Referee 2

This paper investigates the effects of integrating inter-annually varying land cover and vegetation characteristics, derived from satellite observations, on modeled evaporation and soil moisture. The study uses the Hydrology Tiled ECMWF Scheme for Surface Exchanges over Land (HTESSEL) Land Surface Model (LSM) and data from various sources, including ESA-CCI land cover maps, Copernicus Global Land Services (CGLS) data on Leaf Area Index (LAI), and Fraction of green vegetation Cover (FCover) from CGLS. The paper concludes that integrating interannually varying land cover and vegetation significantly improves the representation of evaporation and soil moisture, highlighting the importance of capturing vegetation variability for accurate modeling of land surface-atmosphere interactions. The findings have important implications for refining land surface models and improving the accuracy of climate change predictions. Overall, this paper is well-written and scientifically sound. It provides valuable insights into the future of LSM modeling in the context of pervasive global change. However, several concerns need to be adequately addressed prior to publication.

We would like to thank the referee for the comments. We appreciate the time and effort taken to read our manuscript in detail and to provide us the very useful and interesting thoughts on our research. We will take the comments into account when revising the manuscript.

In the review comments, the provided line numbers did not always match the comment. In these cases, we looked at the line numbers that matched the comment, based on our own interpretation of the comment.

We have separated the different comments (shown in *italic*) and have written our replies below. Text in the original manuscript is shown in '*italic*' and revised text in '***bold***'. Unless differently stated, line numbers mentioned in our reply refer to the original manuscript version.

Comment 2.1

The title of the paper does not effectively summarize the main research content and findings. While representing inter-annual land cover and vegetation variability based on remote sensing data is a part of the paper, another part involves studying the improvement of model simulation ability for E and SM after introducing remote sensing data. Therefore, I recommend that the author modify the title accordingly.

We understand this point and see that the current title does not represent the full scope of the paper. Therefore we will modify the title: *"Representing inter-annual land cover and vegetation variability based on satellite observations in the HTESSEL land surface model"*

to:

"Inter-annual land cover and vegetation variability based on remote sensing data in the HTESSEL land surface model: implementation and effects on simulated water dynamics"

Comment 2.2

The Introduction section could be further improved. The importance of the research in this paper was not well explained. For example, Line 58: The authors may need to justify the statement "most previous LSM studies aimed at improving the temporally fixed boundary condition of land cover and the monthly seasonal cycle of LAI, while not exploring the effects of inter-annual variations of LC and LAI". Numerous studies have attempted to simulate Leaf Area Index (LAI) using Land Surface Models (LSM). These models can also consider the dynamics of vegetation cover, although uncertainties cannot be ignored. Also, the statement "Moreover, previous studies have generally used one spatially fixed relationship between effective vegetation cover and LAI, ..." requires further explanation and justification.

We acknowledge that information on other studies on LAI representation in LSMs other than HTESSEL is missing. Therefore, we will further expand the introduction with information on studies integrating satellite-based vegetation properties in LSMs other than HTESSEL (also see comment 1.1). Moreover, we will clarify the research gap that leads to our objective in L58-61 as follows:

*"The research gap that we identified is that most previous LSM studies **using HTESSEL** aimed at improving the temporally fixed boundary condition of land cover and the monthly seasonal cycle of LAI, while not exploring the effects of inter-annual variations of LC and LAI. Moreover, **these** studies have generally used one spatially fixed relationship between effective vegetation cover and LAI, while there is considerable evidence that this relationship is vegetation type dependent (Chen et al., 2005; Ryu et al., 2010; Zhang et al., 2014)."*

Comment 2.3 - *Line 77: Why didn't the authors use the AVHRR LAI data directly instead of using a combined dataset from AVHRR and CGLS LAI?*

We acknowledge that we could have also used the AVHRR dataset for LAI for the entire period. However, CGLS LAI is based on the newest sensors, and, therefore, we expect it to be more representative. Moreover, the CGLS products are also of interest because its follow-up data that uses the same processing algorithm is provided operationally in near-real-time. In addition, the 1km resolution of CGLS, which is higher than the 0.05degree resolution of AVHRR, allowed us to better isolate vegetation types for the effective vegetation cover parameterization (see also comment 2.8).

Comment 2.4 - *Line 84: Could the authors please provide a brief explanation of the improvements made in this study compared to the previous one? This would help to better understand the novelty of the current study.*

A brief summary of the model improvements made in this study is provided in the introduction L62-67. We intentionally split section 2.2 with the current model representations, and section 2.3 with the model improvements made in this study. To clarify the structure we will make the following changes in the subtitles in section 2:

Section 2.2 from '*Model description*' to ***'Relevant model components for water cycle representation'.***

Section 2.3: From '*The implemented vegetation variability'* to ***'Model developments'***

Section 2.3.1: From *'Land cover variability'* to '***The implemented land cover variability'***

Section 2.3.2: From *'Leaf Area Index variability'* to '***The implemented Leaf Area Index variability'***

Section 2.3.2: From *'Vegetation specific effective vegetation cover parameterization'* to '***The implemented vegetation specific effective vegetation cover parameterization***

In addition we will clarify the structure of our methods section by adding the following texts before section 2.1:

"This section describes how we integrated temporal and spatial variations of land cover and vegetation characteristics in HTESSEL. In Sect. 2.1 we describe the land cover and vegetation data used, in Sect. 2.2 we describe the model characteristics with relevance to water dynamics, and in Sect. 2.3 the model developments performed in this study are reported. Finally, the model experiments and model evaluation are described in Sect. 2.4 and in Sect. 2.5 respectively."

In addition we will clarify the reference to the model improvements described in section 2.3 in L85 as follows: *"This section describes ….* ***Section 2.3 describes the adaptations of these model components made in this study."***

Comment 2.5 - *Line 100: Why 289 cm? Should it be 189 cm?*

We discovered a mistake in line 98 where '100' should be '72'. The fourth layer has a depth of 189, but the total depth of the four layers is 289 cm (layer 1 + 2 + 3 = 100 cm). To avoid this confusion we will clarify this description in lines 98-100 as follows (see also answer to comment 1.15):

"The subsurface in HTESSEL consists of 4 soil layers ***with thicknesses of 7, 21, 72 and 189 cm****. In this study we differentiate between near-surface soil moisture (SM_s) in the top layer (0-7 cm), and the subsurface soil moisture (SM_{sb}) in the three deeper layers (7-289 cm)."*

Comment 2.6 - *Section 2.2.2 mainly describes how LAI affects RC and W1m, rather than the representation of LAI itself. The same issue applies to Sections 2.2.1 and 2.2.3.*

Section 2.2.1-2.2.3 describe the representation of LC, LAI, and effective vegetation cover in the current HTESSEL version as part of the EC-Earth3 ESM, and the role of these representations in the modelled water cycle. To clarify this we will make the adaptions from comment 2.4, and we will further elaborate on the intention of these sections in L85 as follows:

"This section describes the relevant model representations of land cover (2.2.1), leaf area index (2.2.2), and effective vegetation cover (2.2.3) in the current HTESSEL version as part of the EC-Earth3 ESM, and the role of these representations in the modelled water cycle. Section 2.3 describes the adaptations of these model components made in this study."

Comment 2.7- *Line 116: Did the authors take the effects of rising CO2 on rc into account?*

No we did not take this into account. To clarify this, we will modify L104-109 as follows:

"The LAI controls the canopy resistance r_c of the high and low vegetation tiles through the following linear relation:

$r_c = r_{s,min} LAI \; f_1(R_s) f_2(D_a) f_3(SM)$ *(1)*

*with $r_{s,min}$ the **prescribed** vegetation specific minimum canopy resistance, **that does not change in time**, and $f_1(R_s), f_2(D_a)$ and $f_3(SM)$ functions describing the dependencies on shortwave radiation (R_s), atmospheric water vapor deficit (D_a), and weighted average soil moisture based on the root distribution over the four soil layers (SM), respectively**. The effects of CO2 changes on r_c are not explicitly taken into account in present study.**"*

Comment 2.8 - *Line 185: The spatial resolution here is approximately 75x75 km. Why was the LAI and LC data interpolated to 1x1 km?*

The LAI and LC data were interpolated to 1x1km for the here developed parameterization of effective vegetation cover. For this parameterization, we aimed to isolate vegetation types (as much as possible) to be able to get the vegetation specific values for k. This isolation of vegetation types was the most representative when using high resolution (i.e. 1x1km) instead of the model resolution (~75x75km), because vegetation type mixing is minimized at higher resolution. For direct model implementation, LAI and LC were used at the model resolution.

We will clarify this in the following lines:

L172: *"To discriminate vegetation types, the grid cells where each vegetation type maximizes its cover fraction based on the ESA-CCI LC developed in Boussetta and Balsamo (2021) were selected for each year. For each set of grid cells corresponding to each vegetation type, the FCover and LAI 10-daily, 1km data for 1999-2019 were extracted.* ***Here we used a 1x1km resolution for LAI, FCover and LC in order to obtain the most representative discrimination of vegetation types, and to minimize vegetation mixing within each resolved grid cell.****"*

Comment 2.9 - *Section 4.1: The section title does not fit in the discussion section. Additionally, I noticed that the text below does not only summarize the results.*

In Section 4.1 we had the intention to combine and synthesize the different results and to elaborate on the implications of our findings. Therefore we will modify the section title from *"Synthesis of results*" to "***Synthesis and implications".***

Comment 2.10 - *Line 389: It is misleading to say "fixed atmospheric forcing" here.*

We will change line 389 as follows:

"Our model experiments were performed in an offline mode with ***prescribed*** *atmospheric forcing,…"*

Comment 2.11 - *Section 4.2: While it is commendable to acknowledge these limitations, I suggest that the authors provide a more detailed discussion. For example, they could explore the differences in the representation of land cover and vegetation variability between the models used in this study and the ERA5 LSM, and discuss the potential consequences for the comparative analysis.*

Exploring the differences of vegetation and land cover variability between our models and ERA5 would be an interesting and valuable follow up. However, we believe that exploring this in the discussion of this manuscript would need additional analyses that are beyond the scope of present paper.

Comment 2.12 - *Line 435: Many efforts have been made to model global vegetation dynamics, although notable uncertainties still exist. Furthermore, the term 'vegetation evolution' may not be appropriate.*

We will modify L435 as follows:

"Overall, our results emphasize the need for representing spatial and temporal vegetation variability in LSMs used for climate reanalyses and near-term climate predictions. In climate predictions, we cannot rely on satellite retrievals, and, therefore, the development and validation of dynamical or statistical models able to reliably predict ***vegetation dynamics, from leaf to ecosystem scales, remains*** *an important challenge for the future in the land surface modelling community."*