

SPECIAL PROJECT FINAL REPORT

All the following mandatory information needs to be provided.

Project Title:	The role of forest management and land-use changes for anthropogenic climate forcing
Computer Project Account:	spsemay
Start Year - End Year :	2023 – 2025
Principal Investigator(s)	Wilhelm May
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Other Researchers (Name/Affiliation):	None

The following should cover the entire project duration.

Summary of project objectives

The purpose of the project is to assess the role that forest management and land use change play for anthropogenic climate forcing by considering both the terrestrial carbon balance that affects the atmospheric concentration of CO₂ (biogeochemical effects) and the state of the vegetation that affects albedo, roughness length and evapotranspiration (biophysical effects). This will be done by means of the LPJ-GUESS terrestrial ecosystem model and the EC-Earth earth system model, which incorporates LPJ-GUESS to simulate the terrestrial ecosystems. The specific aims are two-fold with some overlap and synergies, in accordance with two externally funded projects. For the GreenPole project the main aim is to simulate the effects of the recent changes in forest policies in the Nordic countries on the climate forcing (carbon pools and fluxes and state of the forests) and for the OptimESM project the main aim is to simulate the effects of severe drought on the state of the Amazon rainforest (carbon pools and fluxes and state of the forest) and assess the risk of reaching the tipping point of Amazon dieback.

Summary of problems encountered

For various reasons, I had to revise the project plan and drop using the LPJ-GUESS terrestrial ecosystem model. I will use the HEUREKA system, which only runs on WINDOWS systems. And, as version 4 of the EC-Earth earth system model has not been released, I have not worked with the earth system model either. Therefore, I have not used the hpc facilities and, thus, none of the assigned SBUs.

Experience with the Special Project framework

The special project framework allows me to plan or pursue projects that demand access to an hpc, which would be very difficult to do otherwise. Also, it gives me the possibility to store relatively large amounts of data on the ecfs system. Together with the relatively large portions of disk space, in particular on /scratch and /perm, this allows for efficiently working on different tasks (each based on relatively large data sets) in parallel. I have only positive experiences with the framework.

Summary of results

The main result of the project is the conclusion of my work on the role of the land-surface atmosphere coupling for the biases in near-surface climate in version 3 of the EC-Earth earth system model (see reference below). The results can be summarized as follows:

Given the important role of the land surface for climate, this study aims at (1) to evaluate the quality of the simulation of surface climate by the land-surface component of the EC-Earth3 ESM and (2) to assess the role of the coupling of the land surface with the atmosphere for the simulation of the surface climate in EC-Earth3. It is based on three simulations with different configurations of the EC-Earth3 ESM: an offline simulation with the land-surface component, a partially coupled simulation with the atmospheric component and a fully coupled simulation with the atmospheric component of EC-Earth3. The land-surface component of EC-Earth3 shows a characteristic geographical distribution of the biases for the different variables describing surface climate. As for the land-surface temperature, the model is characterized by warm biases in the tropics and the mid- and high latitudes of the Northern Hemisphere and a cold bias in the subtropics. For surface soil moisture, on the other hand, the model shows wet biases in the tropics and the mid- and high latitudes of the Northern Hemisphere and a dry bias in the subtropics. As for the surface energy fluxes, net radiation and sensible heat flux are underestimated in the tropics and the mid- and high latitudes of the Northern Hemisphere and overestimated in the subtropics, and the opposite behaviour is found for latent heat flux. The land-surface component of EC-Earth3 is characterised by an overall cold bias and a general underestimation of net radiation and sensible heat flux. Neither the coupling with the atmosphere nor the feedback between the land surface and the atmosphere affect the geographical distribution of the biases in surface climate characterising the offline

simulation with the land-surface component of EC-Earth3 but have impacts on the magnitude of the local biases and regional details. The coupling with the atmosphere decreases land-surface temperature in the tropics and the mid- and high latitudes of the Northern Hemisphere and increases land-surface temperature in the subtropics, resulting in colder land-surface temperature and, thus, amplifying the overall cold bias found in the offline simulation. The feedback between the land surface and the atmosphere, on the other hand, increases land-surface temperature in the tropics and the mid-latitudes of the Northern Hemisphere and decreases land-surface temperature in the subtropics and the high latitudes of the Northern Hemisphere. The overall effect of the feedback between the land surface and the atmosphere is notably smaller than the effect of the coupling with the atmosphere for land-surface temperature and net radiation, similar for the fluxes of sensible and latent heat and stronger for surface soil moisture. The results of this study emphasize the need to improve the quality of the land-surface component of EC-Earth3 parallel with other components of the ESM.

Figure 1 illustrates the effects of the coupling for the land-surface temperatures. The upper three rows show the biases for different model configuration with varying degree of coupling. The first row shows the bias of land-surface component of EC-Earth driven with ERA5 (Figs. 1a, b), the second row the bias of the partially coupled atmospheric component of EC-Earth (the land-surface conditions, i.e., soil moisture below the surface and vegetation, are prescribed from the stand-alone simulation with the land-surface component) (Figs. 1c, d) and the fully coupled simulation with the atmospheric component of EC-Earth (Figs. 1e, f). The fourth row shows the effect of the partial coupling of the land surface with the atmosphere (Figs. 1g, h), introducing strong negative biases in many regions. The fifth row shows the effect of the full coupling of the land surface with the atmosphere (Figs. 1i, j), with an overall tendency to enhance the biases introduced by the partial coupling.

Figure 2 gives an overview of the biases in various hydro-meteorological variables describing different aspects of surface climate for the three different model configurations across the two hemispheres, confirming that. Overall, the degree of coupling between the land-surface and the atmosphere enhances the biases in the simulation of these variables. This is particularly the case for the fluxes of sensible and latent heat at the land surface.

Land-surface temperature

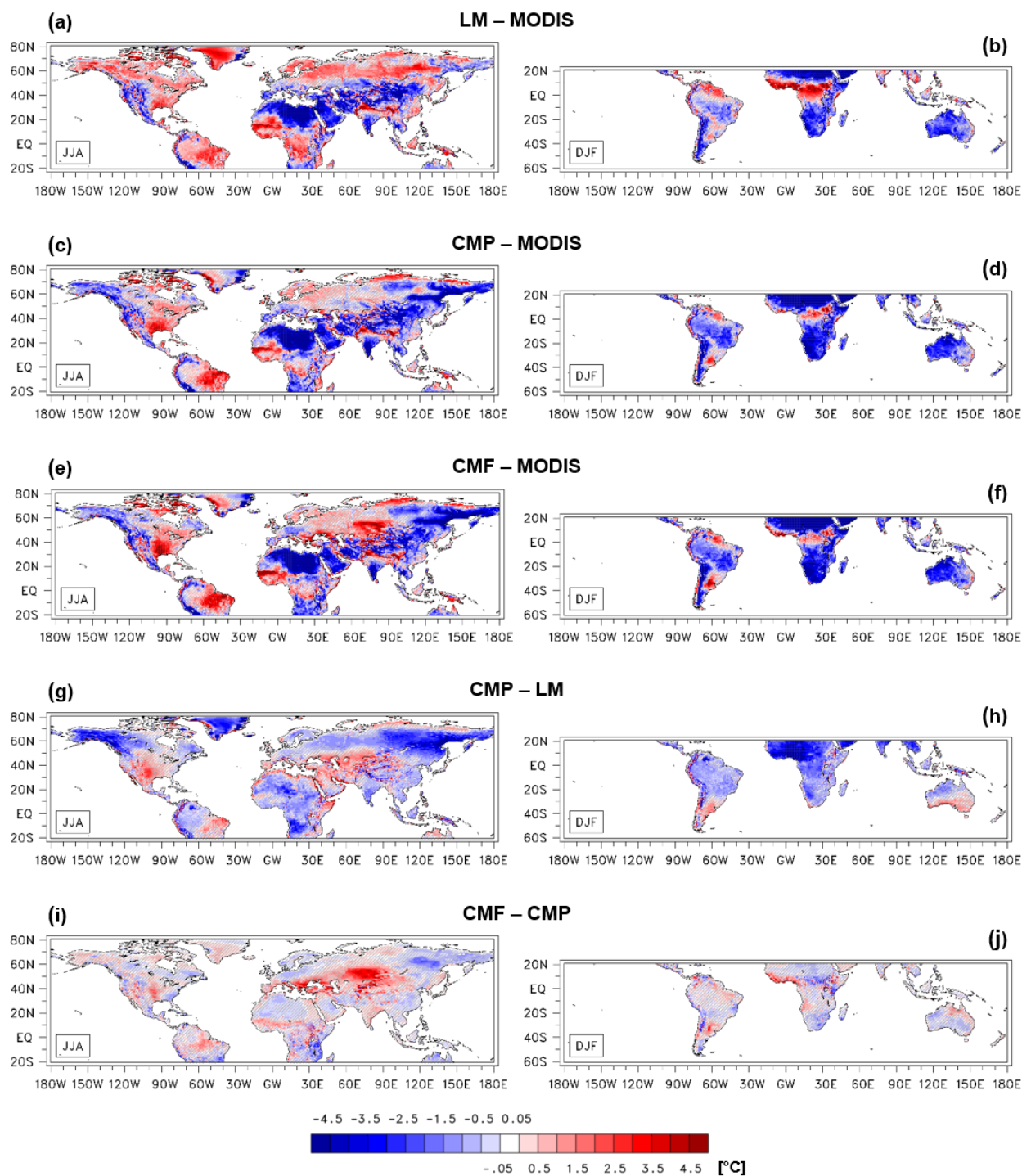


Fig. 1: Seasonal mean differences (JJA in the Northern Hemisphere and tropics and DJF in the Southern Hemisphere and tropics) in land-surface temperature for 2003-2017 for the three simulations and the reference data set (a, b) between the simulation with the land component of EC-Earth3 forced with ERA5 (LM) and MODIS (LM – MODIS), (c, d) between the partially coupled simulation with the atmospheric component of EC-Earth3 with the land-surface conditions prescribed from LM (CMP) and MODIS (CMP – MODIS) and (e, f) between the fully coupled simulation with the atmospheric component of EC-Earth3 (CMF) and MODIS (CMF – MODIS). Also, the differences (g, h) between CMP and LM (CMP – LM) and (i, j) between CMF and CMP (CMF – CMP). The grey hatching marks the areas, where the differences do not exceed the 95% significance level. Units are °C; the contour interval is 0.5 °C.

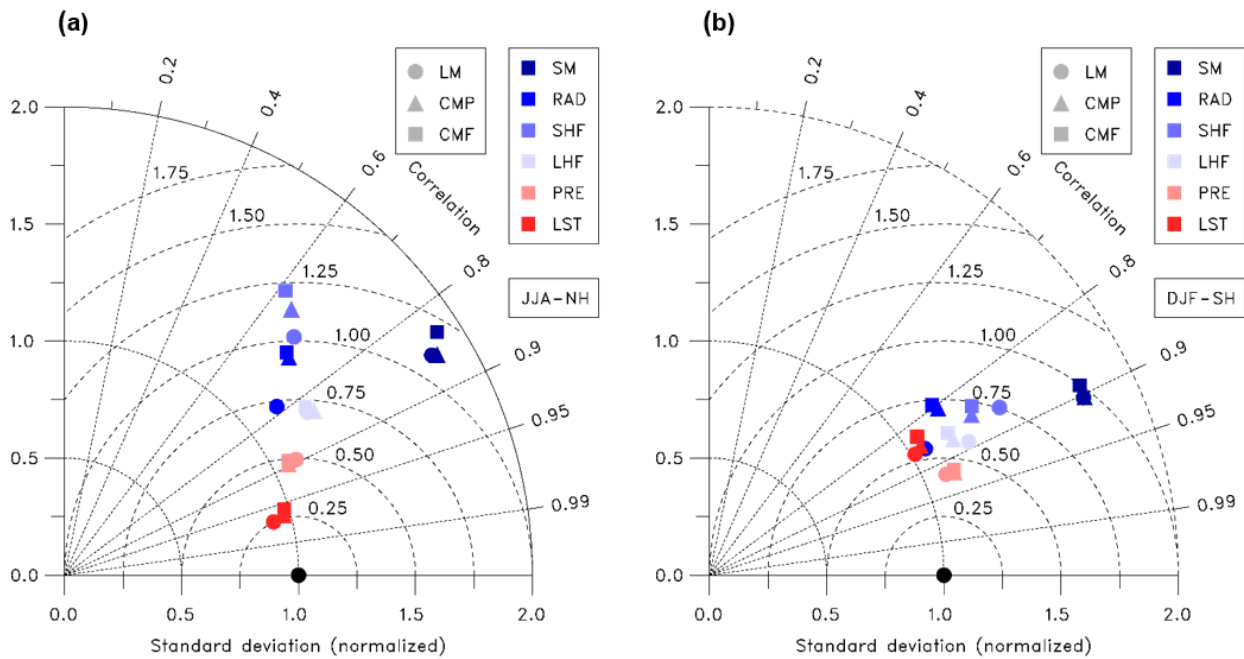


Fig. 2: Taylor diagram for the seasonal means (JJA in the Northern Hemisphere and tropics and DJF in the Southern Hemisphere and tropics) of land-surface temperature (LST), the surface energy fluxes, i.e., net radiative flux (RAD), fluxes of sensible (SHF) and latent heat (LHF), surface soil moisture (SM) and precipitation (PRE) for the simulation with the land component of EC-Earth3 forced with ERA5 (LM; filled circles), the partially coupled simulation with the atmospheric component of EC-Earth3 with the land-surface conditions prescribed from LM (CMP; filled triangles) and the fully coupled simulation with the atmospheric component of EC-Earth3 (CMF; filled squares) with respect to the different reference data, i.e., MODIS for LST, FLUXCOM SAT for the surface energy fluxes, ESA CCI for SM and GPCC for PRE. Periods considered are 1979-2017 for SM and PRE, 2003-2017 for LST and 2001-2015 for RAD, SHF and LHF, respectively. All values, i.e., the root-mean-square difference and standard deviations, are normalized by the standard deviations of the corresponding reference data.

List of publications/reports from the project with complete references

May, W., 2025: The role of the land surface for surface climate: results from a stepwise land-atmosphere coupling experiment. *Climate Dynamics*, 63, 123. <https://doi.org/10.1007/s00382-025-07602-1>

Future plans

I continue some of the work in a new special project entitled *Analysing climate variability and change based on various types of climate simulations*. Namely, the work within the OptimESM project (evaluating high-resolution climate simulations and analysing the regional climate changes associated with certain levels of global warming) and the work with version 4 of the EC-Earth earth system model on the role of the land-surface atmosphere coupling.