SPECIAL PROJECT FINAL REPORT

All the following mandatory information needs to be provided.

Project Title:	Coupling and feedbacks between soil moisture and two dominant monsoon systems for present and future climates
Computer Project Account:	spsemay
Start Year - End Year :	2017 - 2019
Principal Investigator(s)	Wilhelm May
Affiliation/Address:	Centre for Environmental and Climate Research Lund University Sölvegatan 37 223 62 Lund Sweden
Other Researchers (Name/Affiliation):	

The following should cover the entire project duration.

Summary of project objectives

The overall objective of the project (originally) was to investigate the role of soil moisture for the variability of two of the most dominant monsoon systems, i.e. the West African Monsoon and the Indian Summer Monsoon, for present-day and future climate conditions. In particular, the project aimed at investigating the role of the physical processes governing the coupling and feedbacks between soil moisture and the two monsoons and at assessing the contributions of the future changes in soil moisture to the overall future changes in the variability and the mean state of these monsoons in response to the projected increases in the anthropogenic climate forcing.

Summary of problems encountered

The main problem with the special project was that the development of the EC-Earth earth system model for CMIP6 (EC-Earth 3.3) was not finalized before mid-2019. Similarly, the H-TESSEL/LPJ-GUESS offline land model consistent with the earth system model used for CMIP6 was not finalized before late 2019. Therefore, I have only performed a number of short test runs and several 10-year experiments (1991-2000) with a preliminary model version (EC-Earth 3.2), only using preliminary versions of ‘observed’ land surface conditions (i.e. ERA-Interim/Land), and tested different set-ups for the prescription of the state of the land surface, i.e. included a special treatment of frozen soils. Only in the second half of 2019 I have been able to perform longer simulations (1979-2017) with different configurations of EC-Earth 3.3 (with or without coupling to the LPJ-GUESS terrestrial ecosystem model). Given these delays, I haven’t been able to analyse the effects of the land surface conditions on the two monsoon systems, as was originally planned.

Experience with the Special Project framework

Overall, I have a positive experience with the administration of the special project. What I would have liked, would be a more concrete specification of the requirements for the progress reports (Summary of results).

Summary of results

In the course of the project, I have implemented and tested a procedure to restrict soil moisture in EC-Earth by either replacing by or nudging towards a prescribed value of soil moisture after each simulation time step. The procedure is applied at each (land) grid point and at each of the four soil layers of H-TESSEL separately, allowing for different treatments for each soil layer. Also, the procedure allows for a special treatment of frozen soils, i.e. not replacing or nudging soil moisture in soil layers that are frozen or have a frozen soil layer above them. The latter ensures that the energy fluxes in the soil are not disturbed by additional melting or freezing when soil moisture is removed or added, respectively. After a series of sensitivity experiments, the following ‘standard’ set-up for restricting soil moisture in EC-Earth wass recommended: No restriction of the uppermost soil layer (0-7 cm) and nudging of soil moisture for the three lower layers with varying relaxation times (72 hrs for 7-28 cm, 48 hrs for 28-100 cm and 24 hrs for 100-255 cm) and no nudging in the case of frozen soils. This standard set-up will be used in the continuation of the special project (see below).

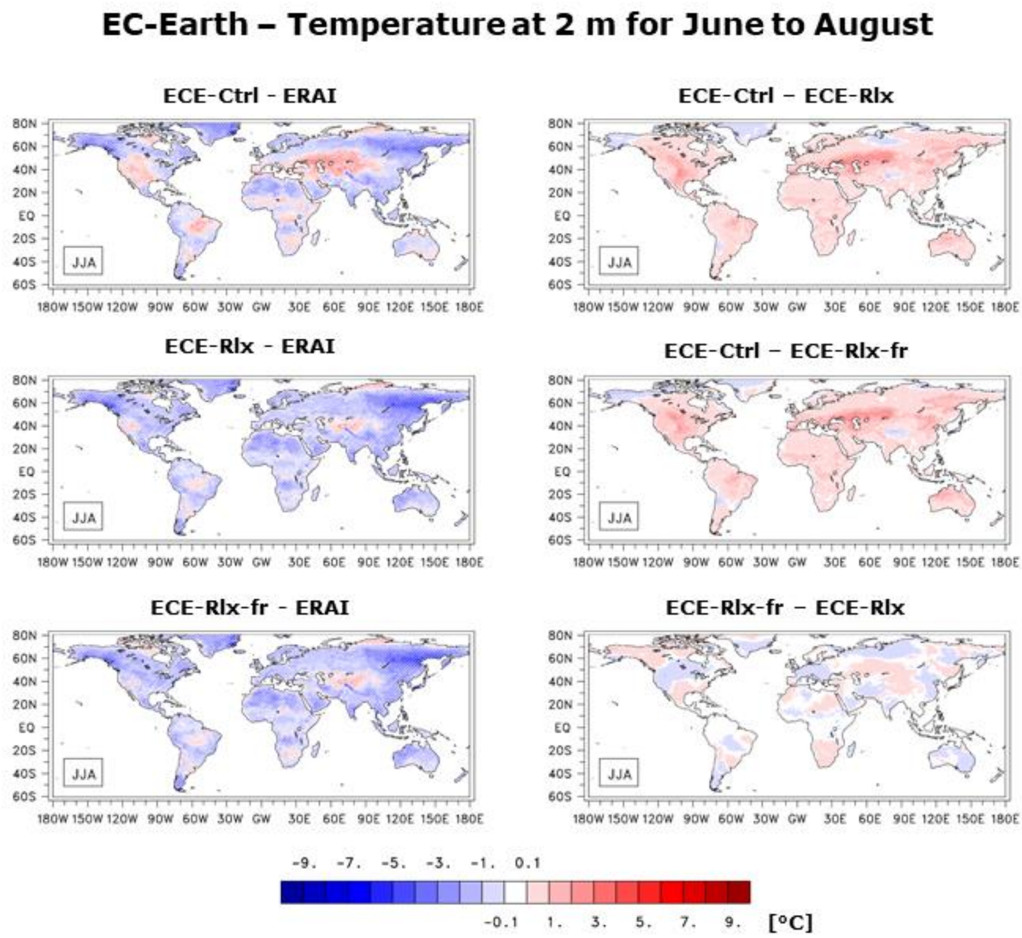

Fig. 1: Differences in seasonal mean temperatures at 2 m for June to August for the period 1991-2000 between three simulations with EC-Earth 3.2 and ERA-Interim (left column) and between the different experiments (right column). ECE-Ctrl is a standard AMIP-type simulation, ECE-Rlx a simulation with soil moisture nudged towards ERA-Interim/Land without the special treatment of frozen soils and ECE-Rlx-fr a corresponding simulation with the special treatment of frozen soils (see above).

The standard simulation ECE-Ctrl shows both negative and positive biases in the seasonal mean temperature (upper left panel). Positive differences, corresponding to too warm temperatures simulated by EC-Earth, are found in the western part of North America and Amazonia, in Central Asia as well as in Western and Southern Africa. When relaxing against soil moisture from ERA-Interim/Land, the geographical distribution of the temperature bias changes so that the extent of the regions with too warm temperatures in EC-Earth is typically reduced and the negative differences, corresponding to too cold temperatures simulated by EC-Earth, are somewhat stronger than for ECE-Ctrl. This is the case for both with (lower left panel) and without (middle left panel) the special treatment of frozen soils. In fact, the differences between the two simulations (lower right panel) do not show any strong systematic differences, indicating that the effect of treating frozen soils in a special way, during boreal summer mainly in the permafrost regions of the high northern latitudes, is limited in EC-Earth.

The generally positive differences between ECE-Ctrl and the two other simulations (upper and middle right panels), illustrating that the warmer temperatures in the standard simulation are consistent with an overall tendency of lower soil moisture over most of the global land areas in ECE-Ctrl (see Fig. 2). The lower soil moisture affects the turbulent energy fluxes at the land surface with increased fluxes of sensible heat and reduced fluxes of latent heat. The increased fluxes of sensible heat, in turn, lead to warmer near-surface temperatures. As a consequence, prescribing restricting soil moisture conditions by observational data generally reduces the temperature bias in EC-Earth in the regions, where the standard model is too warm, and increases the temperature bias where the standard model is too cold.

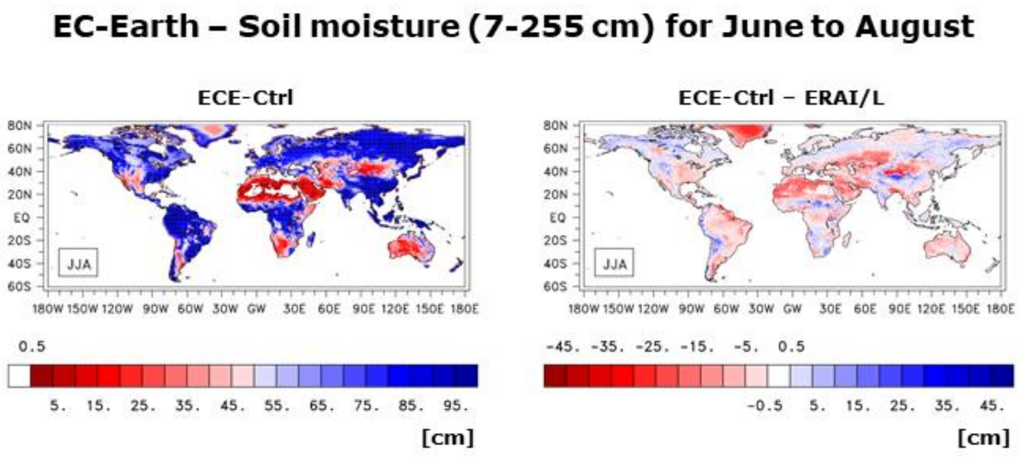

Fig. 2: Seasonal mean soil moisture between 7 and 255 cm depth for June to August for the period 1991-2000 in a simulation with EC-Earth 3.2 (left column) as well as the difference with ERA-Interim/Land (right column). ECE-Ctrl is a standard AMIP-type simulation (see above).

The standard simulation ECE-Ctrl has a general tendency to underestimate soil moisture, particularly in the central tropics, the Northern Hemisphere subtropics and parts of the Northern Hemisphere mid-latitudes. EC-Earth overestimates soil moisture in the northern part of the tropics, the western part of North America and Southern Africa. These deviations are mainly related to corresponding biases in the simulation of precipitation in EC-Earth (see Fig. 5).

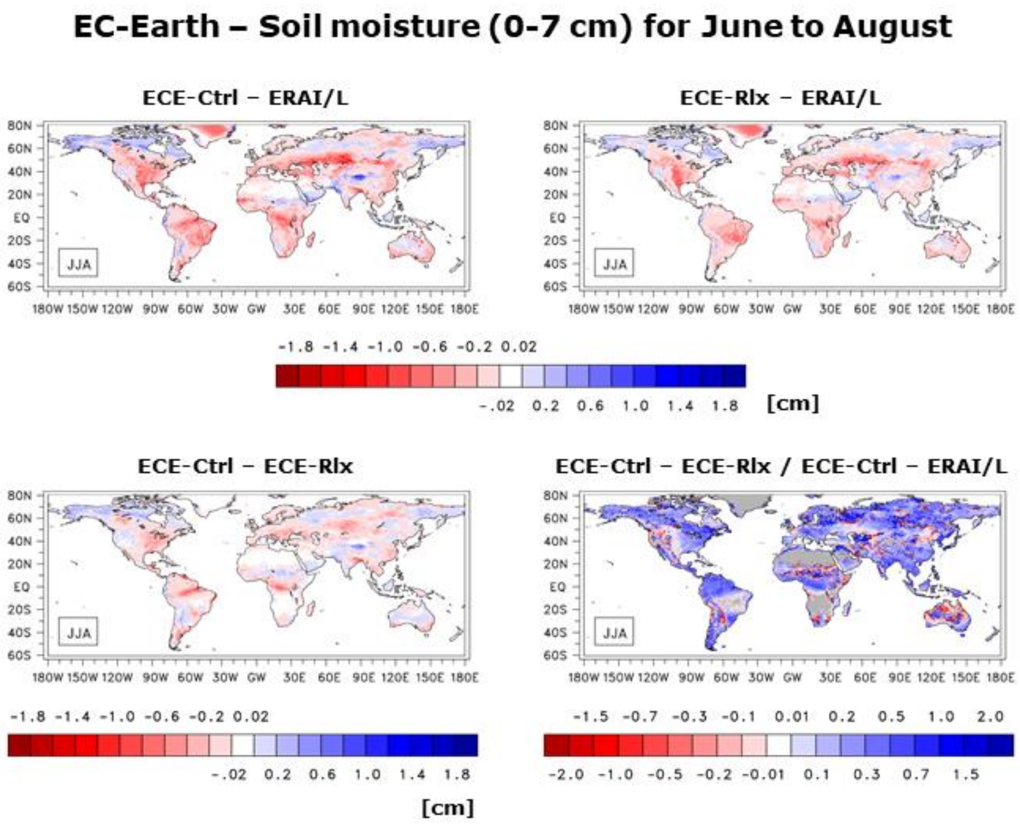

Fig. 3: Differences in seasonal mean soil moisture for the uppermost 7 cm for June to August for the period 1991-2000 between two simulations with EC-Earth 3.2 and ERA-Interim/Land (upper row) and between the different experiments (lower left corner). Also, the ratio between the difference between the two experiments and the bias of the standard simulation. ECE-Ctrl is a standard AMIP-type simulation and ECE-Rlx a simulation with soil moisture nudged towards ERA-Interim/Land without the special treatment of frozen soils (see above).

In the simulation with restricted soil moisture, only the three lower soil layers are nudged towards ERA-Interim/Land, so that the uppermost layer (0-7 cm) is not directly affected. Nevertheless, restricting soil moisture in the three lower layers reduces the bias in soil moisture in the uppermost layer considerably. This can be seen when comparing the bias for the standard simulation (ECE-Ctrl – ERAI/L) with the differences between the two experiments (ECE-Ctrl – ECE-Rlx), where corresponding colours (red or blue) in the two maps indicate improvements in the simulation of soil moisture. This can also be seen in the panel that shows the ratio between the differences of the two experiments and the bias of the control simulation (ECE-Ctrl – ECE-Rlx / ECE-Ctrl – ERAI/L). Blue colours illustrate improvements, with a value of about 1 meaning that the bias is removed when soil moisture is restricted by observational data.

The fact that the simulation of soil moisture in the uppermost soil layer is considerably improved when restricting soil moisture in the three layers below illustrates that it is not necessary to restrict soil moisture in all layers in order to obtain the benefit or the effect of nudging soil moisture. Not restricting the uppermost soil layer, on the other hand, prevents artificial energy fluxes at the land surface associated with precipitation events in situations when the nudging procedure reduces soil moisture in the uppermost layer, which might impair the simulation of atmospheric variability.

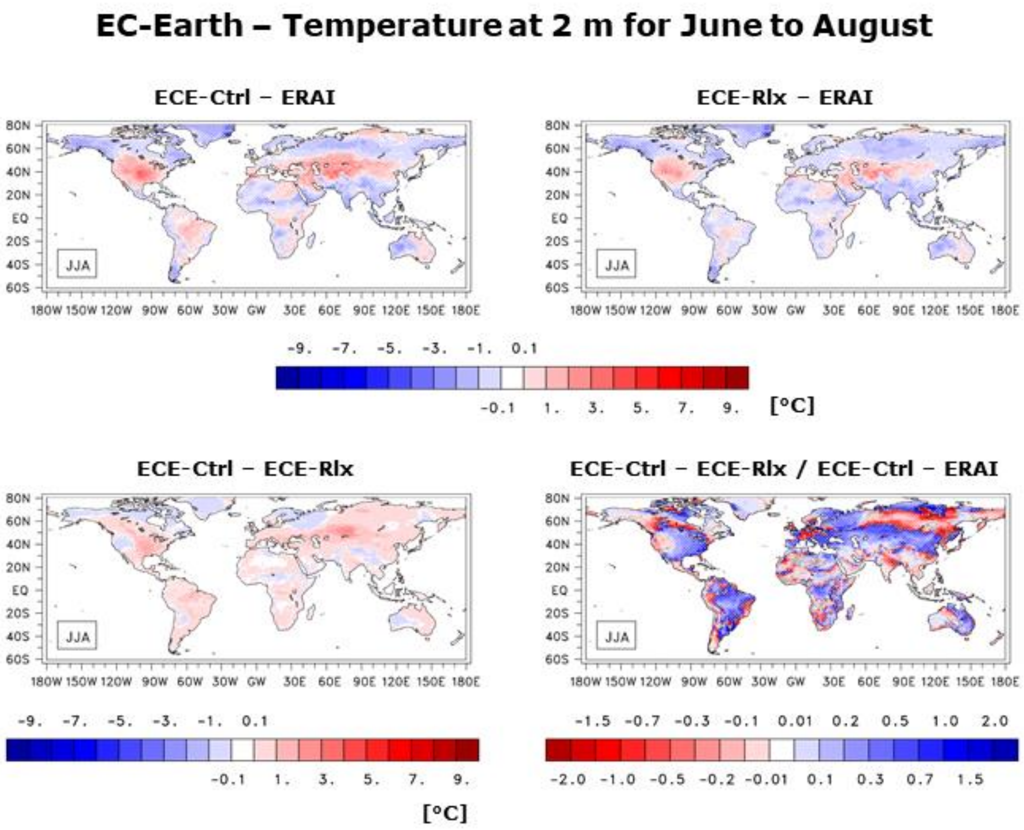

Fig. 4: Differences in seasonal mean temperature at 2 m for June to August for the period 1991-2000 between two simulations with EC-Earth 3.2 and ERA-Interim (upper row) and between the different experiments (lower left corner). Also, the ratio between the difference between the two experiments and the bias of the standard simulation. ECE-Ctrl is a standard AMIP-type simulation and ECE-Rlx a simulation with the soil moisture nudged towards ERA-Interim/Land without the special treatment of frozen soils (see above).

As already seen from Fig. 1, the standard simulation with EC-Earth has a warm temperature bias in the central tropics and in the Northern Hemisphere mid-latitudes and a cold bias in the northern part of the tropics and at high northern latitudes. Restricting soil moisture by ERA-Interim/Land reduces the warm bias in many parts of the globe, i.e. in the central tropics and in the Northern Hemisphere mid-latitudes, except for the western part of North America, but enhances the cold bias in several regions. This can also be seen in the map of the ratio (lower right panel), with blue colours in some regions and red ones in others.

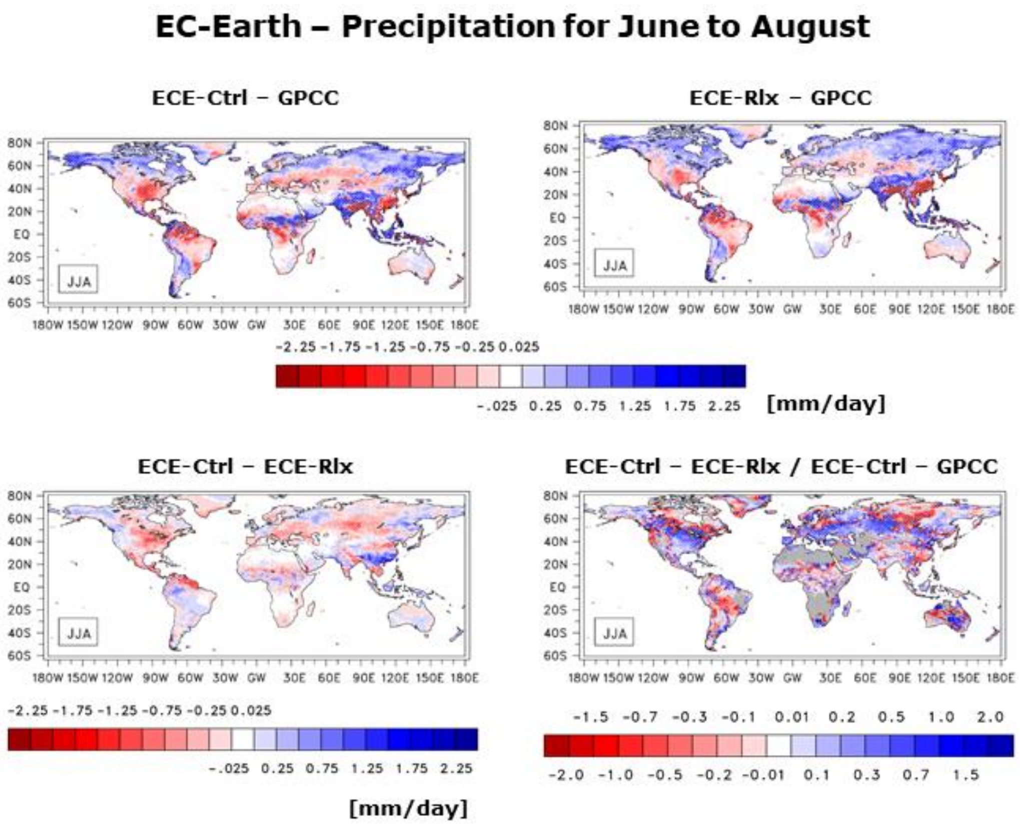

Fig. 5: Differences in seasonal mean precipitation for June to August for the period 1991-2000 between two simulations with EC-Earth 3.2 and GPCC (upper row) and between the different experiments (lower left corner). Also, the ratio between the difference between the two experiments and the bias of the standard simulation. ECE-Ctrl is a standard AMIP-type simulation and ECE-Rlx a simulation with the soil moisture nudged towards ERA-Interim/Land without the special treatment of frozen soils (see above).

The standard simulation with EC-Earth has a general tendency to underestimate precipitation in the central tropics, the Northern Hemisphere subtropics and parts of the Northern Hemisphere mid-latitudes. EC-Earth, on the other hand, overestimates precipitation in the northern part of the tropics and at high northern latitudes. The restriction of soil moisture by ERA-Interim/Land improves the dry bias in several parts of the globe, i.e. the western part of North America, southern Europe and Central Asia, but enhances the wet bias at high northern latitudes.

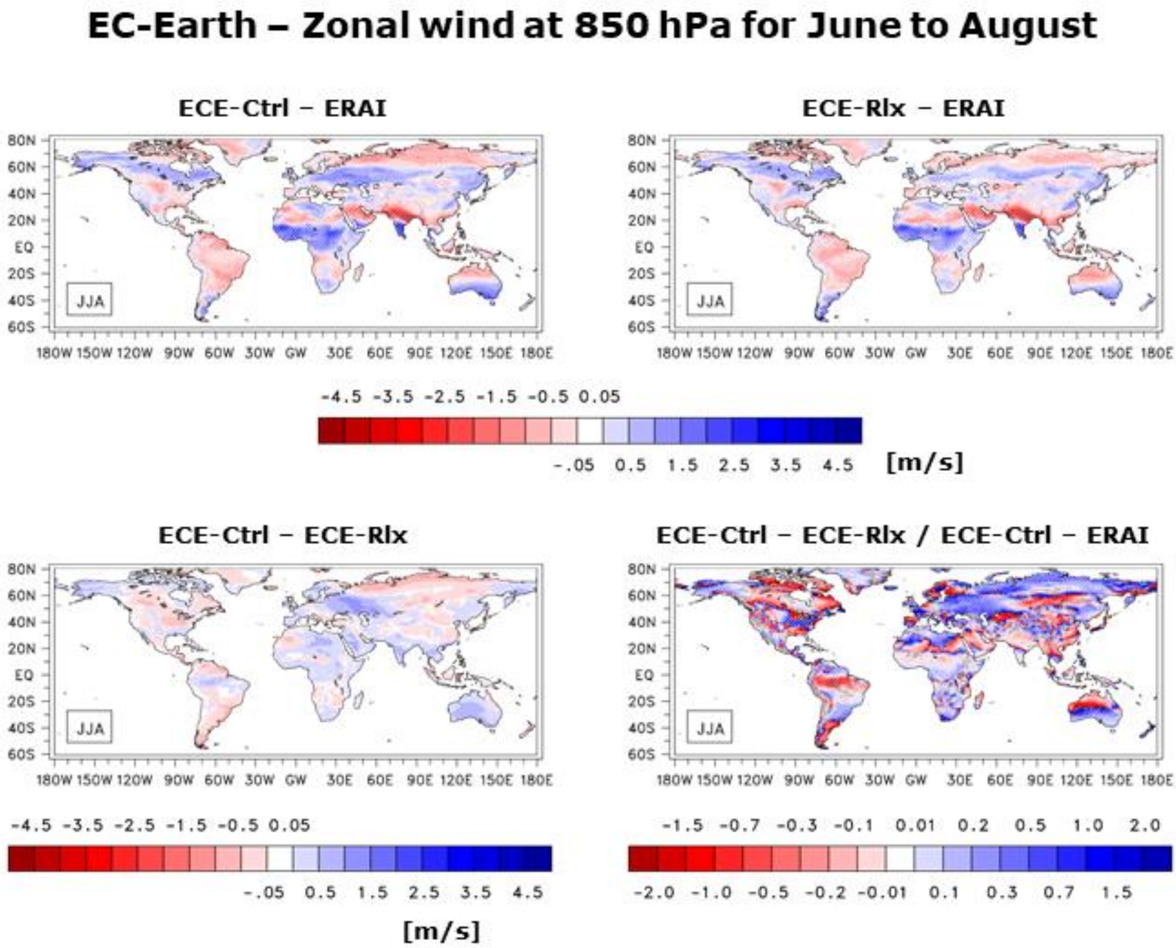

Fig. 6: Differences in seasonal mean zonal wind component at 850 hPa for June to August for the period 1991-2000 between two simulations with EC-Earth 3.2 and ERA-Interim (upper row) and between the different experiments (lower left corner). Also, the ratio between the difference between the two experiments and the bias of the standard simulation. ECE-Ctrl is a standard AMIP-type simulation and ECE-Rlx a simulation with the soil moisture nudged towards ERA-Interim/Land without the special treatment of frozen soils (see above).

The zonal wind component at 850 hPa represents parts of the dominant monsoon flows in the lower troposphere over West Africa and South Asia. In the standard experiment, EC-Earth simulates too strong westerly winds over the southern part of West Africa but too strong easterly winds over the northern part. Similarly, EC-Earth overestimates the westerly flow over the southern part of India but overestimates easterly winds over the Ganges plain. Restricting soil moisture has only little effects on the zonal wind component in the two monsoon regions, but clearly reduces the westerly wind bias over Central Asia.

In conclusion, the surface climate in EC-Earth is characterized by two general biases, i.e. a cold bias in near-surface temperatures and a dry bias in precipitation, with the latter resulting in a general underestimation of soil moisture. Nudging soil moisture against ERA-Interim/Land, thus, increases the fluxes of latent heat at the land surface and reduces the fluxes of sensible heat. As a consequence, cold temperature biases are enhanced by restricting soil moisture, while warm temperature biases are reduced.

The results presented here are based on a preliminary version of EC-Earth, 3.2. First experiments with the final version for CMIP6, 3.3, with some slight modifications (“tuning”), reveal that the overall cold bias of the model is even slightly stronger in EC-Earth 3.3., while the overall dry bias is not affected. This means that restring soil moisture by ‘observational’ values, i.e. from an offline-simulation with H-TESSEL+LPJ-GUESS forced with ERA5 will probably enhance the cold bias of the model over much of the globe.

List of publications/reports from the project with complete references

Given the late start of the long simulations with the final version of the EC-Earth earth system model for the CMIP6 initiative, there wasn’t any opportunity for scientific publications based on the work in the special project. Instead, I have presented the work at various meetings and scientific conferences, i.e. at the 8th GEWEX Open Science Conference ‘Extremes and water on the edge’ in Canmore (Canada) – see the enclosed slide announcing the poster below, at the LandMIP Meeting in Toulouse (France), and at the EGU General Assembly 2019 ‘Land-climate interactions from models and observations: Implications from past to future climate’ in Vienna (Austria), as well as at the MERGE Autumn Meeting 2017 in Helsingborg (Sweden) and the EC-Earth Meeting 2018 in Reading (UK).

Future plans

The research activity is continued in a new special project entitled “Land surface-climate interactions in the EC-Earth ESM: their role for climate variability and contribution to future climate” for the period 2020-2022.