

Review “A general physiologically driven representation of leaf turnover in grasslands in the QUINCY land surface model (revision: 974a6b7f)”

We thank the reviewer for their valuable comments and the time spent reviewing our manuscript. Below, the reviewer comments are in black, our responses in red and manuscript changes in blue. Line numbers refer to the revised manuscript.

However, some state-of-the-art land surface models (LSMs) already account for the same set of drivers within their senescence parameterizations, such as the Community Land Model (Lawrence et al., 2019) and LPJ-GUESS (Smith et al., 2014). The authors should extend their discussion on the differences, similarities, and complementarity of their approach compared to the ones implemented in other LSMs. Besides this main point, some typos should be addressed before the manuscript is ready for publication.

Thank you for this suggestion, we agree that it is important to contextualise model development with advances from the wider modelling community. While we did touch on this in the introduction (lines 54-57), we did not come back to the topic in the discussion, which has now been rectified. While other models, prominently CLM and LPJGUESS, have introduced similar multi-factor phenology models, our approach is more flexible as we allow for continuous rather than trigger-based turnover and our model can shed leaves partially and gradually throughout the season.

L463: *Traditional leaf phenology research often focused on mid-latitude temperate systems, where a temperature threshold for both start of season and end of season may be a good approximation, but even in those ecosystems, the modelling focus has been largely on start of season phenology, with end of season processes being much more poorly understood. While progress has been made in stand-alone phenology models (Lang et al., 2019; Yang et al., 2023), implementation in LSMs has been slow (Richardson et al., 2012) and mainly focused on trees and shrubs (Chen et al., 2024). Many models, including LPJ-GUESS (Sitch et al., 2003) and CLM5 (Lawrence et al., 2019), have integrated similar multi-factor phenology models, yet they often rely on discrete environmental triggers. For instance, CLM5 simulates leaf senescence of grasslands through accumulated stress based on moisture, temperature, and day length thresholds. Once these predefined thresholds are surpassed, senescence is triggered. Similarly, LPJ-GUESS utilizes survival fractions of leaves based on climatic conditions and sheds all leaves on the statistically coldest day of the year, therefore introducing a hard-coded threshold for grasses. These discrete, trigger-based mechanisms often fail to capture how ecosystems respond to environmental stress.*

Grasslands may be one of the most moisture-sensitive ecosystems on the planet (Cherwin and Knapp, 2012) and drought frequency and intensity is expected to increase with climate change (Spinoni et al., 2018). Yet, models are not able to reproduce observed drought responses of grasslands (De Kauwe et al., 2017), even though the timing of these events has implications on C fluxes (Felton and Goldsmith, 2023) and the capability of shifting grasslands from a C sink to a source (Zhang et al., 2020). To address these limitations, our new dynamic model moves away from binary triggers, allowing us to capture the seasonal drought response in a dehesa, savanna-like, ecosystem, ES-LMa, more accurately and show [...]

Specific comments

Figure 1c: Is the light function symmetrical with respect to the equator?

The light response function is symmetrical with respect to the equator. We show an example of the behaviour for the northern latitude here, but rates of change are symmetrical, the only difference being the time of the year at which they occur. We have specified in the methods that latitude (ϕ_{deg}) can take on values between -90 and 90 (L229).

L229: '*where $-90^\circ \leq \phi_{deg} \leq 90^\circ$, ϕ_{rad} and δ_{rad} are the site latitude and declination in radians, respectively and $D_n \in [0, 24]$ h.'*

Line 222: "[...] only of the factors is limiting. [...]" should be "[...] only one of the factors is limiting. [...]"

We have added the word 'one'.

Lines 228-229: "The results of our sensitivity test reveal that 10% or a shedding of all leaves over 10 days at the highest shedding rate ($f_{shed,max} = 0.1$) is a more suitable value for our model." Are these sensitivity tests evaluated against observations? If yes, it would be worth mentioning here.

We have clarified that these tests were conducted at the four main sites and state that they have been evaluated against observational daily GPP data.

L265: '*The results of these tests, which we have conducted at the four main sites, reveal that 10% or a shedding of all leaves over 10 days at the highest shedding rate ($f_{shed,max} = 0.1$) is a more suitable value for our model in terms of daily GPP fit to observational data.'*

Lines 229-230: "Finally, we have added an additional condition to the growing season in the dynamic model so that an accumulated snow depth of > 2 cm stops the growing season." Is a snow depth of 2 cm creating an immediate shedding of all leaves? Is it applied throughout the year or only during the fall season?

We agree this wasn't very clear in the text - this does not lead to an immediate shedding of all leaves. Importantly, the dynamic turnover is not linked to the growing season which was the main objective of our study. However, the growing season still controls tissue growth in the dynamic model. The reason for why we have added the snow condition to end the growing season in the dynamic model is that we want to avoid that the plant wastes carbon by growing new tissue under unfavourable conditions such as snow cover. Since the growing season in the default QUINCY model is only controlled by a 7-day moving average air temperature threshold, there may be a lag until the average air temperature over 7 days 'has caught up' with the current conditions. We have expanded on this sentence in L268 to make this clearer.

L268: '*Finally, we have added an additional condition to the growing season in the dynamic model so that an accumulated snow depth of > 2 cm stops the growing season. This does not directly impact the dynamic turnover model as it is not controlled by the growing season, but it stops the growth of new tissue under unsuitable conditions and when the turnover rate is already high due to low air temperature.'*

Table 2: add also the reference of Nair et al. (2024) for the ES-LMa site.

We have included a reference to Nair et al. (2024) as source for the ES-LMa GPP data in the table.

Caption Figure 3: describes in detail the level of significance given by the letters a and b.

We have rephrased this sentence and specified level of significance.

Caption Figure 3: *‘Letters above each bar indicate statistical significance (Tukey’s $p < 0.05$), where groups sharing the same letter are not significantly different and groups with different letters represent a significant difference between means (for p-values see Table 4).’*

Figure 3: ES-LMa site provides observed data of GPP from 2003 to 2006 (4 years) plus 2015-2018 (4 years) as reported in table 2 and Figure 2. Which are the 7 years used by the authors in figure 3?

We apologize for the oversight and have corrected this to 8 years in the figure as well as the associated Table 4.

Caption Figure 4: “ecosystem C (a), vegetation C (b) and soil organic carbon (SOC; c)”. The panel letter could be placed before the variable names, such as “(a) ecosystem C, (b) vegetation C, and (c) soil organic carbon (SOC)” to improve readability.

We have moved the letters in brackets before each word to improve readability.

Line 372: “similar model fits (Table 5,” closing bracket is missing.

Closed bracket

Line 602: NDdormancy should be consistent with equation A1 and written as NDdormance.

We have changed description from NDdormancy to NDdormance.

Line 616: GPP_{labile} should be GPPlabile

In line with the growing season equations Eq.4 it should be ‘GPP_{labile}’. We have changed it therefore to match this as GPP_{labile} in l616.

L678: *‘where GPP_{labile} is labile C assimilated through photosynthesis averaged over the last 7 days [...]*

Figure B1: Is it possible to distinguish the 37 sites used for evaluating the EOS timing as well?

Perhaps report those sites with a square instead of a circle on the map

We have changed the symbols to squares to indicate the 37 sites.