Evaluation of a Fully Coupled Atmospheric-Hydrological Modeling System for the Sissili Watershed in the West African Sudanian Savannah

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JOEL ARNAULT[1,2], L. HINGERL[1], J. BLIEFERNICHT[1],
S. ANDRESEN1[1], T. RUMMLER[1], A. ADUNA[3], H. KUNSTMANN[1,2]

[1] Institute of Geography, Augsburg University, Alter Postweg 118, 86159 Augsburg, Germany
[2] Institute of Meteorology and Climate Research, Karlsruhe Institute of Technology, Germany
[3] WASCAL Competence Center, Ouagadougou, Burkina Faso

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3. SET-UP OF THE NUMERICAL EXPERIMENT (WRF & WRF-HYDRO)
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1. OBJECTIVES

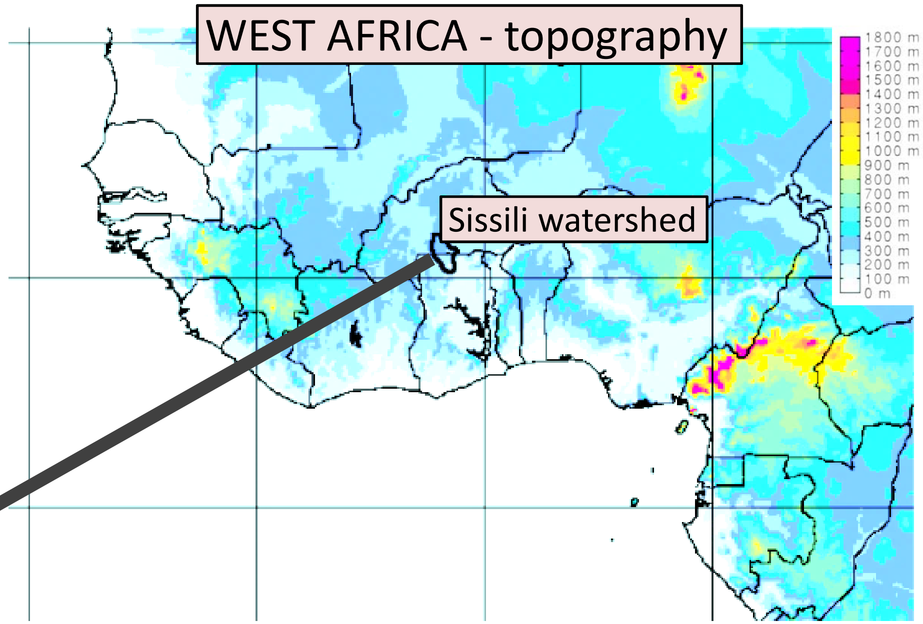
- **LONG TERM GOAL:**
  - **Evaluate the impact of land use change on the West African climate with WRF-Hydro (i.e. the Weather Research and Forecasting Model coupled with the NCAR Distributed Hydrological Modeling System NDHMS), in the framework of WASCAL (West African Science Service Center for Climate Change and Adaptive Land Use)**

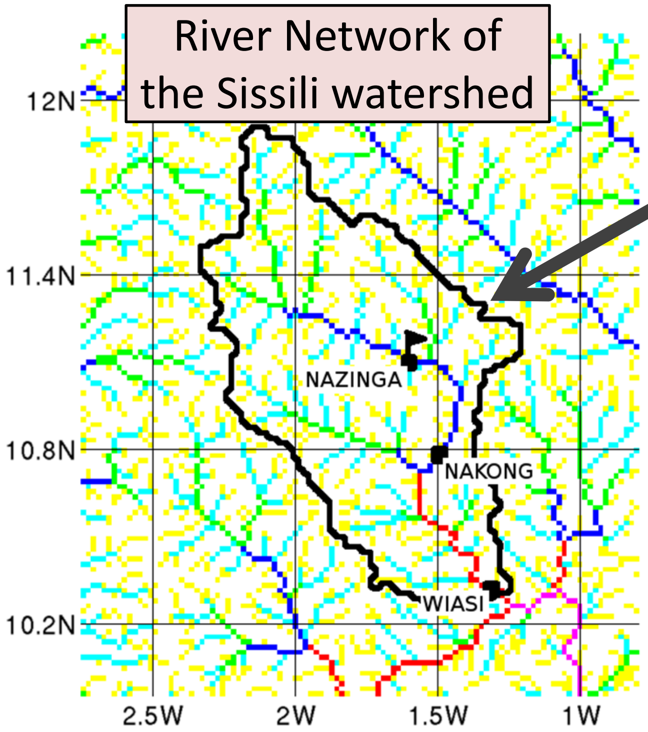
- **SHORT TERM GOAL:**
  - **Provide a WRF-Hydro set-up able to reproduce both atmospherical and hydrological components of the observed West African climate**

2. OBSERVATIONAL DATA AVAILABLE

- **GROUND MEASUREMENTS (2013)**

  - **Flux measurements at the eddy covariance tower site of the Nazinga Park, since October 2012**





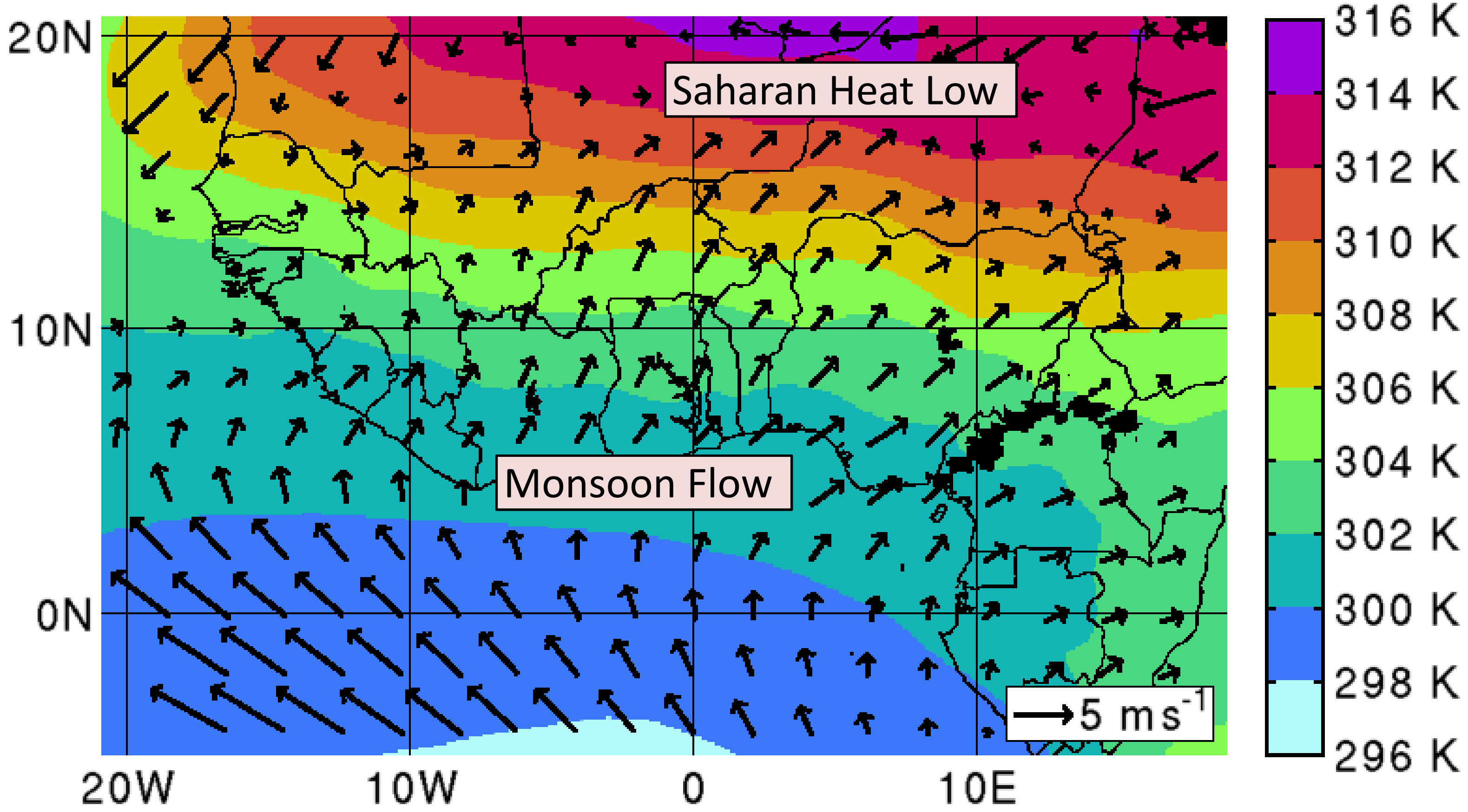
- **Daily discharge observations at two hydrological stations along the Sissili river: Nakong and Wiasi, available for the period 2003-2008**

- **Discharge data for 2013 will be available soon**

2. OBSERVATIONAL DATA AVAILABLE

- **GRIDDED OBSERVATIONAL DATA (2013)**

  - **ERA-Interim reanalyses → Dynamics of the West African Monsoon**
    - ✓ **Low-level winds (arrows) and potential temperature (colors) @1000m height temporally averaged for May – October 2013.**



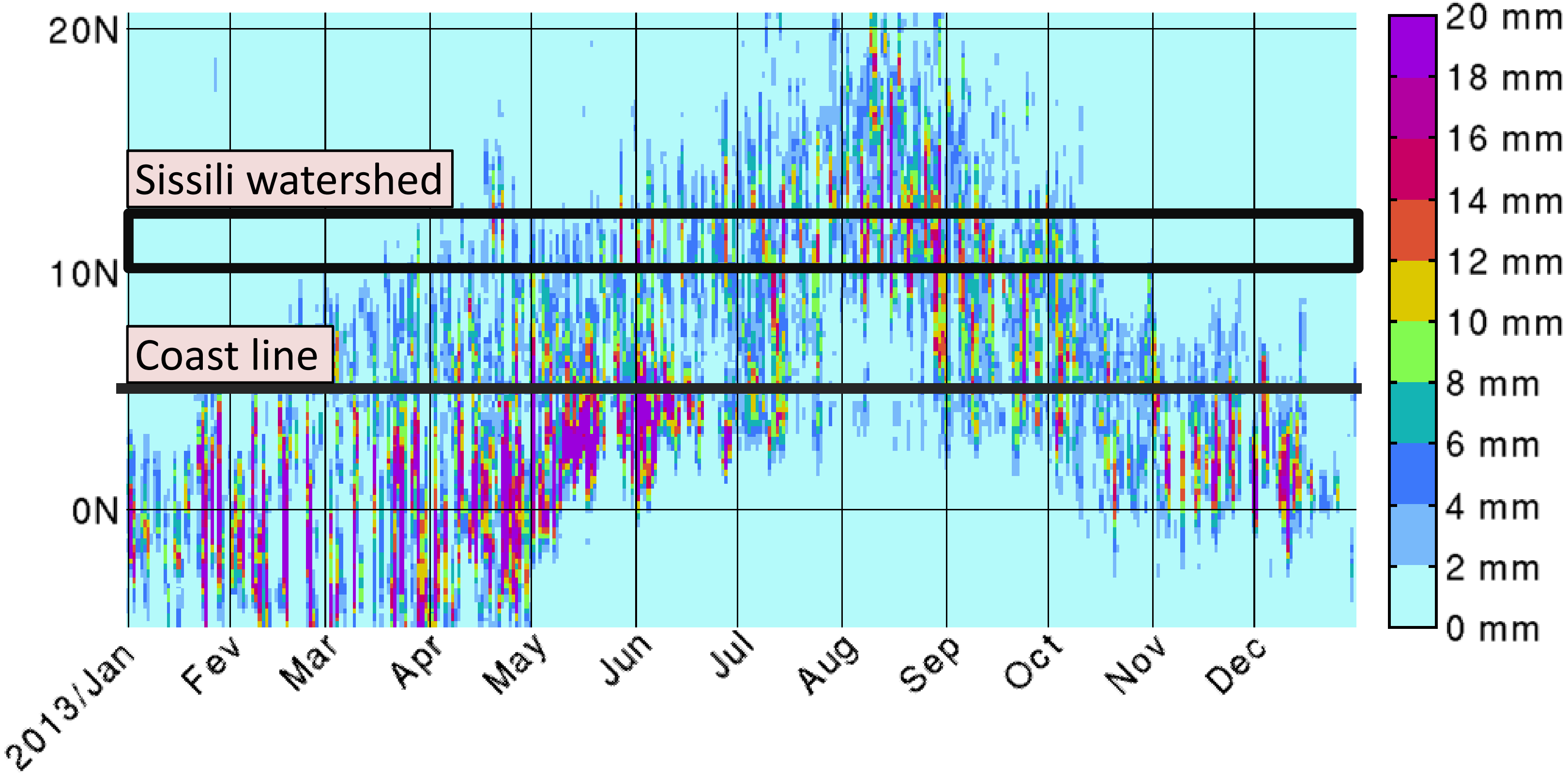
2. OBSERVATIONAL DATA AVAILABLE

- **GRIDDED OBSERVATIONAL DATA (2013)**

  - **Daily Precipitation from the Tropical Rainfall Measuring Mission (TRMM)**

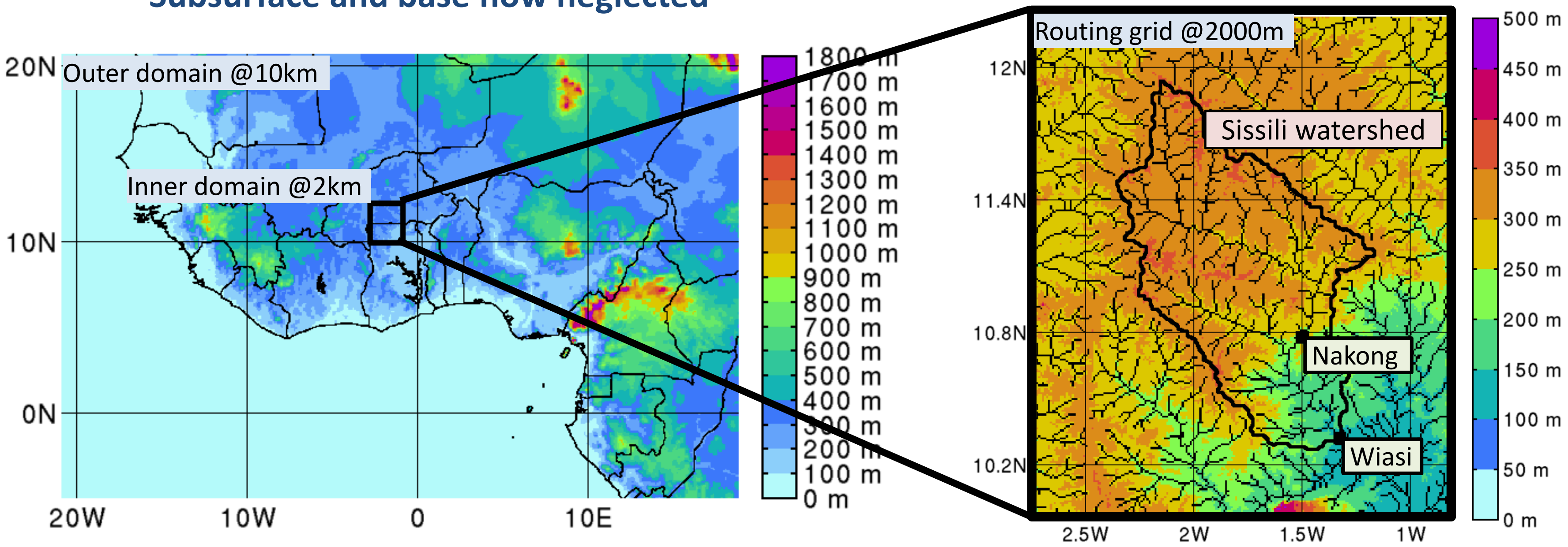
  → **Latitudinal displacement of the tropical rainbelt**

    ✓ **Time-latitude diagram of daily precipitation zonally averaged between 8°W and 8°E**



3. SET-UP OF THE NUMERICAL EXPERIMENTS

- <u>WRF:</u> Two nested domains @10km and @2km (Outer domain forced by ERA-Interim data)
  - 35 vertical levels with a pressure model top at 20 hPa
  - Long and short wave radiation: RRTM and MM5 schemes
  - No Cumulus scheme, Microphysics: WSM 5-class scheme
  - Planetary boundary layer: YSU (Yonsei University) scheme
  - Land-atmosphere exchanges: 1-dimensional NOAH Land Surface Model
- **<u>WRF-Hydro:</u> Inner domain coupled with NDHMS using a routing grid @2000 m**
  - **Infiltration excess controlled by kdt_{ref} = 3 (default value)**
  - **Overland flow and stream flow computed with default surface and channel roughnesses**
  - **Subsurface and base flow neglected**



- **These WRF and WRF-Hydro set-up are run for a 12-month period in 2013**

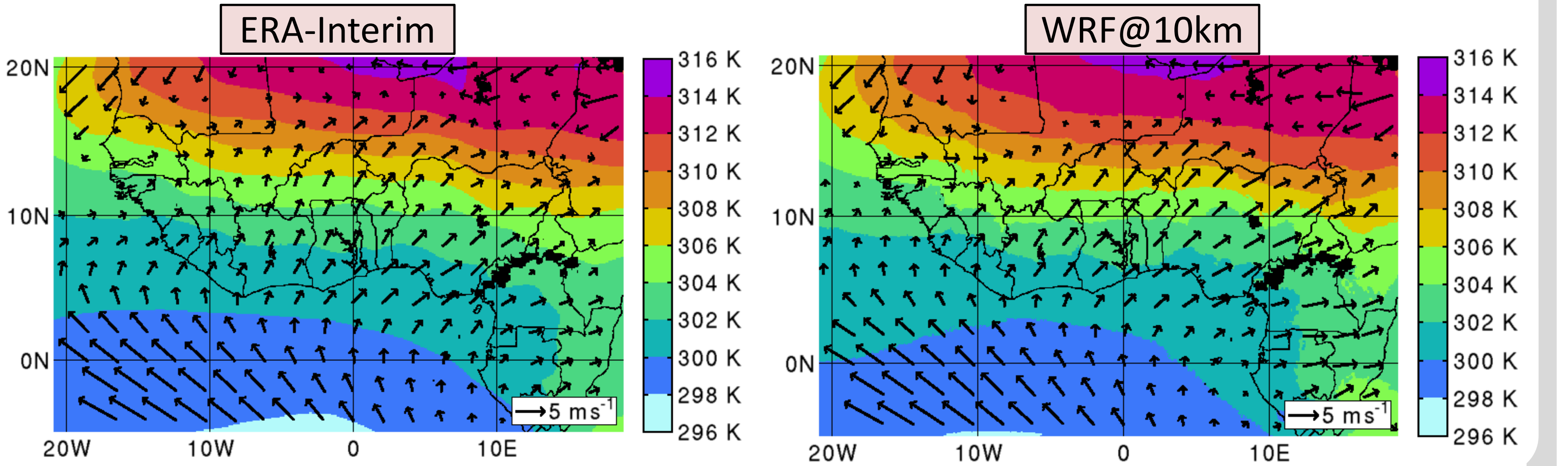
4. RESULTS

- <u>DYNAMICS OF THE WEST AFRICAN MONSOON IN 2013</u>
  - ✓ **Low-level winds (arrows) and potential temperature (colors) @1000m height temporally averaged for May – October 2013.**

➢ **Compared to ERA-Interim, WRF@10km slightly overestimates the strength of the monsoon winds on the continent**

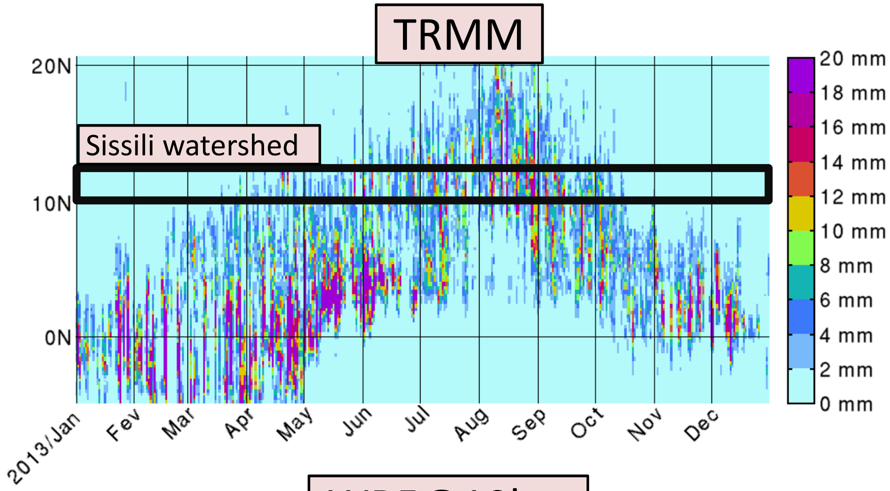
➢ **In WRF@10km the northern boundary of the southwesterlies is 2 degrees south compared to ERA-Interim**

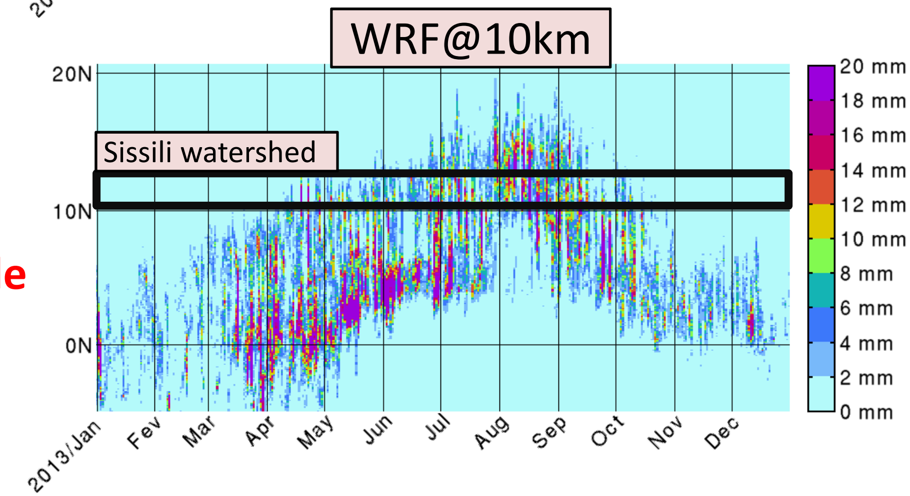
➢ **These dynamical differences certainly have an impact on the precipitation modelled by WRF**



4. RESULTS

- <u>LATITUDINAL DISPLACEMENT OF THE TROPICAL RAINBELT IN 2013</u>
  - ✓ **Time-latitude diagram of daily precipitation zonally averaged between 8°W and 8°E)**

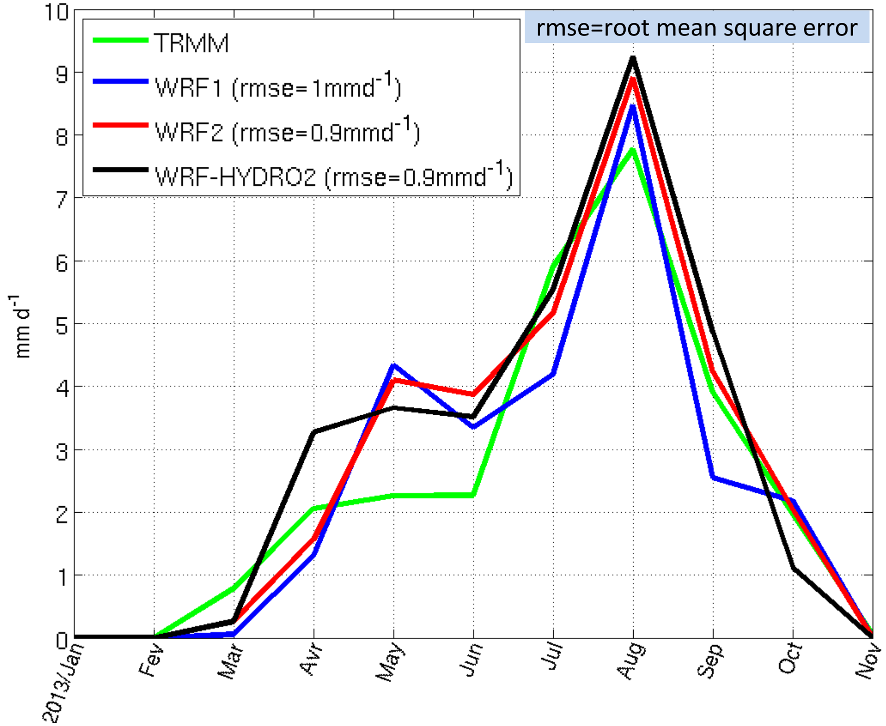


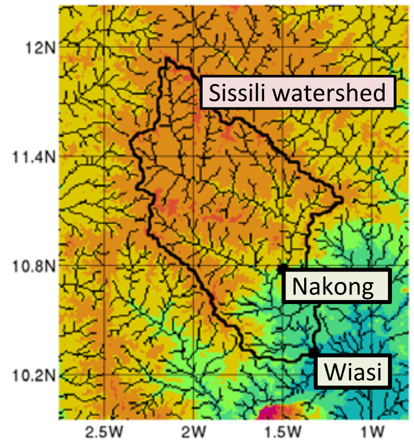


- ➢ **WRF is able to reproduce the latitudinal displacement of the rainbelt**
- ➢ **Modelled daily precipitation amounts are comparable to TRMM, especially at the latitudes of the Sissili watershed**
- ➢ **The simulated rainbelt is shifted 2 degrees south at its northern boundary, as the simulated southwesterlies (previous slide)**
- ➢ **Continental precipitation during the West African Monsoon is mainly due to Mesoscale Convective Systems, which are apparently well resolved in a WRF simulation @10km without cumulus scheme**

4. RESULTS

- **MONTHLY AREAL RAIN FOR THE SISSILI WATERSHED (2013)**
  - from TRMM
  - from the outer domain of the WRF simulation
  - From the inner domain of the WRF simulation
  - from the inner domain of the WRF-Hydro simulation

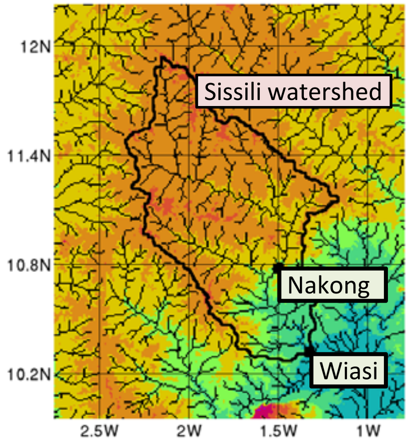


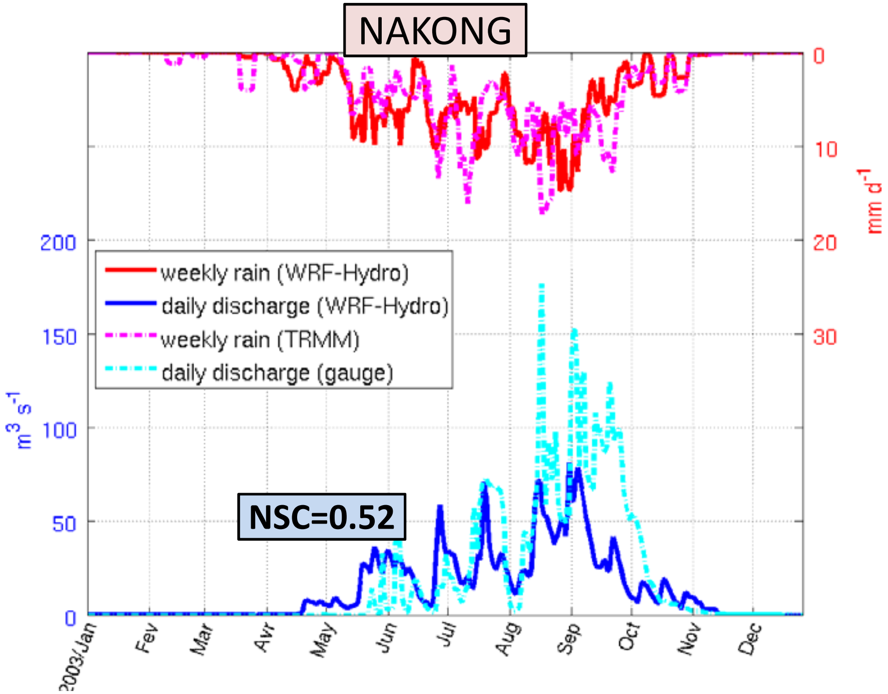


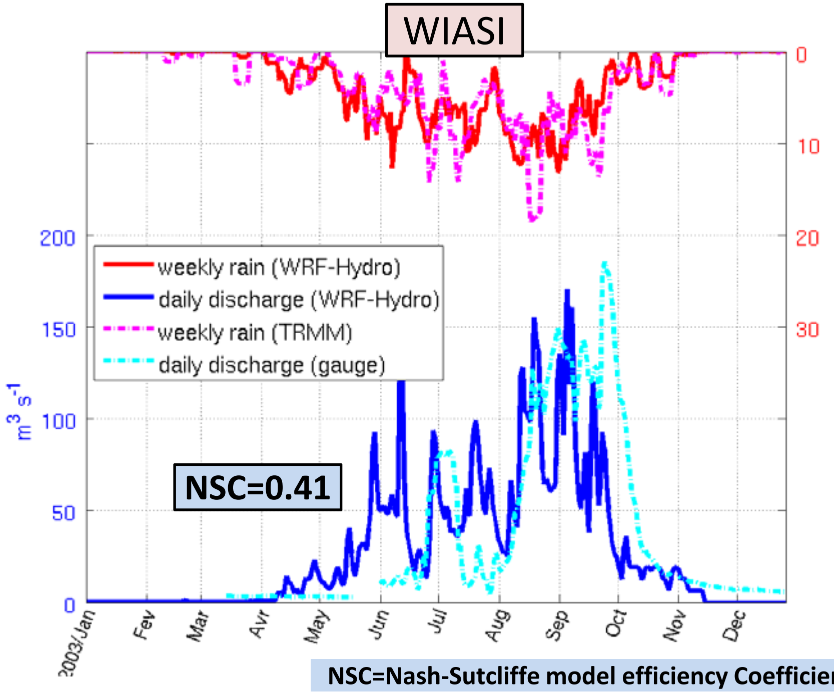
- **The outer, inner domains of the WRF and WRF-Hydro simulations all produce different monthly precipitation amounts, but relatively close to TRMM (rmse ~ 1 mmd^{-1})**

4. RESULTS

- DISCHARGES FOR THE SISSILI WATERSHED (2003)
  - An additional WRF-Hydro simulation has been run for 2003, when discharges data at Nakong and Wiasi is available
  - Default infiltration excess, surface and channel roughnesses already give reasonable modelled discharges
  - Lack of modelled discharge in September:
    - lack of modelled precipitation ?
    - subsurface and base flow not taken into account yet ?



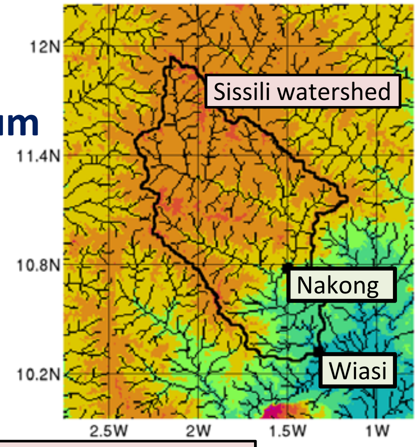




NSC=Nash-Sutcliffe model efficiency Coefficient

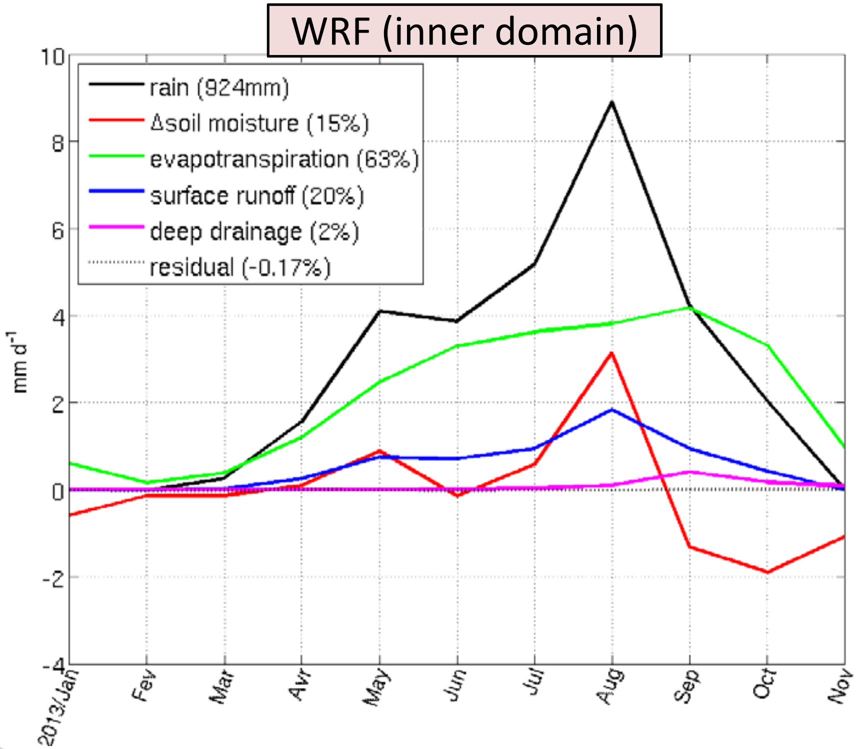
4. RESULTS

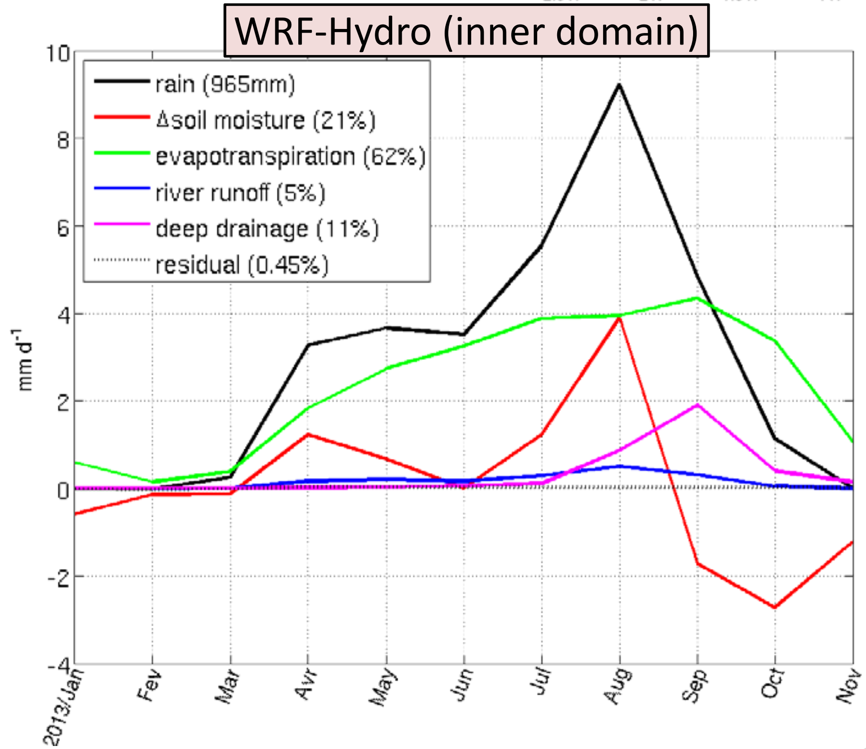
- **WATER BUDGET FOR THE SISSILI WATERSHED (2013)**



Rain = ΔSoil Moisture + Evapotranspiration + runoff + deep drainage + Residuum

- **The surface runoff neglected in WRF is distributed to river runoff, soil moisture, and deep drainage by WRF-Hydro**
- **Which proportion of the drained water comes back to the surface in reality ? → Need for a Ground Water Model**

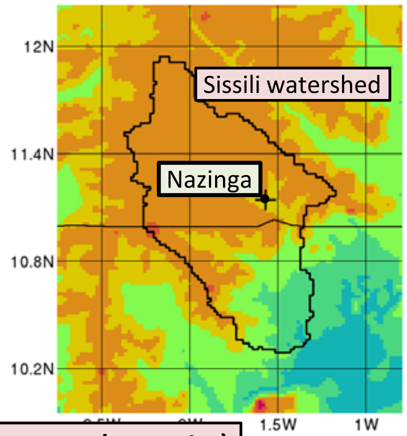




4. RESULTS

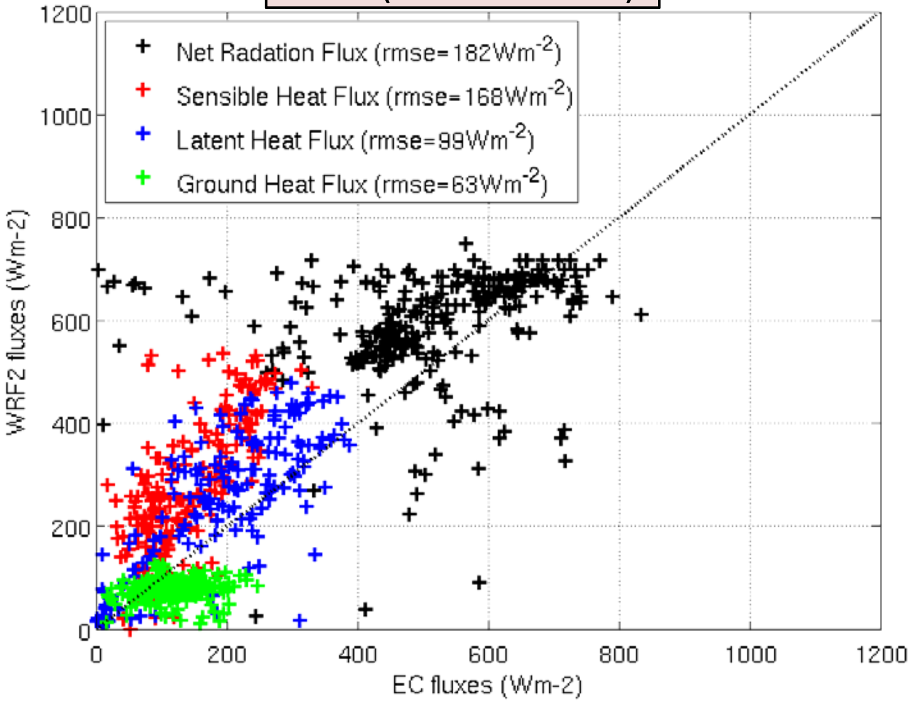
- **ENERGY FLUXES AT THE TOWER SITE OF „NAZINGA“ (2013)**

Net Radiation = Sensible Heat + Latent Heat + Ground Heat + Residuum

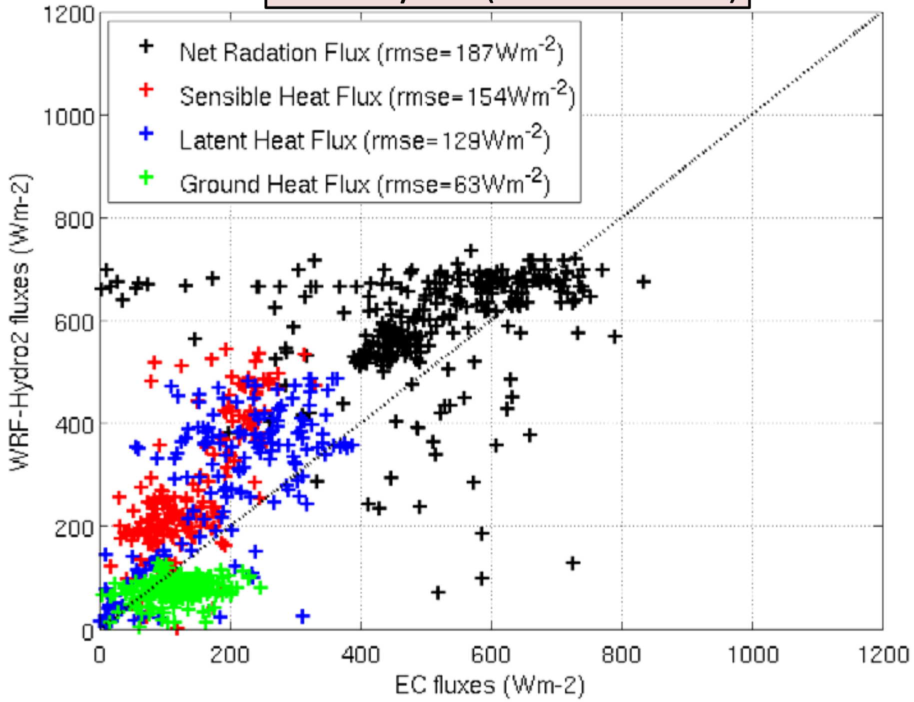


- ➢ **Observed fluxes between 12 and 13 UTC for the whole year 2013 are compared with the simulated ones**
- ➢ **Compared to WRF, WRF-Hydro decreases the rmse of Sensible Heat, but increases the rmse of Latent Heat**

WRF (inner domain)

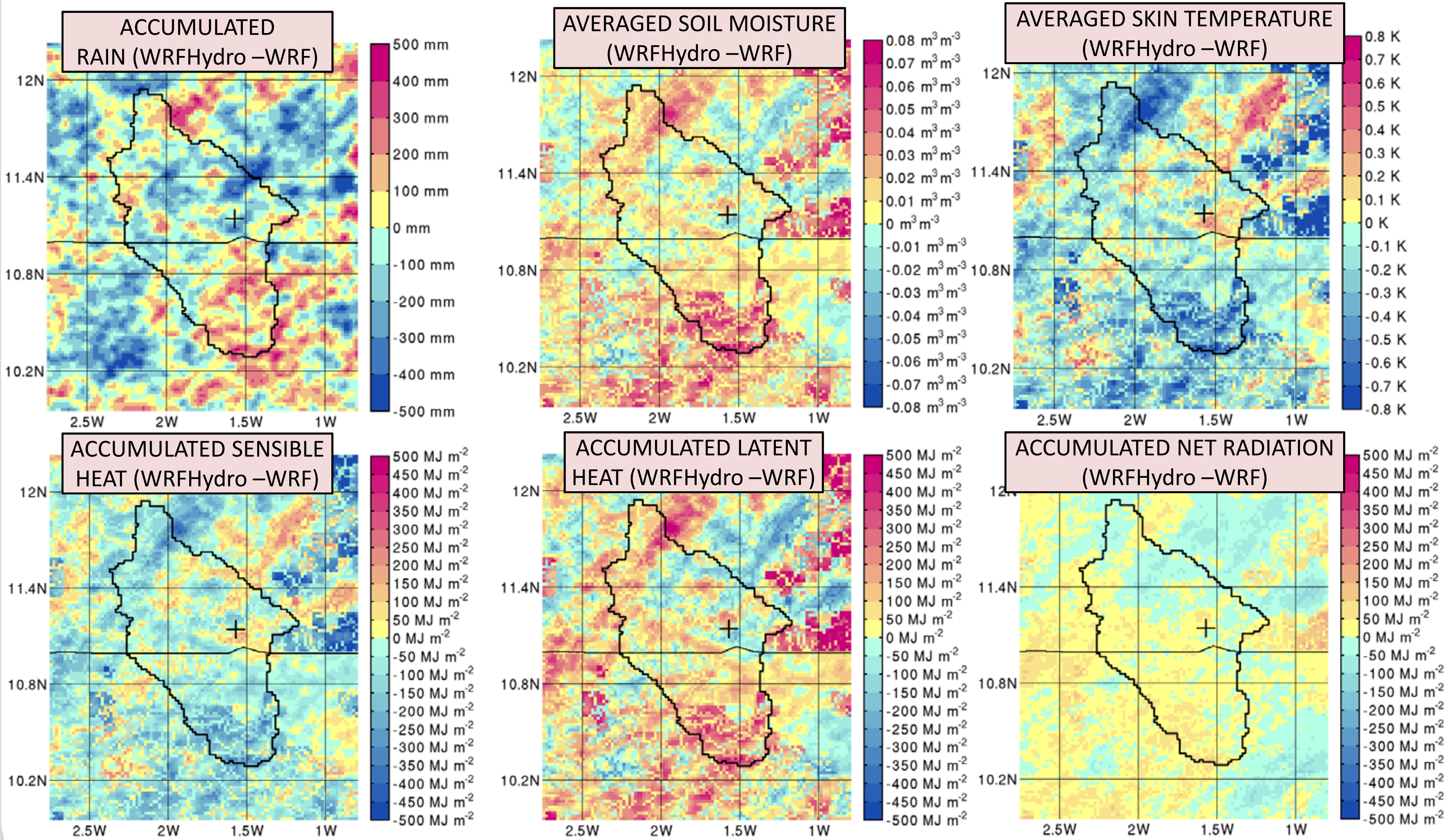


WRF-Hydro (inner domain)



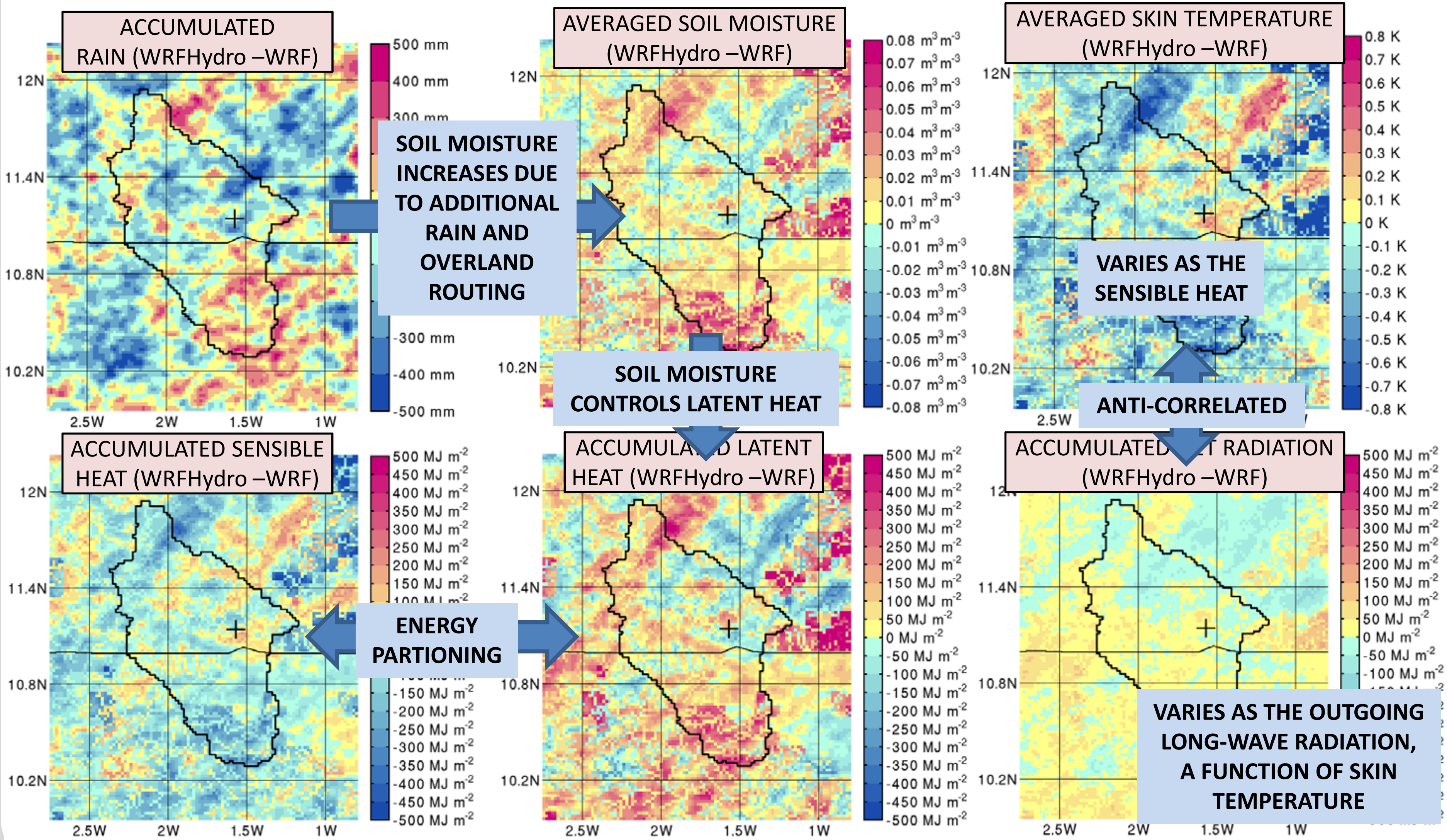
4. RESULTS

- **OUTCOMES OF WRF-Hydro (May-October 2013)**



4. RESULTS

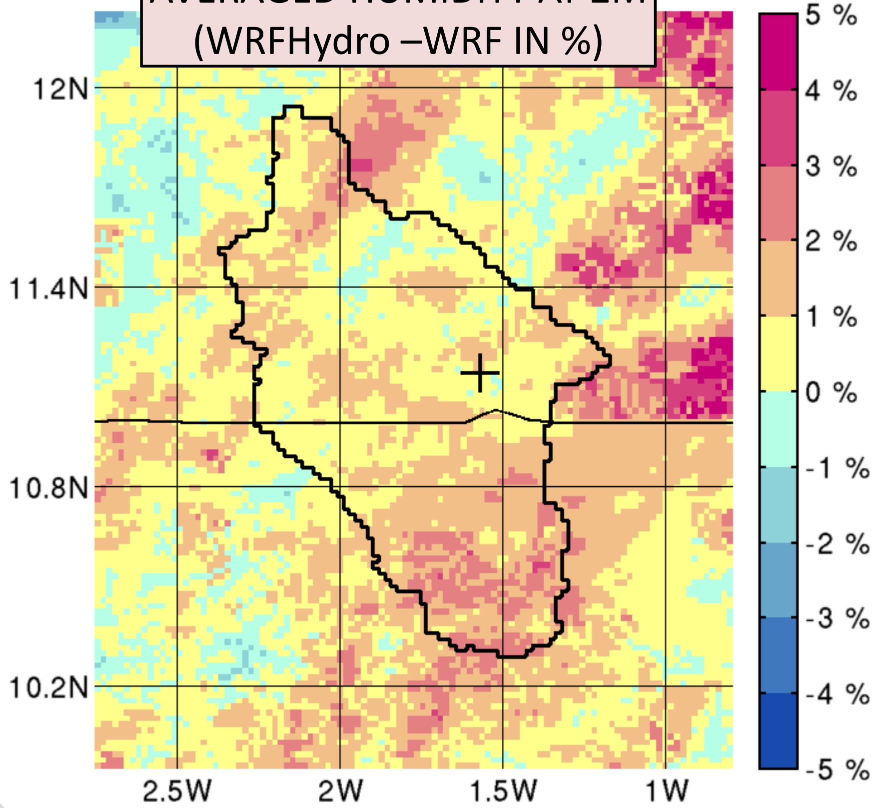
- <u>**OUTCOMES OF WRF-Hydro (May-October 2013)**</u>



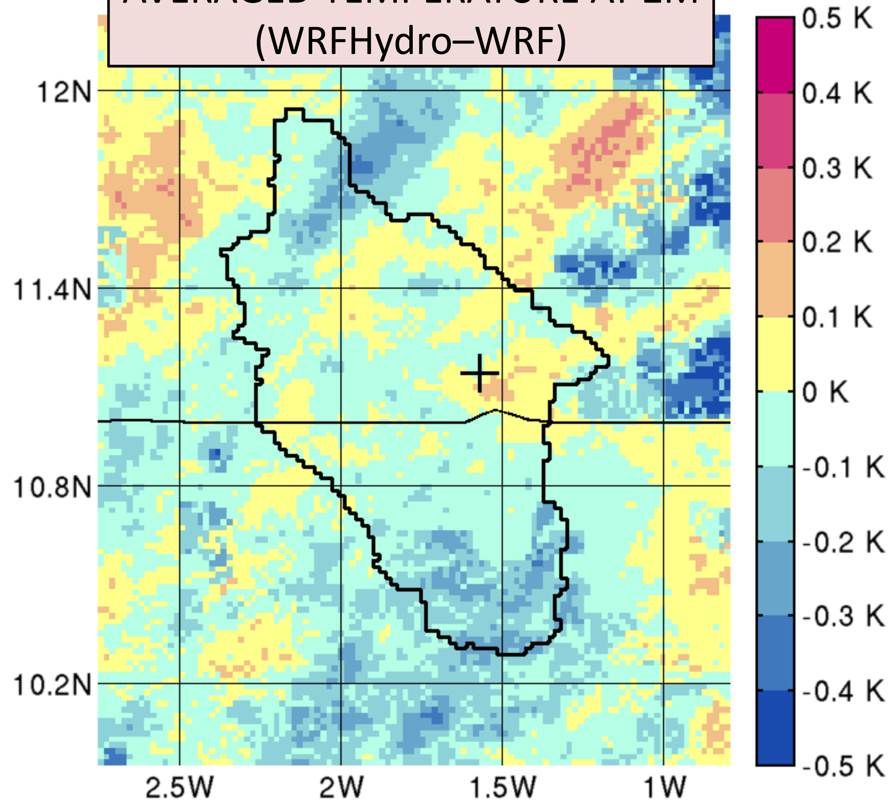
4. RESULTS

- **OUTCOMES OF WRF-Hydro (May-October 2013)**
  - **Compared to WRF, WRF-Hydro does modify the bottom boundary condition of the modelled atmosphere for the period May-October 2013:**
    - **Increase of humidity at 2m up to 5%**
    - **Decrease of temperature at 2m up to 0.5 K**

AVERAGED HUMIDITY AT 2M (WRFHydro –WRF IN %)

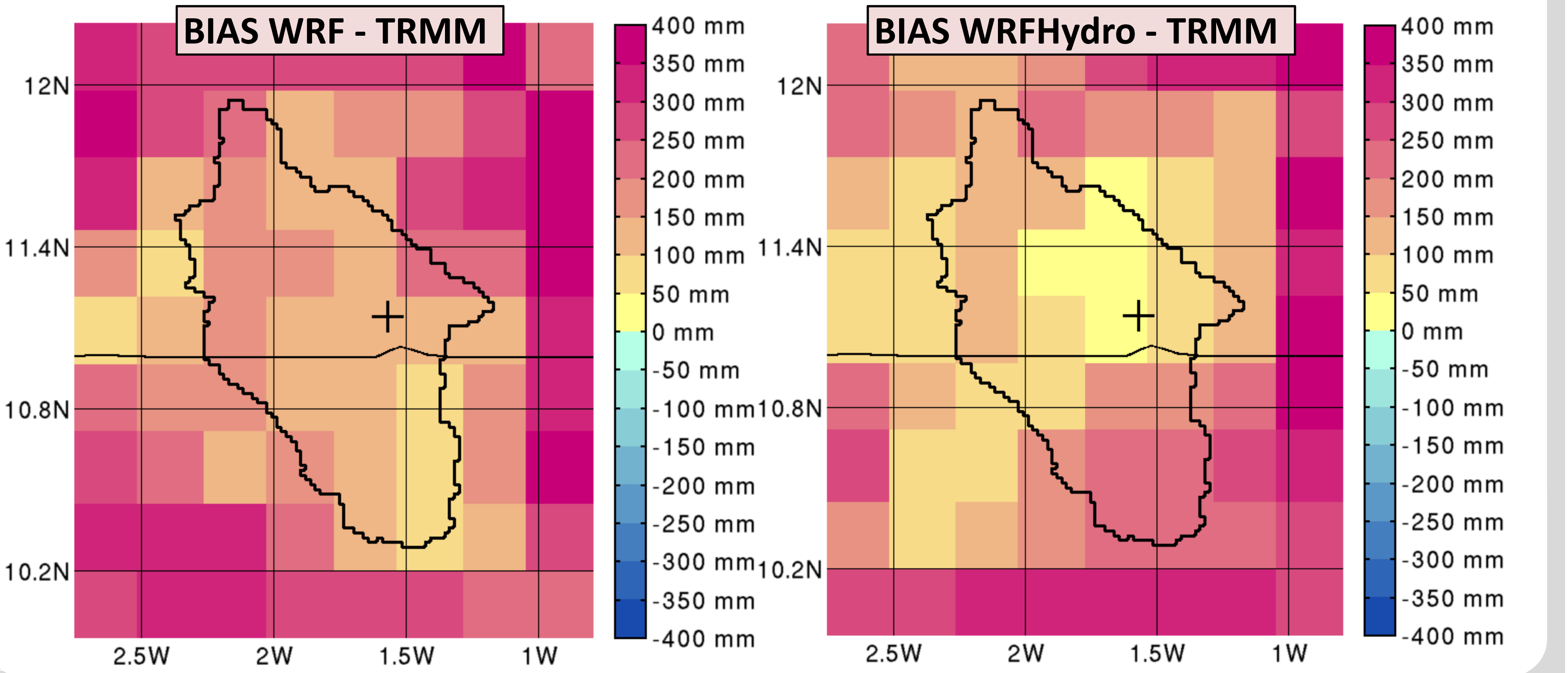


AVERAGED TEMPERATURE AT 2M (WRFHydro–WRF)



4. RESULTS

- **OUTCOMES OF WRF-Hydro (May-October 2013)**
  - **Compared to WRF, WRF-Hydro locally reduces / increases the bias with TRMM precipitation for the period May-October 2013**
  - **Need to validate this result for a longer time period and also with other observational datasets**



4. RESULTS

- OUTCOMES OF WRF-Hydro (May-October 2013)

SUMMARY:

- In our case, compared to WRF, WRF-Hydro increases soil moisture
- As a consequence, WRF-Hydro produces more latent heat, less sensible heat,
  - As a result, air humidity increases, air and skin temperature decrease,
  - Outgoing long wave radiation, as a function of skin temperature, also decreases, inducing a net radiation increase
  - This has a positive feedback on latent heat, increasing air humidity even further
- THESE WRF-HYDRO RESULTS ARE CAUSED BY A BETTER REPRESENTATION OF HYDROLOGICAL PROCESSES, AS COMPARED TO WRF STAND-ALONE.
- THE QUESTION STILL REMAINS WETHER OR NOT THIS ADDITIONAL LAND SURFACE INFORMATION IMPROVES THE SIMULATED CLIMATE

5. CONCLUSIONS AND PERSPECTIVES

- **The WRF outer domain provides realistic large-scale dynamic features with respect to ERA-Interim input data (partially shown)**

- **Both outer and inner WRF domains give monthly and daily rainfall close to TRMM data for the Sissili watershed**

- **In this model configuration, the NDHMS coupled with the inner WRF domain reproduces observed daily discharges in the Sissili watershed with a Nash-Sutcliffe model efficiency coefficient of 0.41-0.52**

- **NDHMS results can certainly be improved by model tuning, and also by taking into account sub-surface lateral water flows**

- **The outcomes produced by WRF-Hydro will be further investigated in multi-year simulations**

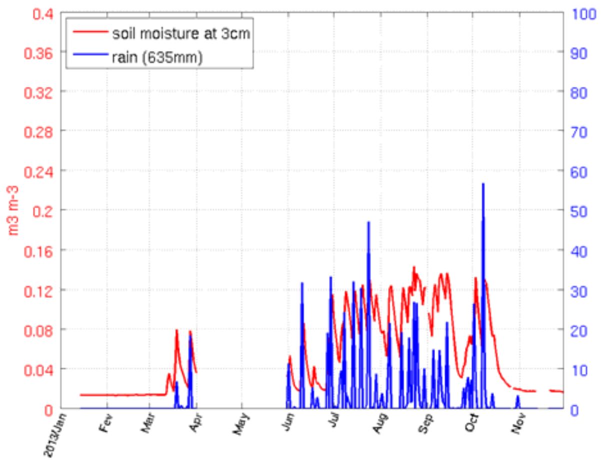
THANK YOU FOR YOUR ATTENTION !

TUNING OF THE DIRECT EVAPORATION IN NOAH LSM

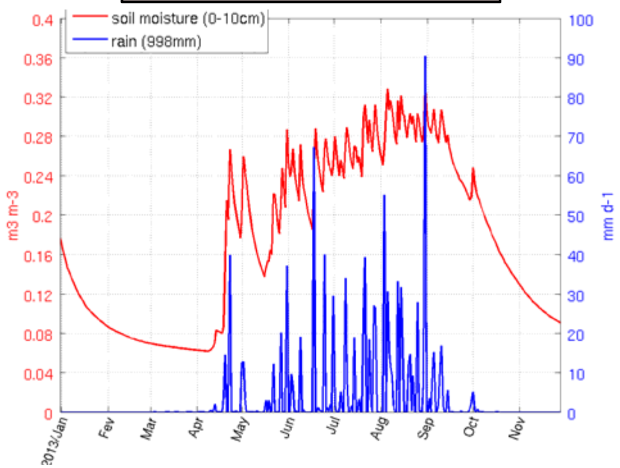
- In the NOAH LSM the direct evaporation E_{dir} is extracted from the volumetric water content of the first soil layer Θ_1, as a function of:
  - vegetation cover fraction σ_F,
  - soil moisture saturation fraction $(\Theta_1 - \Theta_{dry})/(\Theta_{sat} - \Theta_{dry})$,
  - potential evaporation E_p ,
  - an empirical coefficient fx,

  according to the formula: $E_{dir} = E_p * (1 - \sigma_F) * [\ (\Theta_1 - \Theta_{dry})/(\Theta_{sat} - \Theta_{dry})\ ]$^fx
- Soil moisture and precipitation from two WRF simulations @10km, one with fx=2 (default) and the other with fx=1, are compared with measurements at Nazinga (see plots below)
- ➢ In both simulations the soil moisture is overestimated by a factor two with respect to measurements, certainly due to larger amounts of simulated rainfall than what observed
- ➢ With fx=1 the soil moisture falling off after a rain event looks more comparable to the observation

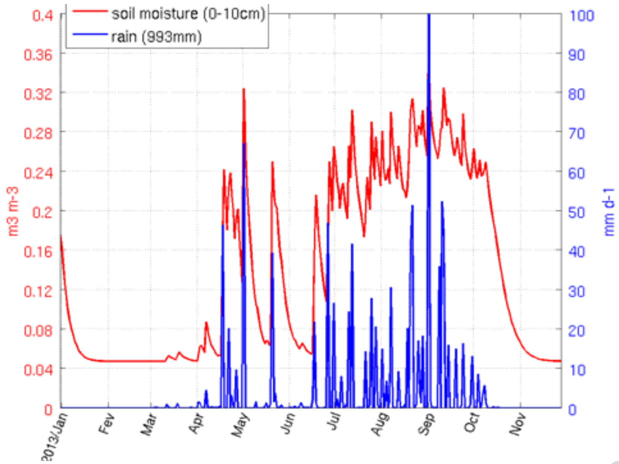
EC-Nazinga



WRF@10km_fx=2

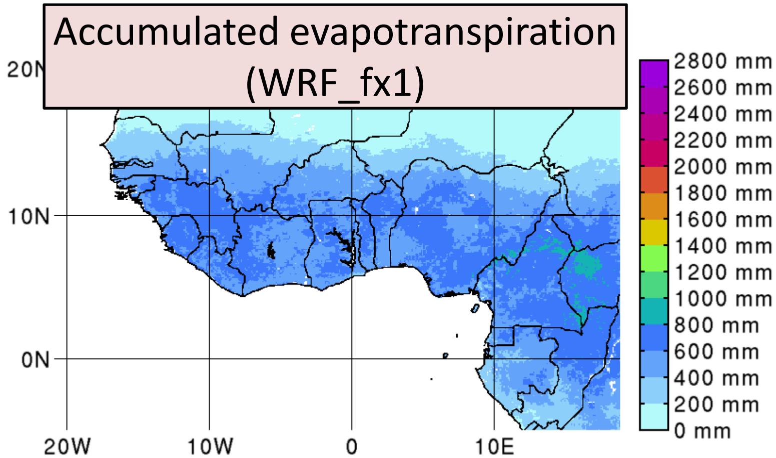


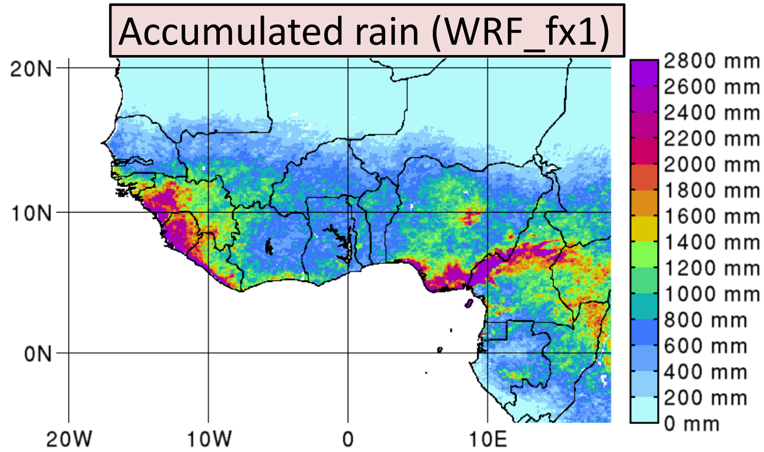
WRF@10km_fx=1

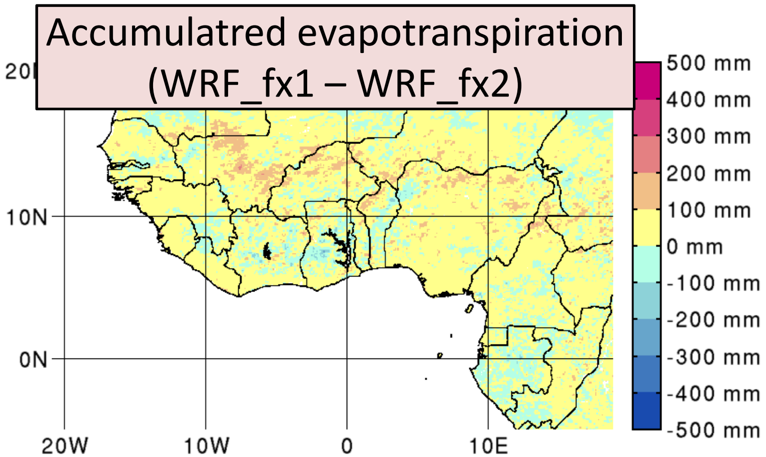


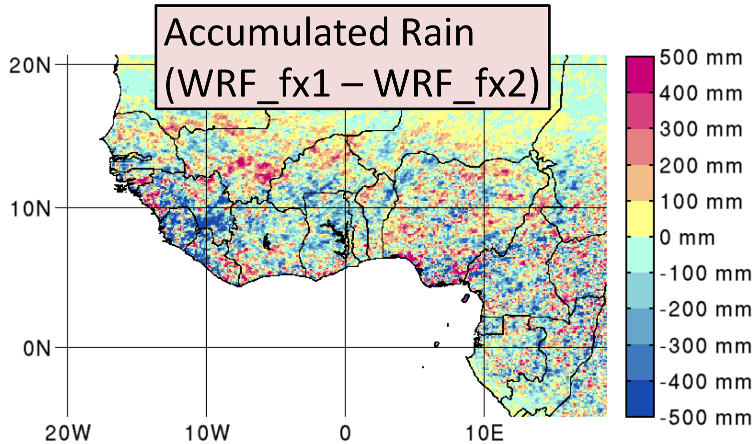
TUNING OF THE DIRECT EVAPORATION IN NOAH LSM

- Evapotranspiration and precipitation bias between the two WRF simulations with fx=1 and fx=2, for the period May to October 2013
  - ➢ Using fx=1 increases the total amount of evapotranspiration in the Sahel region north of 10°N, and modifies the precipitation patterns









TUNING OF THE DIRECT EVAPORATION IN NOAH LSM

- Rain bias between precipitation derived from the two WRF simulations, with fx=1 and fx=2, and from TRMM, for the period May to October 2013

  - Using fx=1 reduces the bias in the focus region (inside the dark circle)