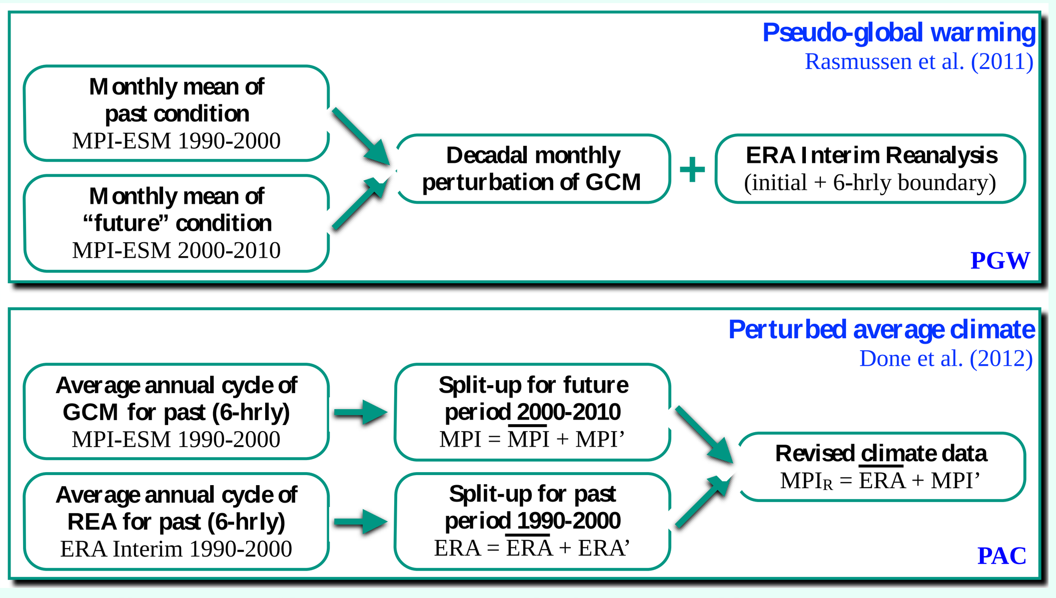

Fig. 4: Illustration of bias correction methods compared here

Bias correction code

- A fully parallelized Python/Redis code was developed to perform the bias-correction (Fig. 5)
- Validation of the generated input data at boundary and surface
- Verification of WRF model output for temperature, rainfall, pressure, wind (see Figs. 6-8 for examples)

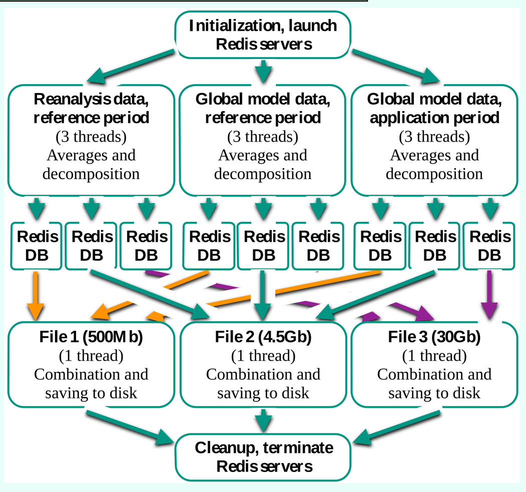

Fig. 5: Flowchart of bias correction code

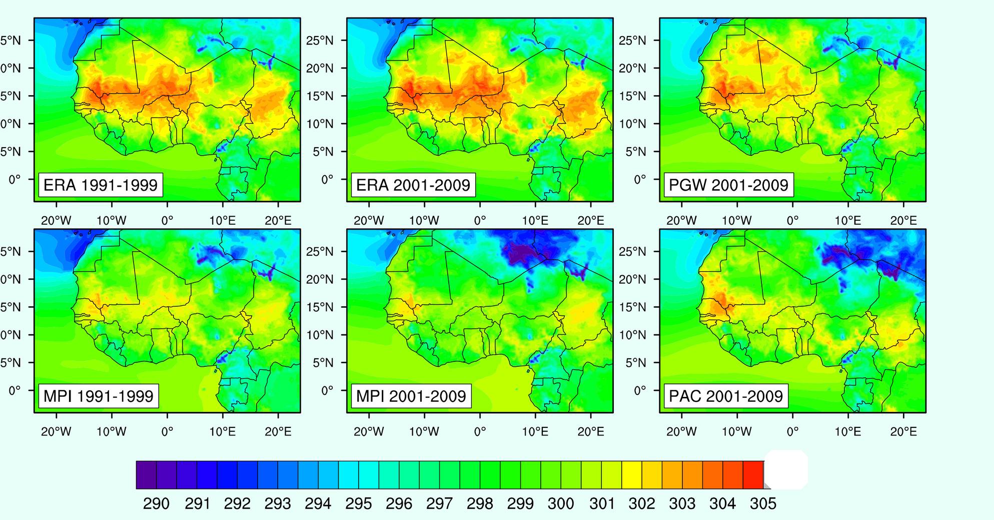

Fig. 6: WRF 10-year mean 2m temperature [K]

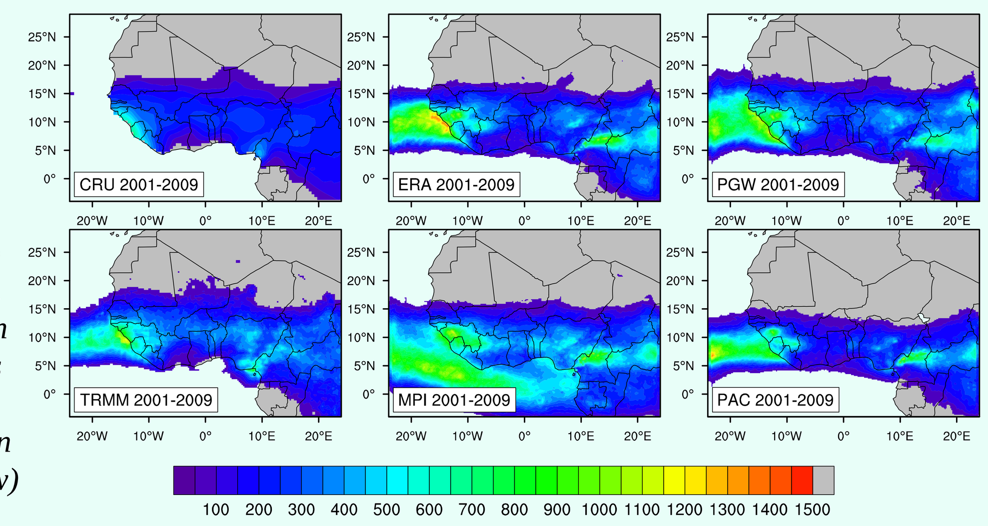

Fig. 7: WRF 10-year mean rainfall [mm] in August. PGW is closer to ERA, while PAC is close to MPI over land. Bias-correction of SST corrects offshore rains. Sahel too dry in PAC (see below)

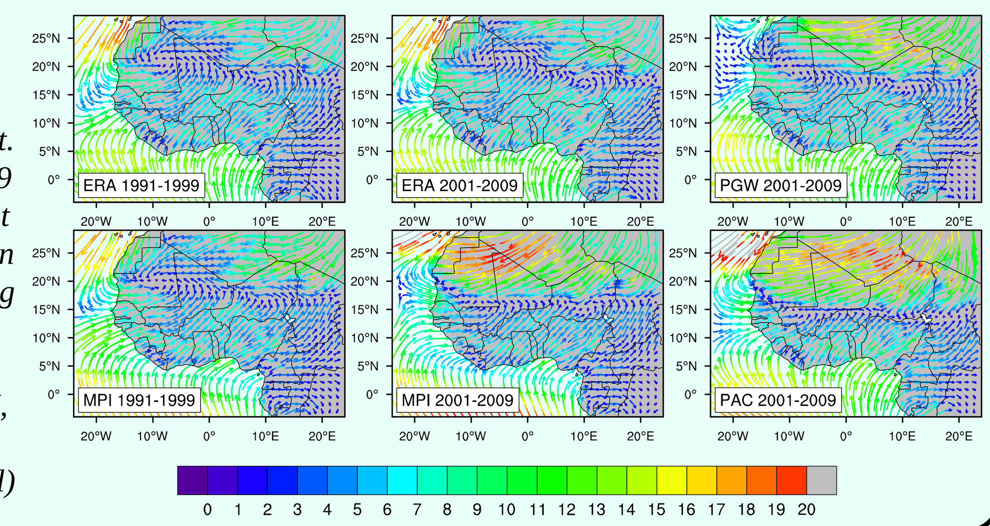

Fig. 8: WRF 10-year mean surface wind [m/s] in August. MPI 2000-2009 and PAC do not show a Saharan heat low. Strong onshore winds push moisture inland for MPI, but less so for PAC (dry Sahel)

HYDROLOGICAL COUPLING

Atmospheric-Hydrological Model (WRF-Hydro) Set-up

- It is questionable whether a more detailed representation of hydrological processes would improve the simulated climate
- To test this hypophesis we use **WRF-Hydro** for the case of the undamed Sissili watershed (figs 9, 10) in **2013**, when **hydro-meteorological fluxes observations** are available (energy fluxes at the EC station of Nazinga and streamflow at Wiasi)

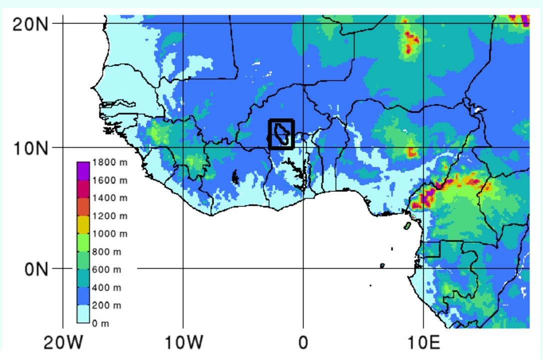

Fig. 9: Topography of the WRF domains

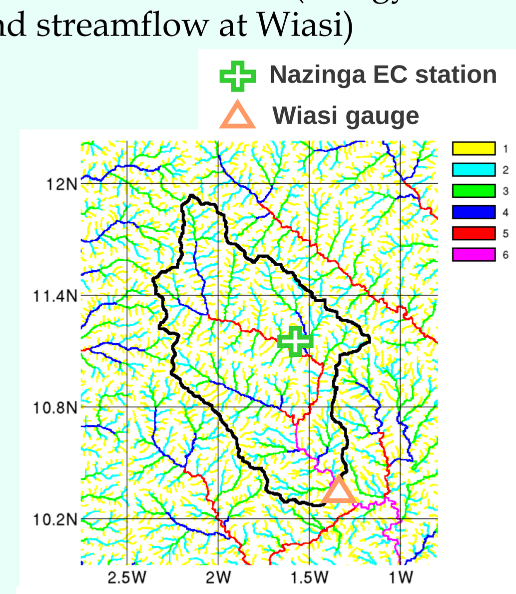

Fig. 10: River network (with Strahler stream order) of the Sissili watershed

Model strategy:

- Two nested **WRF** domains at 10 and 2 km resolution (Fig. 9) for the year 2013,
- Inner WRF domain coupled with **NDHMS**[1] for computing overland and river water flow on a 200 m resolution grid (Fig. 10)

[1]NCAR Distributed Hydrological Modeling System

Precipitation – Discharge (Sissili watershed)

- **WRF-Hydro** reproduces reasonably well the weekly areal rainfall obtained from the Tropical Rainfall Measuring Mission (TRMM) (fig. 11)
- Simulated weekly discharge at Wiasi (fig. 11) will be validated in a future study when the observed streamflow in 2013 will be delivered

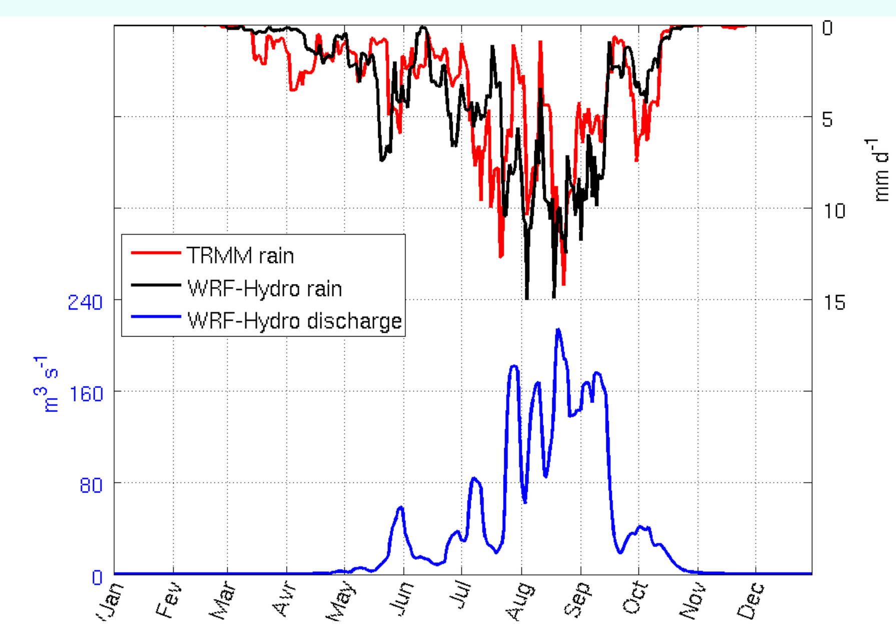

Fig. 11: Weekly rain (for the Sissili watershed) and weekly discharge (at Wiasi) from TRMM and WRF-Hydro for the ***year 2013***

Energy Fluxes at the Nazinga EC station

- Net Radiation flux (R_{NET}), sensible (H) and latent (LH) heat fluxes are generally overestimated, and the ground heat flux (G) underestimated (Fig. 12)
- The overestimation of R_{NET} mainly comes from the overestimation of the incoming short radiation flux (SW DOWN in Fig. 13)
- The outgoing shortwave radiation flux (SW UP in Fig. 13) is also generally overestimated

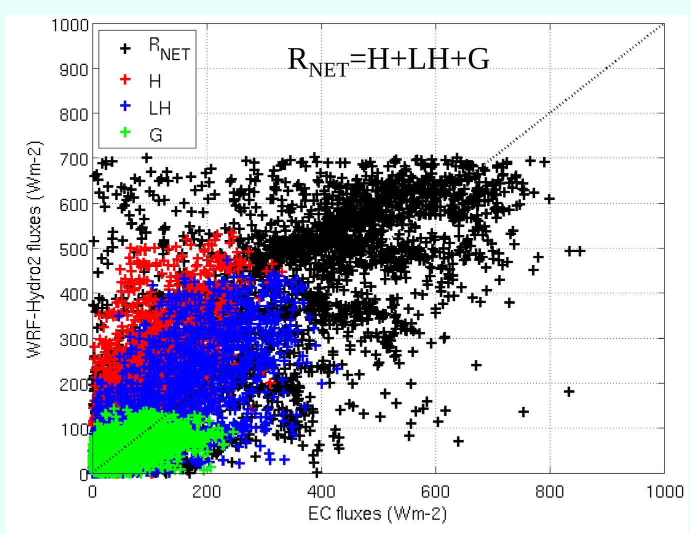

Fig. 12: Scatterplot of hourly surface energy fluxes for the ***year 2013****, between WRF-Hydro and EC observations*

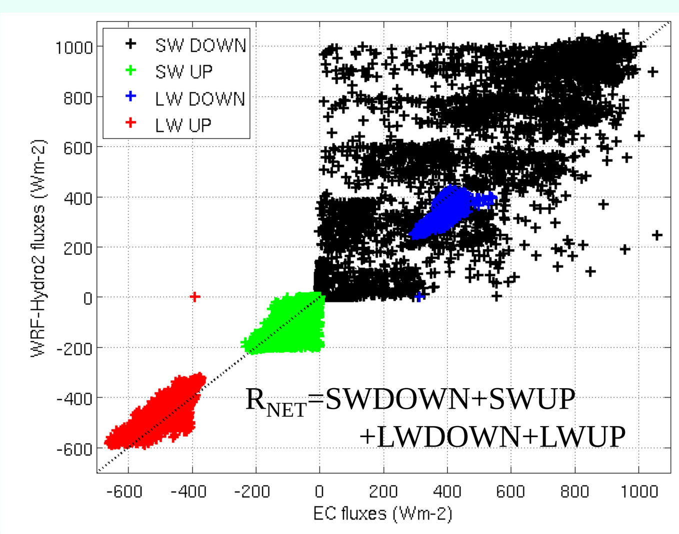

Fig. 13: Scatterplot of hourly surface radiation fluxes for the ***year 2013****, between WRF-Hydro and EC observations*

CONCLUSIONS AND PERSPECTIVES

Sensitivity study: The impact of the parameterization schemes could be classified with respect to their impact on the monsoon dynamics. This knowledge will be used to set up the model for subsequent land-atmosphere interaction studies with improved land-use information.

Bias correction: Both methods improve temperatures compared to observations. PGW follows re-analysis and removes GCM features. PAC does not produce monsoon rains over the Sahel (GCM does, but for the wrong reasons)

Hydrological coupling: Calibrate model parameters for a period when Wiasi discharge data are available, validate for a multiyear run, diagnose to which extend WRF-Hydro improves the simulated climate with respect to WRF

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