# SPECIAL PROJECT FINAL REPORT

All the following mandatory information needs to be provided.

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|---|---|
| **Project Title:** | Land surface-climate interactions in the EC-Earth ESM: their role for climate variability and contribution to future climate |
| **Computer Project Account:** | spsemay |
| **Start Year - End Year :** | 2020 – 2022 |
| **Principal Investigator(s)** | Wilhelm May |
| **Affiliation/Address:** | Centre of Environmental and Climate Science, Lund University, Sweden |
| **Other Researchers (Name/Affiliation):** | Not applicable |

The following should cover the entire project duration.

## Summary of project objectives

The intention of the special project had been to contribute with computer resources for an envisaged research project that I had applied for at the same time as for the special project. As this research project was not granted, the project plan had to be adjusted, and the focus of the project was changed from the contribution of land-surface interactions to future climate change to the role of interactions with the land surface for the biases of the EC-Earth3 earth system model. The results of the special project show that the land-surface component of EC-Earth3 is characterized by marked regional biases in various aspects of surface climate and that the coupling with the atmosphere leads to somewhat stronger biases in surface climate considered in the study, particularly for land-surface temperatures and surface soil moisture.

## Summary of problems encountered

First of all, I lost a lot of data (from the /scratch partition) that had been essential for running the EC-Earth ESM in spring 2021. It would have taken a long time to recollect and recreate these data, and it wouldn't be certain that this would result in identical initial conditions and forcing data.

Secondly, the transition from the access to the hpc via ecgate to the new system was (still is) very cumbersome for people working from a WINDOWS platform. This is because one first had to install a linux client and then teleport etc., a very cumbersome and error-prone process. And suddenly everything stops working…

## 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 the possibility to store relatively large amounts of data on the ecfs system. I have only positive experiences with the framework.

## Summary of results

In the project I have (among others) performed the following simulations that either are considered in the submitted paper (1&2) or in the planned follow-up paper (2-5):

1. Simulation with the land component of EC-Earth3, HTESSEL+LPJ-GUESS, forced by ERA5 (1959-2018; "LM")
2. Simulation with the atmospheric component of EC-Earth3, IFS, with the land-surface conditions (soil moisture content and vegetation) prescribed from the offline simulation with HTESSEL+LPJ-GUESS (1970-2017; "GCM")
3. Simulation with IFS, with the vegetation prescribed from the offline simulation with HTESSEL+LPJ-GUESS (1970-2017)
4. Simulation with IFS coupled with LPJ-GUESS, with the soil moisture content prescribed from the offline simulation with HTESSEL+LPJ-GUESS (1970-2017)
5. Simulation with IFS coupled with LPJ-GUESS (1970-2017)

In this summary, the biases of land-surface temperatures and surface soil moisture (where the coupling with the atmosphere has the most pronounced impacts) will be shortly presented, together with some estimates for the global land areas (between 60 °S and 80 °N). More information can be found in the manuscript submitted to Earth System Dynamics.

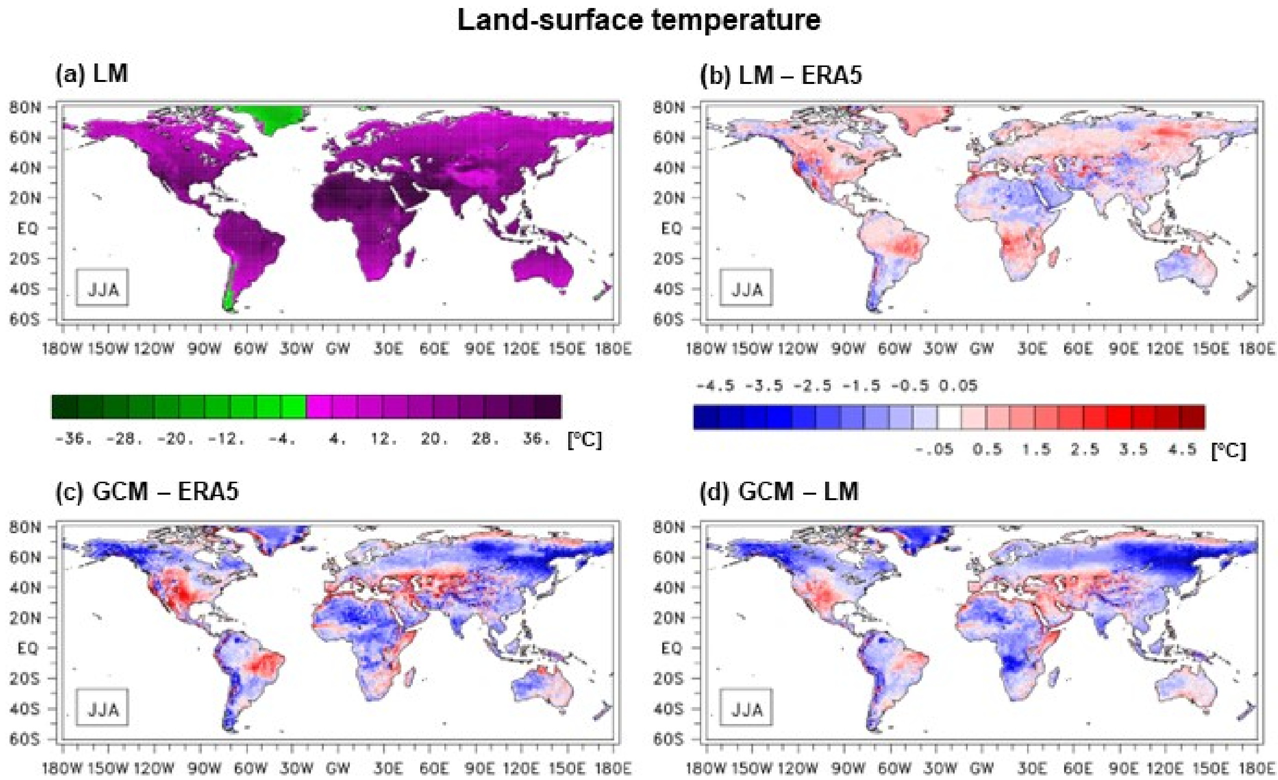


**Figure 1:** Seasonal (June through August; JJA) mean values of land-surface temperatures for 1979-2017 for the simulation with the land component forced with ERA5 (LM) (a) as well as the differences (b) between LM and ERA5 (LM – ERA5), (c) between the simulation with the atmospheric component of EC-Earth with the land-surface conditions prescribed from LM (GCM) and ERA5 (GCM – ERA5) and (d) between GCM and LM (GCM – LM). Units are °C; the contour interval is 2 °C in (a) and 0.5 °C in (b-d), respectively.

In boreal summer (June through August), the land component of EC-Earth3, HTESSEL+LPJ-GUESS, is characterized by warm biases in north-eastern Brazil and in Africa south of the equator as well as in much of North America, Central Asia and in the north-eastern part of the continent (Fig. 1b). Cold biases, on the other hand, are found in the southern part of South America, the Sahara and the Arabian Peninsula as well as in the western part of Australia. This distribution leads to an overall warm bias of 0.1 °C (see Table 1).

The atmospheric component of EC-Earth3, IFS, with the land-surface conditions prescribed from the offline simulation is characterized by both stronger local biases and a different geographical distribution of the temperature biases (Fig. 1c). Warm biases remain in the north-eastern part of South America and the south-eastern part of Africa as well as in the western part of the USA and Central Asia. Pronounced cold biases occur in the high latitudes of the Northern Hemisphere, particularly in the north-eastern part of Asia, as well as in Central Africa and the southern part of Asia. This distribution results in a marked overall cold bias of 0.42 °C (see Table 1). The two values of the root-mean-square deviations (RMS), 1.78 vs. 0.97°, reflect the stronger local biases in the simulation incorporating the coupling with the atmosphere.

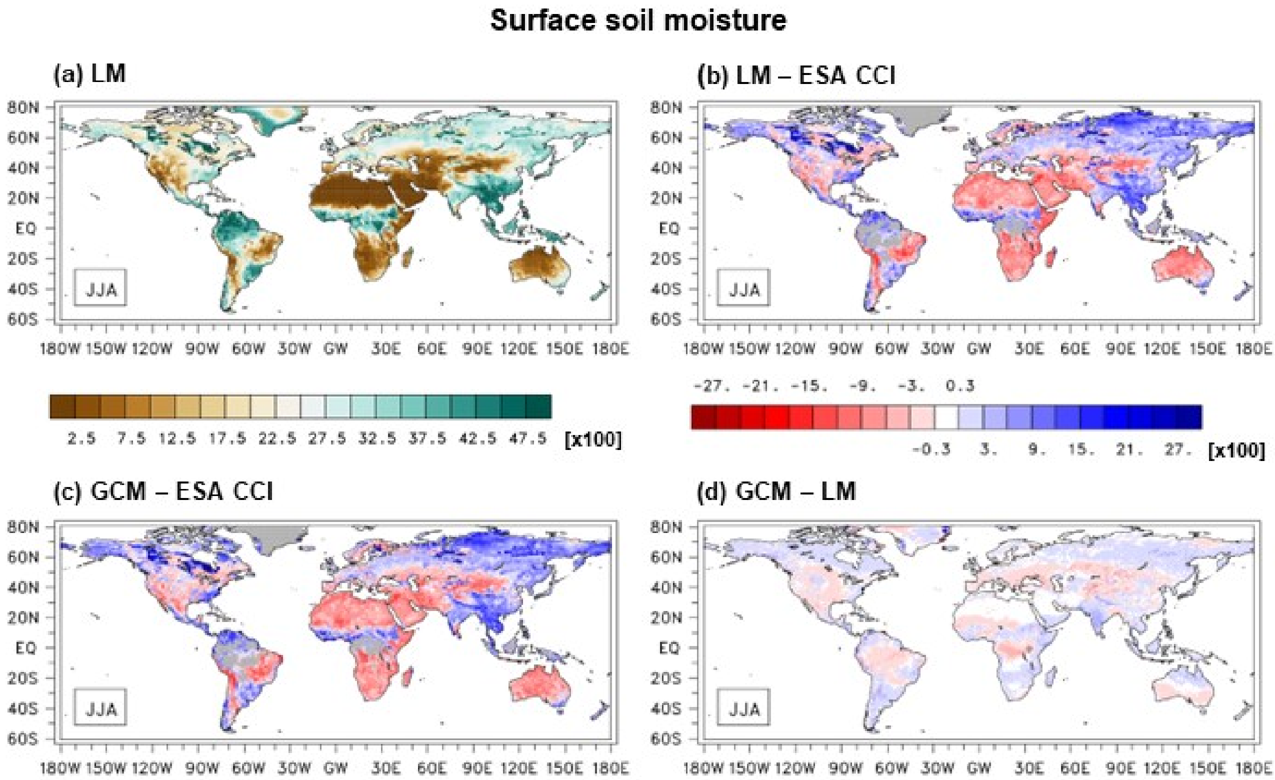


**Figure 2:** Seasonal mean values of surface soil moisture for 1979-2017 for LM (a) as well as the differences (b) between LM and ESA CCI (LM – ESA CCI), (c) between GCM and ESA CCI (GCM – ESA CCI) and (d) between GCM and LM. Units are m3/m3 (x100); the contour interval is 2.5 $m^3/m^3$ (x100) in (a) and 3 $m^3/m^3$ (x100) in (b-d), respectively. Note the swap of the colour scale with red colours indicating small values (a) or negative differences (b-d) and blue colours indicating high values (a) or positive differences (b-d). Missing data in ESA CCI are marked in grey.

The land component of EC-Earth3 is characterized by dry biases in surface soil moisture in the sub-tropical regions and wet biases in the high latitudes of the Northern Hemisphere and Southeast Asia (Fig. 2b). The geographical distribution of the biases is similar for the simulation incorporating the coupling with the atmosphere (Fig. 2c). There are some local differences between the two simulations such as the higher surface soil moisture in the simulation with IFS in the high latitudes of the Northern Hemisphere as well as in parts of the sub-tropics (Fig. 2d). For surface soil moisture, the coupling with the atmosphere changes a slight dry bias (-0.11 %) into a comparable wet bias (0.14 %) bur similar values for the RMS deviation (see Table 1).

| **Differences** | **LST [°C]** | | **SM [%]** | | **PRE [mm/day]** | | **RAD [W/m²]** | | **SHF [W/m²]** | | **LHF [W/m²]** | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| LM-OBS | 0.10 | 0.97 | -0.11 | 8.54 | 0.29 | 1.44 | -7.18 | 14.74 | -10.53 | 21.92 | -1.50 | 19.43 |
| GCM-OBS | -0.42 | 1.78 | 0.14 | 8.66 | 0.18 | 1.37 | -3.21 | 16.65 | -6.23 | 22.33 | -3.01 | 19.96 |
| GCM-LM | -0.52 | 1.55 | 0.18 | 1.86 | -0.12 | 1.43 | 3.94 | 12.20 | 4.20 | 9.36 | -1.36 | 8.41 |

**Table 1:** Mean differences and the root-mean-square deviation between LM and the primary observational data sets (LM-OBS), between GCM and the observational data (GCM-OBS) as well as between the two simulations (GCM-LM) for land-surface temperature (LST), surface soil moisture (SM), precipitation (PRE), net radiation (RAD) as well as sensible (SHF) and latent heat flux (LHF). Periods considered are 1979-2017 for LST, SM and PRE and 2001-2015 for RAD, SHF and LHF, respectively. Note that the difference between the two simulations does not necessarily harmonize with the corresponding differences between GCM-OBS and LM due to additional grid points for GCM-LM for all variables except LST and PRE.

The findings of the study, also considering precipitation and the surface energy fluxes (see Table 1) are summarized in the abstract of the submitted manuscript:

Land-surface conditions have prominent effects on local and regional climate through the exchanges of energy and moisture with the atmosphere and on global climate by the exchanges of carbon dioxide. Therefore, it is important that land-surface components of earth system models (ESMs) like EC-Earth3 can simulate the processes governing the energy and water cycles and the carbon cycle realistically. The aim of this study is twofold, first to evaluate the quality of the simulation of surface climate by the land-surface component of the EC-Earth3 ESM, combining the HTESSEL land-surface model and the LPJ-GUESS dynamic vegetation model, and second to assess the role of the coupling of the land surface with the atmosphere for the simulation of the surface climate in EC-Earth3. To this end, two simulations with different configurations of the EC-Earth3 ESM are considered: an offline simulation with HTESSEL+LPJ-GUESS forced with meteorological data from the ERA5 re-analyses and a simulation with the atmospheric component of EC-Earth3, where the land-surface conditions (soil moisture and vegetation characteristics) are prescribed from the offline simulation. The land-surface component of EC-Earth3 is characterized by marked regional biases in various aspects of surface climate. These are, for instance, too warm land-surface temperatures in the tropics and in the mid- and high latitudes of the Northern Hemisphere, resulting in a warm overall bias. Surface soil moisture, on the other hand, is characterized by a dry bias in the subtropics and parts of the extra-tropics and a wet bias in the tropics and the eastern part of Asia, resulting in a slightly negative overall bias. The incoming net radiation is underestimated by the model over much of the global land area, causing a negative overall bias. For the fluxes of sensible heat, the model also shows a negative overall bias with a clear tendency to underestimate the sensible heat fluxes in regions, where they are relatively strong, and underestimate them in regions where they are rather weak. The biases in the fluxes of latent heat generally correspond to the biases in the sensible heat fluxes (with opposite sign) with an underestimation of the fluxes of latent heat in regions where the sensible heat fluxes are too strong and an overestimation in the regions where the sensible heat fluxes are too weak. The coupling with the atmosphere leads to somewhat stronger biases in the aspects of surface climate considered in the study. The most pronounced effect of the coupling is found for land-surface temperature, including a change in the sign of the overall bias from a warm overall bias in the simulation with the land-surface component to a considerable cold bias in the atmospheric component of EC-Earth3. For surface soil moisture, the coupling with the atmosphere changes a dry overall bias of the land-surface component to a wet bias in the atmospheric model. Analysing the correspondence between the global patterns for the simulations and the reference data reveals relatively large effects of the atmospheric coupling on land-surface temperature as well as on net radiation and sensible heat flux but small effects on surface soil moisture and latent heat flux.

## List of publications/reports from the project with complete references

In two publications, the method to nudge the soil moisture content in EC-Earth developed in the special project has been applied by colleagues in the EC-Earth consortium:

Luo, F., F. Selten, K. Wehrli, K. Kornhuber, P. Le Sager, **W. May**, T. Reerink, S. I. Seneviratne, H. Shiogama, D. Tokuda, H. Kim, and D. Coumou, 2022: Summertime Rossby waves in climate models: substantial biases in surface imprint associated with small biases in upper-level circulation. Weather and Climate Dynamics, 3, 905-935.

Wehrli, K., F. Luo, M. Hauser, H. Shiogama, D. Tokuda, H. Kim, D. Coumou, **W. May**, P. Le Sager, F. Selten, O. Martius, R. Vautard, and S. I. Seneviratne, 2022: The ExtremeX global climate model experiment: investigating thermodynamic and dynamic processes contributing to weather and climate extremes. Earth System Dynamics, 13, 1167-1196.

Another publication based on the simulations performed in the special project was submitted and will be open for discussion (and accessible through the journal's webpage) in a short while:

**May, W.**, 2023: The role of land-surface interactions for surface climate in the EC-Earth3 earth system model. Earth System Dynamics, submitted.

In addition, results obtained in the special project were presented at scientific meetings and conferences, either oral or as a poster:

**May, W.**, 17.5.2022: The role of land-surface interactions for the climate biases in the EC-Earth earth system model. Presented at the Swedish Climate Symposium in Norrköping, Sweden, (poster).

**May, W.**, 15.12.2022: The role of land-surface interactions for the surface energy fluxes in the EC-Earth earth system model. Presented at the MERGE annual meeting in Helsingborg, Sweden, (oral).

**May, W.**, 28.4.2023: The role of land-surface interactions for the surface energy fluxes in the EC-Earth earth system model. Presented at the EGU General Assembly 2023 in Vienna, Austria, (poster).

## Future plans

If the submitted paper is accepted, I have plans to prepare a follow-up paper focusing on EC-Earths sensitivity to restricting the land-surface conditions based on the simulations performed in the special project.

I have been granted another special project "The role of forest management and land-use changes for anthropogenic climate forcing" for 2023-2025, where the LPJ-GUESS terrestrial ecosystem model to simulate the effects of changes in forest policies on forest ecosystems in Fenno-Scandinavia. This meddling work is part of the GreenPole project granted by the Nordic Research Council (https://www.nordforsk.org/sv/projects/green-forests-policies-comparative-assessment-outcomes-and-trade-offs-across-fenno).