SPECIAL PROJECT PROGRESS REPORT

All the following mandatory information needs to be provided. The length should *reflect the complexity and duration* of the project.

Reporting year	2021……………………………………………………………
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……………………………………………………
Principal Investigator(s):	Wilhelm May…………………………………………… ………………………………………………………………
Affiliation:	Centre of Environmental and Climate Science, Lund University, Sweden………………………………………
Name of ECMWF scientist(s) collaborating to the project (if applicable)	……………………………………………………………… ………………………………………………………………
Start date of the project:	1.1.2020……………………………………………………
Expected end date:	31.12.2022…………………………………………………

Computer resources allocated/used for the current year and the previous one
(if applicable)
Please answer for all project resources

		Previous year		Current year	
		Allocated	Used	Allocated	Used
High Performance Computing Facility	(units)	9,000,000	8,400,000	9,000,000	0
Data storage capacity	(Gbytes)	45,000	36,500	70,000	49,000 (run ecfs_status on ecgate)

Summary of project objectives (10 lines max)

The project activities continued with several simulations and started the analysis of these simulations. In relation to the original project description, a second long simulation with EC-Earth (1900-2014; #1.5) has been performed. Instead of running the remaining long simulations (#1.2 and #1.4) right away, I have continued to run several shorter corresponding experiments for the late observational period (1979-2017) and started to analyse those. In these simulations, the land-surface forcing, i.e. soil moisture and vegetation, was obtained from an offline simulation with H-TESSEl+LPJG forced with ERA5 instead of GSWP3. These simulations have the advantage that they cover a period with a wealth of observational data, e.g. soil moisture and surface flux estimates from remote sensing.

Summary of problems encountered (10 lines max)

No problems encountered, except that I have lost some initial and boundary conditions etc. of EC-Earth (as well as some post-processed data) that had been stored in the $SCRATCH partition of cca (which I hadn't put onto the ecfs system). I have spent some time to re-establish things but still haven't recovered from that. It would have been nice with some more space in the $PERM partition.

Summary of plans for the continuation of the project (10 lines max)

There are plenty of computer resources for one of the long simulations left for this year. They will be used for one (hopefully two) of the remaining long simulations (1900-2014; #1.4 and #1.2) and possibly for some of the planned simulations for the observed period (1950-2014; #3.n and #4.n). I will also need to plan for the transfer of EC-Earth to ATOS in 2022. I will presumably not need all the granted resources, though (will inform the special project service on that).

List of publications/reports from the project with complete references

No publications yet.

Summary of results

In the first part, some preliminary results from the two long simulations (1901-2014) with EC-Earth, with prescribed sea surface temperatures and sea ice, are presented. In particular, results for the temperature at 2 m during boreal summer (June through August) for the recent period 1979-2014 are shown.
The following two experiments with EC-Earth are considered:
ECE-V+SM; IFS coupled with LPJ-GUESS, with soil moisture nudged against the values from the offline simulation with HTESSEL+LPJG forced with GSWP3, and
ECE+SM+VEG; IFS, with soil moisture nudged and vegetation prescribed from the offline simulation with HTESSEL+LPJG forced with GSWP3.

EC-Earth is characterized by considerable temperature biases in many parts of the globe, mostly cold biases, indicating that the model has a general tendency of simulating too cold near-surface temperatures (see Fig. 1). During boreal summer both simulations are characterized by marked cold biases at high northern latitudes and most of Eurasia as well as in parts of South America, Africa and Australia. Considerable warm biases, on the other hand, are located in the western part of the United States, southeast of Amazonia, the Mediterranean region and Central Asia as well as in parts of Africa and Australia. The overall geographical distribution of the temperature biases is not really affected by the extent to which the land-surface conditions are restricted, either the soil moisture conditions (middle right panel) or the soil moisture conditions and vegetation combined (middle left panel). Nevertheless, restricting also the vegetation has an impact on the magnitude of the regional temperature biases. The map of the differences between the two long simulations (lower row) reveals that also restricting vegetation can reduce the temperature bias (i.e. in those regions, where the difference between the two simulations has the opposite colour type than the bias of the simulation, where only soil moisture is restricted). The cold bias is, for instance, reduced in Siberia, over the Sahara, southeast of Amazonia and the western part of Australia. In the northern part of North America and Eurasia, on the other hand, the cold bias is enhanced. Restricting vegetation also reduces the warm bias in all areas but Southern Africa, particularly in the western part of the United States, Amazonia and Central Asia.

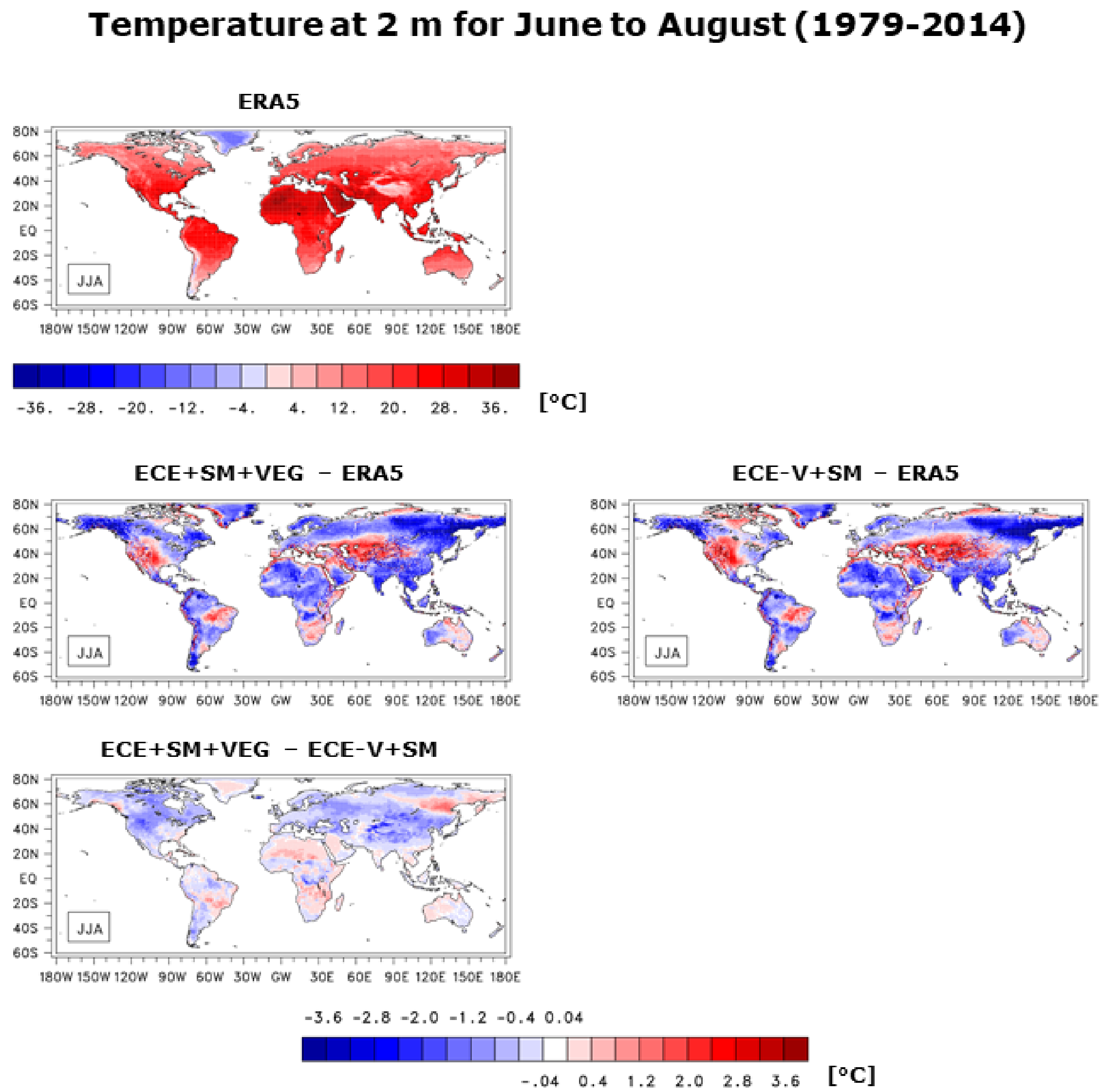

Fig. 1: Long-term seasonal mean of the temperature at 2 m from ERA5 (upper row) as well as the differences between the two simulations and ERA5 (middle row) and between the two simulations (lower row). Units are [°C]

<u>In the second part</u> some preliminary results from the short simulation (1979-2017) with HTESSEL+LPJG forced with the meteorological conditions from ERA5 are presented. In particular, various aspects of this simulation are evaluated against suitable reference data sets for boreal summer (June through August).

The soil moisture conditions and vegetation from this simulation have been used to restrict the land-surface conditions in two experiments with EC-Earth:

<u>ECE-V+SM</u>; IFS coupled with LPJ-GUESS, with soil moisture nudged against the values from the offline simulation with HTESSEL+LPJG forced with ERA5, and

<u>ECE+SM+VEG</u>; IFS, with soil moisture nudged and vegetation prescribed from the offline simulation with HTESSEL+LPJG forced with ERA5.

In addition, a third experiment with EC-Earth has been performed where the land-surface conditions develop freely (ECE-V).
Some preliminary results of these simulations with different configurations of EC-Earth were presented in the previous progress report in 2020.

As for the soil moisture, the two different observational estimates considered here (GLEAM_A gives very similar estimates than GLEAM_B) have different magnitudes (see Fig. 2). There is a general tendency that GLEAM_B is wetter than ESACCI in regions where soils are relatively wet and dryer in areas where soils are rather dry.

This has also some effect on the estimated bias in the simulation of soil moisture by the land-surface component of EC-Earth, HTESSEL+LPJG. Compared to ESACCI (lower left panel), the simulation shows a wet bias at high northern latitudes, in the central tropics and in Southeast Asia. A dry bias is found in the western part of the Unites States, Central Asia, the subtropical parts of Africa, Australia and parts of South America, i.e. southeast of Amazonia. To a small extent, the precipitation bias in ERA5 with two much rainfall i at high northern latitudes, in the central tropics and in Southeast Asia and too little rainfall in the Sahel region (not shown) contributes to this soil moisture bias. With respect to GLEAM_B, on the other hand, the model underestimates soil moisture over most of the globe (lower right panel). As a consequence, many of the dry soil moisture biases already found with respect to ESACCI are amplified.

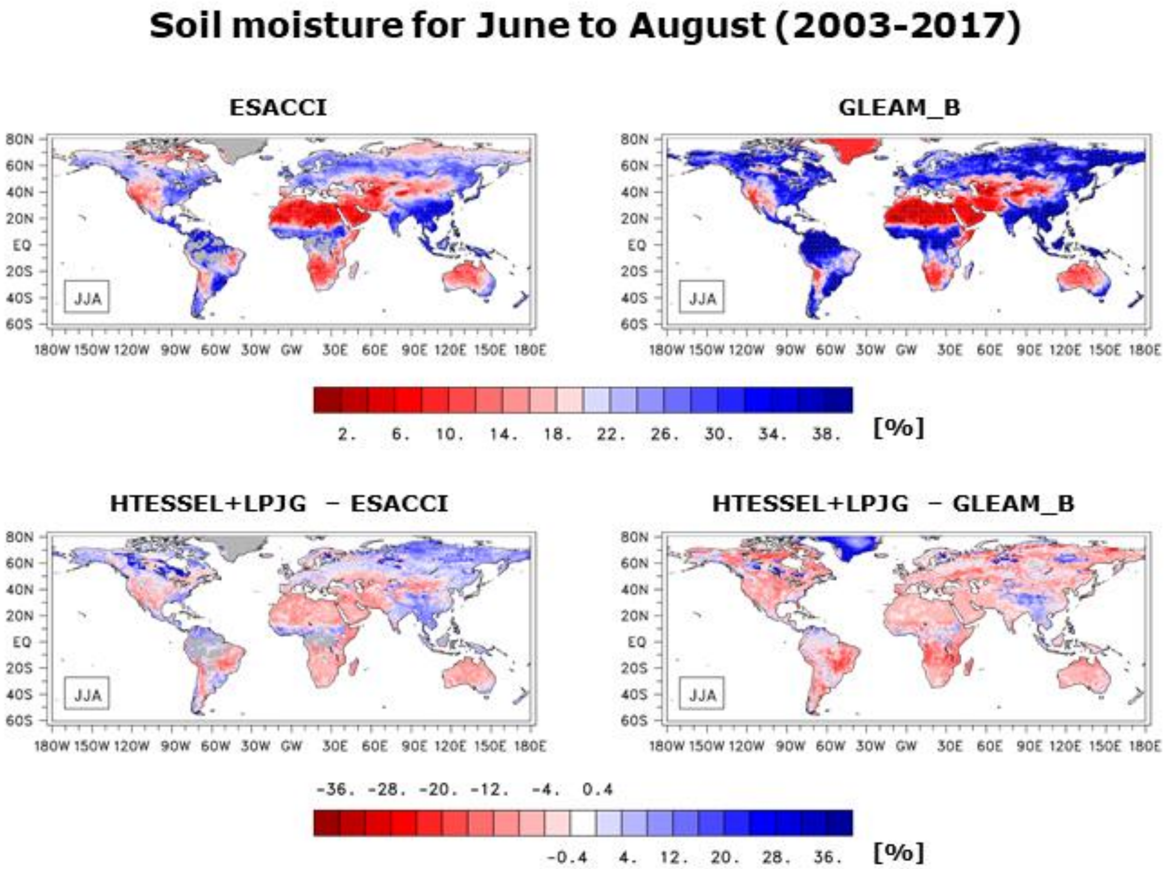

Fig. 2: Long-term seasonal means of the volumetric soil moisture in the surface layer from ESACCI and GLEAM_B (upper row) as well as the differences between the simulation and ESACCI and GLEAM_B, respectively (lower row). Units are [%]

Both observational data sets show rather strong fluxes of latent heat at the land-surface in the central tropics, the eastern part of the Unites States and in Southeast Asia (see Fig. 3). Relatively weak fluxes of latent heat are found in the subtropical parts of the Southern Hemisphere as in the eastern part of the Unites States, in Central Asia and at high northern latitudes. The two observational estimates reveal some regional differences. The data set using satellite products as forcing (FLUXCOM_SAT), for instance, gives stronger fluxes of latent heat southeast of Amazonia and in the southern part of Central Africa. The data set using meteorological data (FLUXCOM_MET), on the other hand, gives somewhat stronger fluxes in much of Eurasia.

These differences have implications for the bias of the simulation. Compared to FLUXCOM_SAT, the simulation considerably underestimates the fluxes of latent heat in the area southeast of Amazonia and over much of Southern Africa (lower left panel). Compared to FLUXCOM_MET, on the other hand, the negative bias also shows up (with a much smaller magnitude) but the bias over Southern Africa in not visible any more (lower right panel). The simulation generally overestimates the fluxes of latent heat in the Northern Hemisphere extratropics, the central tropics and Southeast Asia. The positive bias in the Northern Hemisphere extratropics is somewhat stronger compared to FLUXCOM_SAT than to FLUXCOM_MET. By and large, the geographical distribution of the bias in the latent heat fluxes follows the biases in soil moisture with respect to ESACCI (see Fig.1). This could indicate that ESACCI more realistically describes soil moisture in the surface layer than the GLEAM data sets.

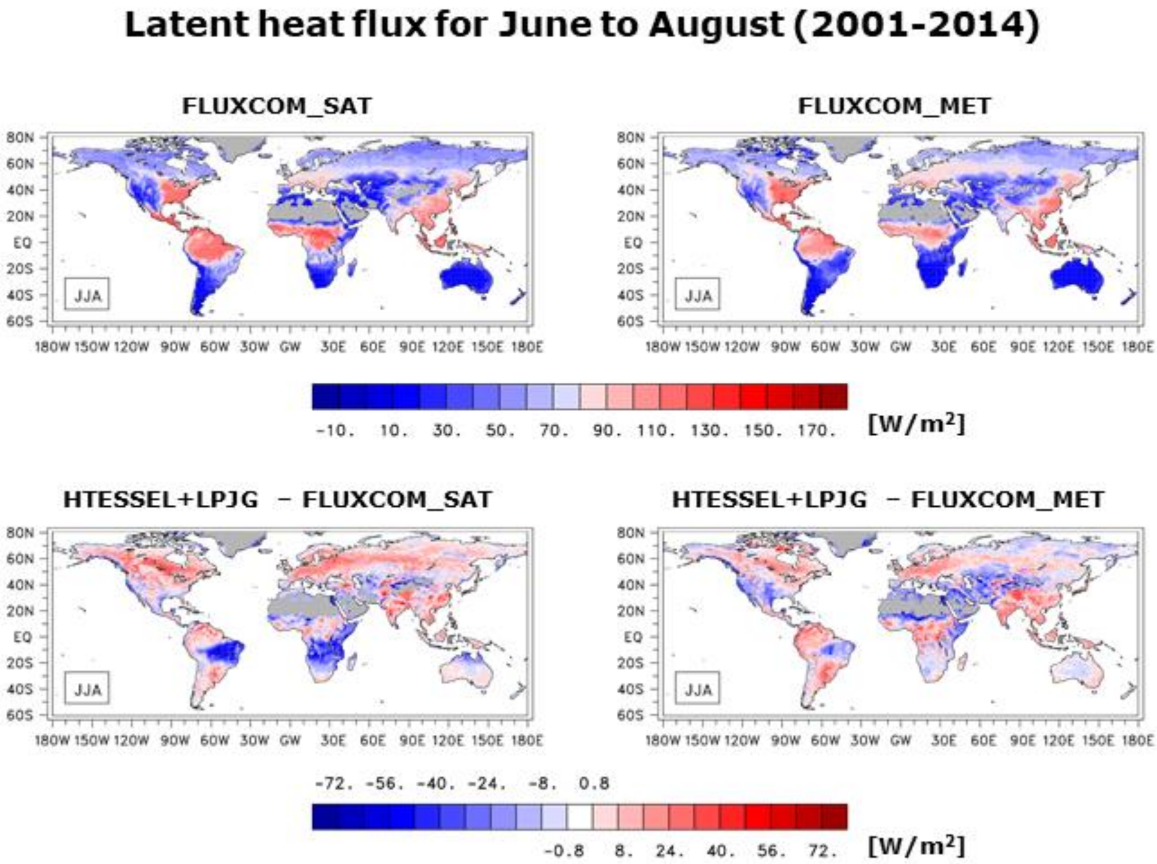

Fig. 3: Long-term seasonal means of the latent heat flux from FLUXCOM using satellite products (SAT) and the GSWP3 meteorological data (MET) as forcing (upper row) as well as the differences between the simulation and FLUXCON_SAT and FLUXCOM_MET, respectively (lower row). Units are [W/m^2]

As for the fluxes of sensible heat, both data sets show rather strong fluxes in the western part of the United States, the Mediterranean region and the southern part of Central Africa (see Fig. 4). While the fluxes in the western part of the Unites States and the Mediterranean region are somewhat stronger in FLUXCOM_SAT, the fluxes in the southern part of Central Africa are stronger in FLUXCOM_MET. Similarly, the sensible heat fluxes southeast of Amazonia are relatively strong in FLUXCOM_MET. By this, the deviations between the two data sets for the fluxes of sensible heat show the opposite behaviour tham in the case of the latent heat fluxes. The sensible heat fluxes are rather weak in the Southern Hemisphere extratropics, the eastern part of the Unites States, Southeast Asia and at high northern latitudes.

The biases in the simulation of the fluxes of sensible heat are characterized by a very similar geographical distribution as for the latent heat fluxes but with the opposite sign, i.e. the sensible heat fluxes are typically overestimated where the latent heat fluxes are underestimated and vice versa. The simulation underestimates the fluxes of sensible heat in the Northern Hemisphere extratropics, the central tropics, Southeast Asia and the Southern Hemisphere extratropics. The sensible heat fluxes are overestimated in the western part of the Unites States and Central Asia as well as in the area southeast of Amazonia and Southern Africa. The overestimation in the area southeast of Amazonia and in Southern Africa is particularly pronounced with respect to FLUXCOM_SAT (lower left panel).

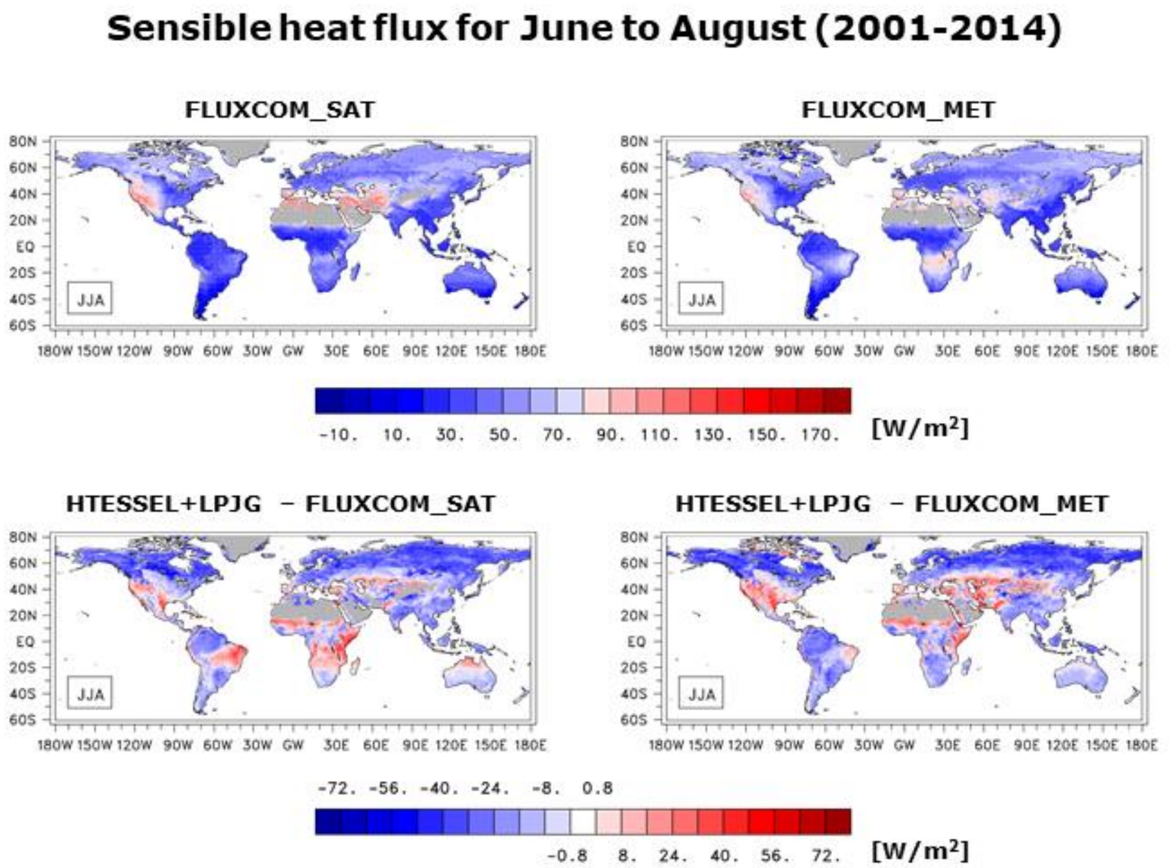

Fig. 4: Long-term seasonal means of the sensible heat flux from FLUXCOM using satellite products (SAT) and the GSWP3 meteorological data (MET) as forcing (upper row) as well as the differences between the simulation and FLUXCON_SAT and FLUXCOM_MET, respectively (lower row). Units are [W/m^2]

The evaporative fraction is defined as the ratio between the fluxes of latent heat and the total energy flux at the land-surface, combining the latent and sensible heat flux (see Fig. 5). According to the observational estimates, the fluxes of latent heat exceed the sensible heat fluxes in the eastern part of the United States, the central tropics, Southeast Asia and in parts of Eurasia. The fluxes of sensible heat, on the other hand, exceed the latent heat fluxes in the western part of the United States, Central Asia, Southern Africa and Australia. Consistent with the differences for the latent and sensible heat fluxes between the two observational data sets, the evaporative fraction is notably stronger for FLUXCOM_SAT than for FLUXCOM_MET in the area southeast of Amazonia and the southern part of Central Africa.

Compared to the two observational data sets, the simulation overestimates the evaporative fraction over most of the global land area. This is particular the case in the extratropical regions in both hemispheres as well as in the central tropics and Southeast Asia. The evaporative fraction is underestimated in the western part of the United States, the Mediterranean region and Central Asia with respect to both observational data sets and in the area southeast of Amazonia and Southern Africa compared to FLUXCOM-SAT (lower left panel).

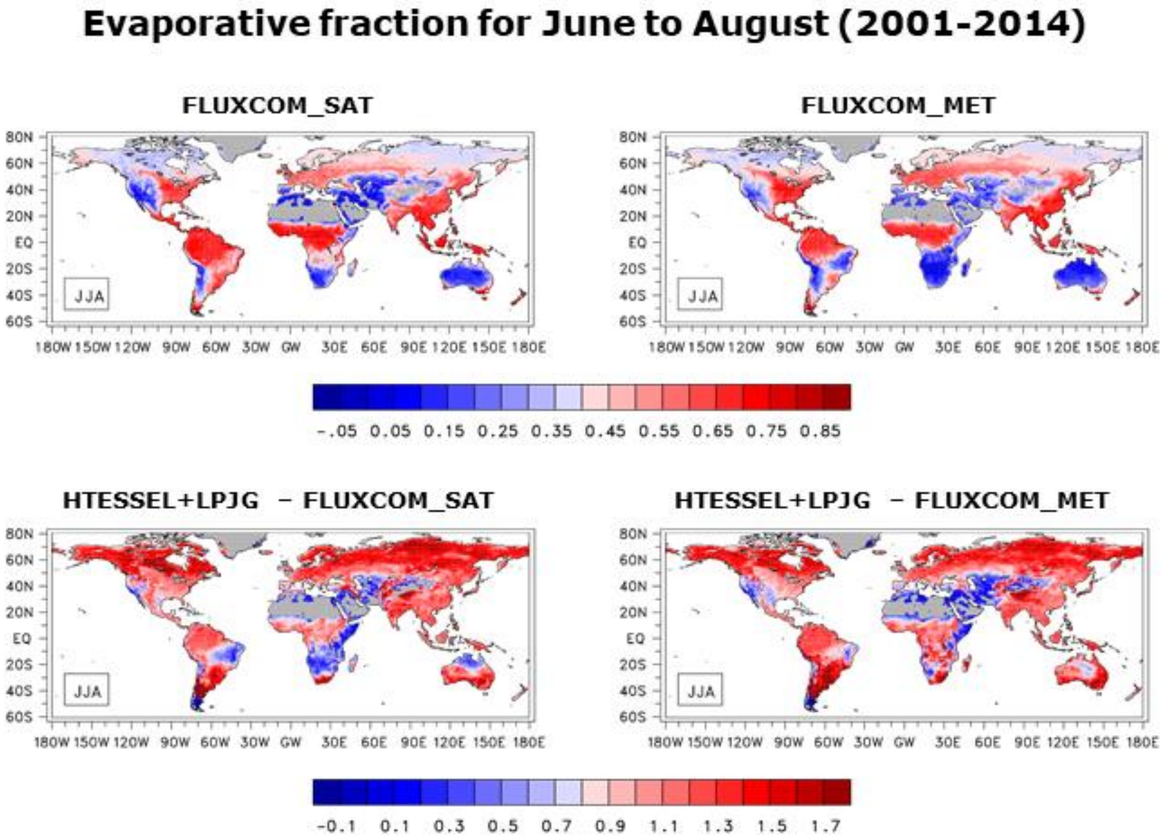

Fig. 5: Long-term seasonal means of the evaporative fraction from FLUXCOM using satellite products (SAT) and the GSWP3 meteorological data (MET) as forcing (upper row) as well as the ratio between the simulation and FLUXCON_SAT and FLUXCOM_MET, respectively (lower row). Units are standard unit

In conclusion, the evaluation of the offline simulation with the land-surface component of the EC-Earth earth system model, HTESSEL+LPJG, indicates a bias in soil moisture that exceeds the error introduced by the systematic precipitation bias in ERA5. The soil moisture bias affects the simulation of the fluxes of latent heat and, thus, of the sensible heat fluxes and the evaporative fraction in a physically consistent manor.

It will be interesting to compare these biases with the simulations with the different configurations of EC-Earth, where the interaction with the atmosphere and, thus, the contribution from the model's characteristic state of the atmosphere comes into play.