Decadal predictability of West African monsoon and impact of improved initial and boundary conditions: *Land surface*

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FONA Decadal Climate Prediction BMBF — MiKlip

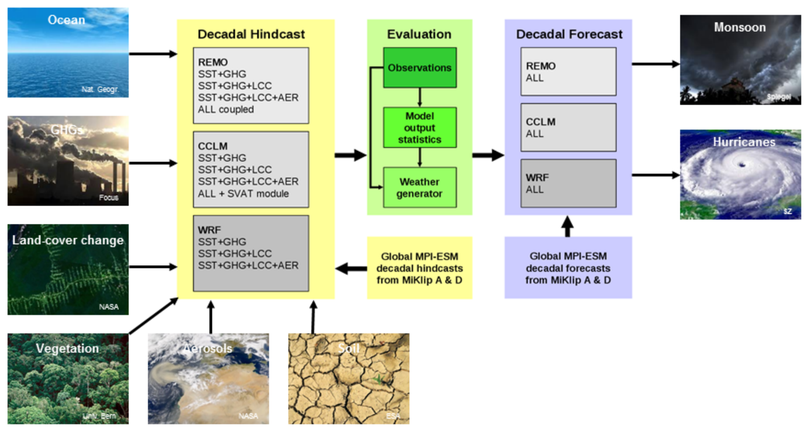
MiKlip DEPARTURE project

Project aim: Assessment of decadal predictability of West African monsoon rainfall and Atlantic hurricane activity

Project motivation:
- Socio-economic relevance of monsoon and hurricane events
- High potential decadal climate predictability in West Africa from realistic initial and boundary conditions

Project design:
- Hindcast: global MPI-ESM hindcasts downscaled by regional climate models REMO, CCLM and WRF with different boundary conditions (SSTs, greenhouse gases, **land cover changes**, aerosols), **soil initialisation**, coupled ocean and **SVAT module**
- Evaluation: multi-model ensemble forecast skill and uncertainty
- Forecast: global MPI-ESM forecasts downscaled by regional climate models REMO, **CCLM** and WRF

Project overview



Observation and model data

Observations: Gridded precipitation and temperature from Willmott & Matsuura (WMMA), University of Delaware, 0.5°

Model simulations:
- MPI-ESM LR Baseline1 (based on ECHAM6/MPI-OM): 10 decadal simulations initialised from a quasi-realisitic assimilation run for each hindcast decade with start years 1960-2013, T63/ GR15 with 47/ 40 vertical levels
- REMO/ **CCLM**/ WRF: 3 decadal simulations forced by selected MPI-ESM LR Baseline 1 simulations with best, middle and worst performance in global SST validation for selected hindcast decades 1966-1975, 1981-1990, 1991-2000 and 2001-2010, GHG forcing with RCP4.5 scenario, soil initialisation from spin-up simulations forced by ERA40 or ERAinterim reanalyses, model domain 59.4°W-59.4°E and 44°S-44°N, 0.44° with 31/ 35/ 38 vertical levels

Influence of Anthropogenic Land Use Changes

- Africa experienced significant land use / land cover changes (LULCCs) in recent decades
- LULCCs are strongly influenced by population growth
- Population growth is predictable over several decades

→ *Do LULCCs enhance the predictive skill?*

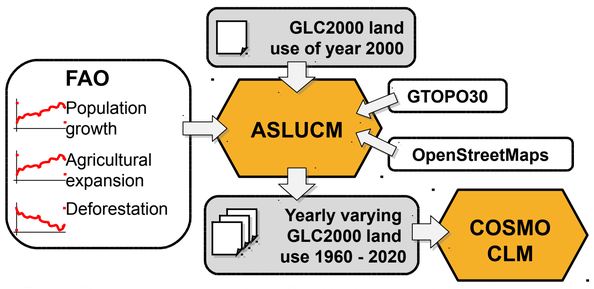


Fig. 1: Processing chain of the ASLUCM to generate new land use datasets used as boundary condition of COSMO-CLM

- The Advanced Stochastic Land Use Change Model (ASLUCM) uses FAO-statistics to generate new land use maps of past and future decades (Fig. 1)
- ASLUCM produces plausible patterns of land use, e.g. of agricultural or forested areas (Fig. 2.)

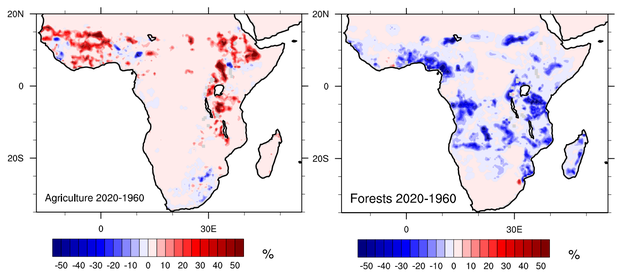


Fig. 2: Changes of fraction of agricultural area (left) and forested area (right) per 0.44° grid cell between 1960 and 2020, from ASLUCM simulation E8 with GLC2000 land use data starting in year 2000.

- Land use data applied to generate new boundary forcing for decadal climate predictions with COSMO-CLM (CCLM)
- LULCCs show influence, but do not enhance correlation to observed annual precipitation in CCLM in 1966-75 (Fig. 3)
- Precipitation changes over ocean (Fig. 4) → Teleconnection

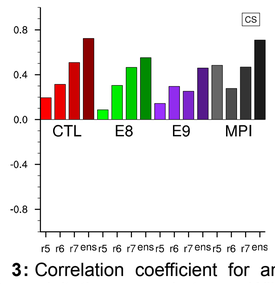


Fig. 3: Correlation coefficient for annual JJAS precipitation mean between Willmott-Matsuura and COSMO-CLM (CTL, E8, E9) and MPI-ESM-LR in Cental Sahel (CS)

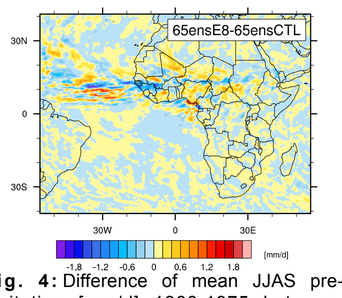


Fig. 4: Difference of mean JJAS precipitation [mm/d] 1966-1975 between CCLM-simulation with changing (65ensE8) and original land use data (65ensCTL)

Evaluation of CCLM simulations coupled with two different SVATs (TERRA_ML and VEG3D)

We investigate the influence of the soil-vegetation-atmosphere interaction on the predictability of the West African Monsoon by performing CCLM simulations coupled with different SVATs

- Fig. 5 shows the added value of the more sophisticated SVAT **VEG3D** compared to the standard (TERRA_ML) for the monthly mean 2m temperatures and the total yearly precipitation sum.
- Red colours indicate areas where VEG3D simulations achieve a higher agreement with observations, while in areas with blue colour TERRA_ML exhibits better matches.

→ For 2m temperature, coupling of CCLM with VEG3D improves the hindcast simulations significantly nearly all over West and North Africa.
→ In most parts of West and North Africa, the simulations with VEG3D exhibit an added value for the total precipitation.
→ Some parts of GC and WS do not have an added value.

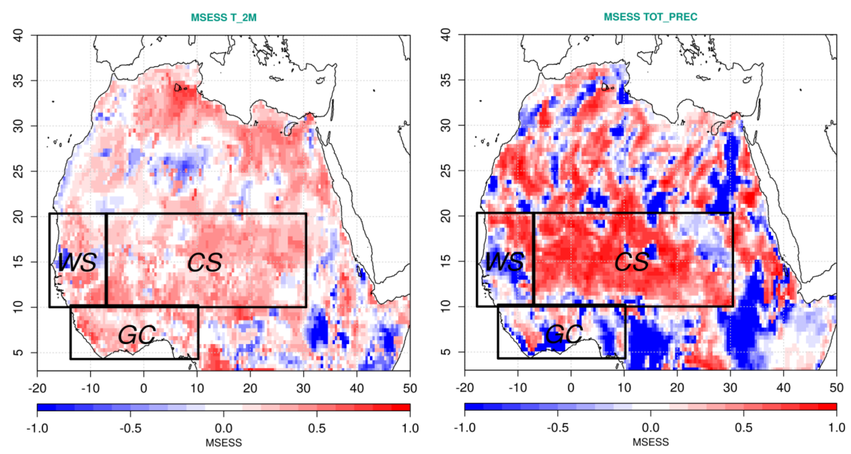


Fig. 5: Mean Square Error Skill Score (MSESS) of the CCLM ensemble mean for the monthly mean 2m temperatures (left) and the yearly sum of total precipitation (right) of the decade 2001-2010.

- The benefit of VEG3D compared to TERRA_ML concerning the 2m temperatures is caused by a more realistic yearly cycle (Fig. 6). This improvement is due to an explicit vegetation layer in VEG3D.

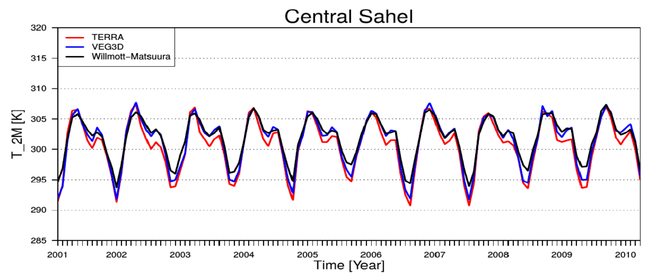


Fig. 6: Monthly mean 2m temperatures in Central Sahel (CS) for CCLM simulations coupled with TERRA_ML (red) and VEG3D (blue), compared to the Wilmott-Matsuura observational dataset (black).

Improving the initial state of soil moisture and temperature

Motivation
As for the ocean, the deep soil exhibits a long-term memory.
→ *Its proper initialisation should improve decadal predictions.*
Methods (Fig. 7)
Data assimilation combines models with observations to obtain optimized state estimates, the (re)analyses. We apply an offline version of CCLM's land surface module (TERRA_ML).

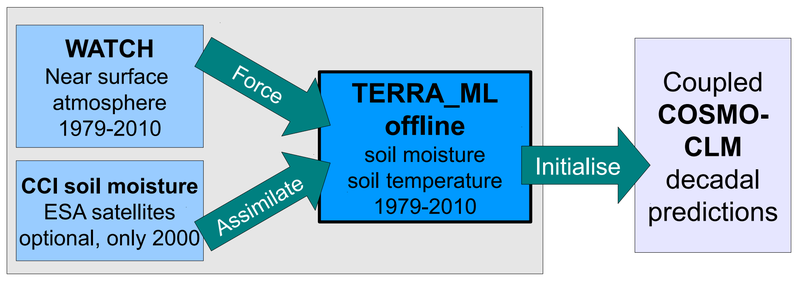


Fig. 7: The data assimilation system (gray box) produces soil states, used as initial conditions in CCLM.

(1) We generated a land surface reanalysis 1979-2010 using WATCH forcing data.
(2) We implemented an ensemble Kalman filter to additionally assimilate satellite soil moisture in 2000 (Fig. 8).
→ The new soil initial states are used in CCLM simulations.

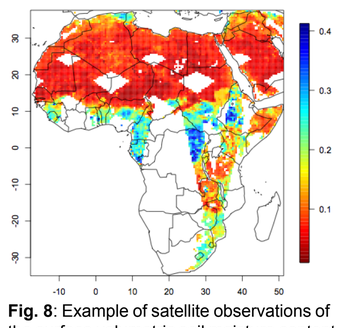


Fig. 8: Example of satellite observations of the surface volumetric soil moisture content on day 168 in 2000.

Results
For monsoon (JJAS) precipitation for decade 2001-2010. The triangles (Fig. 9) show the correlations with observations for all sub-periods of at least 3 years for standard and for newly-initialised CCLM simulations (for the sub-regions as in Fig. 5).

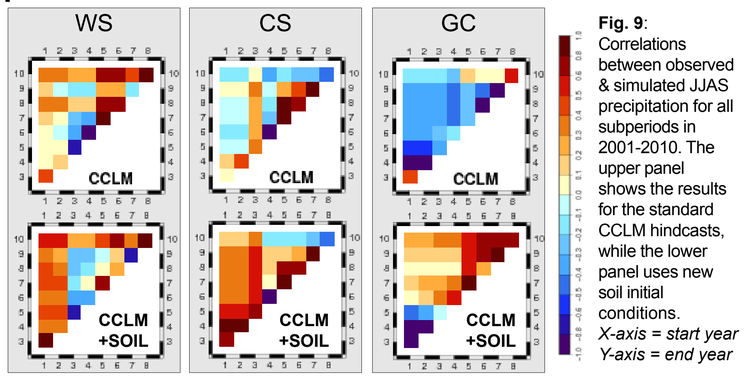
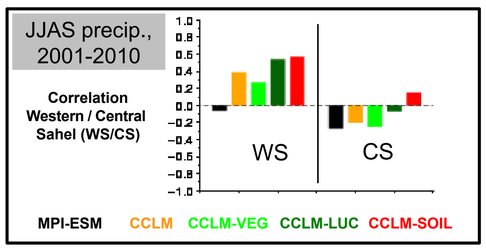


Fig. 9: Correlations between observed & simulated JJAS precipitation for all subperiods in 2001-2010. The upper panel shows the results for the standard CCLM hindcasts, while the lower panel uses new soil initial conditions. *X-axis = start year Y-axis = end year*

Discussion
Soil initialisation can consistently improve the predictability of sub-periods in all regions:
- WS/CS: particularly for longer periods
- GC: particulary at end of decade → long-term memory

An overall view: Correlations on decadal scale

Fig. 10: Correlations between the observed monsoon (JJAS) precipitation sums and hindcasts:
MPI-ESM: global model
CCLM: standard COSMO-CLM
CCLM-VEG: with VEG3D instead of TERRA_ML
CCLM-LUC: with new land use data to generate the BC
CCLM-SOIL: with new soil initial fields



Correlation as measure of „pure predictability" (neglects biases in mean & variance) in Western/Central Sahel:
- Here, RCMs outperform the GCM. However, the land surface BCs influence the decadal predictability.
- VEG3D has similar correlations as std.CCLM, but higher MSSS indicate better simulated variances (Fig. 5).
- Improved soil initialisation and land use change increase CCLM's skill in both regions.

Conclusions

In addition to the ocean, the land surface is a relevant BC for decadal predictions.

→ Land use changes influence the predictive skill with CCLM by modifying the external surface parameters.
→ Improved soil initialisation (data assimilation) can enhance predictability due to the long-term memory of the deep soil.
→ An advanced SVAT like VEG3D can improve predictive skill due to more realistic land surface physics.

Outlook

- Advancing the land use model and the evaluation of improved initialisation
- CCLM+VEG3D simulations with revised AOD climatologies