Referee #2

The description of fire emission calculations requires further elaboration and should clarify the following points without assuming in-depth familiarity with Exbrayat et al. (2018):

- How is "burnt area" used as a driver? Is there a specific step that converts burnt area into biomass or "vegetation pools in the burned area"?

We can adjust the text to provide detail of how the burned area impacts on the C cycle, with specific equations:

Equation 1

$$E_x = B.K_x.C_x$$

For each model pixel, fire emissions from pool *x* (E_x) are a function of pixel burned area fraction (*B*), a combustion completeness parameter for tissue type *x* (K_x) and the C stock size of pool *x*. K_x is calibrated by CARDAMOM.

Equation 2

$$M_{x,fire} = B.(1 - K_x).(1 - r).C_x$$

For the same pixel, fire-driven mortality of tissue *x* ($M_{x,fire}$) is the uncombusted component of fire-impacted pool x, further modified by a vegetation resilience parameter *r*, also calibrated by CARDAMOM.

Fire-driven mortality

- On Page 10, Line 7, it is stated that emissions are calculated by multiplying burnt area by a combustion fraction parameter from Exbrayat et al. (2018). How does this differ from the "specific combustion parameters" applied to each C pool?

These are the same parameters. We will clairfy the text to use the same terminology.

- The same resilience factor is applied to all C pools (except SOM). How is this assumption justified?

We confirm that for each pixel a single vegetation fire resilience parameter is applied to all live pools. Across the 1506 analysed pixels, however, the independent pixelwise calibration results in a variation in the vegetation fire resilience parameter (Fig 8). We assume that vegetation in the SAW region displays characteristics distributed across a spectrum of fire resilience. Thus, some vegetation types have evolved to be resilient to fire, and others less so. Resilience is thus a holistic property of vegetation, rather than a tissue-specific property. Reflecting a common evolutionary history, fire resilience in vegetation is assumed to be similar across all vegetation pools within a pixel. Resilience is a property of vegetation.

The vegetation biomass resilience parameter will be constrained by the interactions between burned area and two vegetation observables - LAI dynamics and C_{wood} dynamics. LAI data are more frequent and extend over a longer period that biomass data, so the strongest constraint on resilience will arise from the interactions between burned area observations and LAI observations. Thus, spatial patterns of fire resilience in the analysis will be inferred from the temporal interaction of the forest canopy (LAI) with burned area.

Combustion completeness is assumed to vary across live pools within each pixel, reflecting how differences in structure, location and unit size of each vegetation pool affect combustion. These parameters also vary spatially across pixels.

We can adjust the text to provide this explanation of these assumptions.

- Without a diagram, it is difficult to understand the flow of C from pool to emission and between pools, as described on Page 10, Lines 9–12 (although Figure 3 in the results section is somewhat helpful).

  Figure 3 shows the model structure, and includes all pools and fluxes. We will reference this figure on P 10 to provide more context.

Section 3.2.2 would benefit from an expanded explanation of how the fire and combustion parameters are constrained. Specific clarifications needed include:

- Is the only observational data available to constrain these parameters a rapid change in aboveground biomass/LAI, coinciding with a time step where significant burnt area is observed in the forcing?
  Yes that is largely correct. However, even a small, sustained drop in biomass coinciding with burned area over a period provides information on fire impacts. We will adjust the text in this section to clarify.

- Within the EDC framework, is there a mechanism to explicitly link biomass changes to fire occurrence, thereby impacting fire and combustion parameters? Alternatively, does the optimization infer fire, disturbance, and turnover parameters solely from biomass changes?
  We confirm that EDCs do not relate explicitly to fire.
  It is the repeat time series data on biomass that provides the key information on biomass change and therefore on the processes that drive change. Biomass observations are combined with (i) expected patterns of inputs to biomass (i.e. NPP, driven largely by LAI observations and climate, linked to the modelling of GPP) and (ii) outputs from biomass, linked to observed disturbance (from burned area and deforestation data), to infer the biomass dynamics.

- What happens if/when observations of rapid biomass changes and burnt area forcing do not align in space and time?
  In this case, the calibration will adjust the non-fire mortality parameter in that pixel to match the biomass dynamics over the full analytical period. So, the overall trend in biomass change should be captured, but not attributed to fire. The analysis will not produce a biomass step change without an aligned forcing with burning or deforestation. We do note however, that operating at 0.5 degree

resolution reduces the likelihood for temporal misalignment. We aggregate multiple burned area (500 m resolution) and biomass (25 m resolution) measurements to the analytical resolution (0.5 degrees). We can update the discussion to note this point.

- The simulated change in aboveground biomass appears to depend on both combustion completeness for wood and biomass resilience. What are the implications for estimating these parameters, which exhibit significant equifinality when constrained only by biomass change observations? How does this affect the fire-related Mort_wood flux and the subsequent C_som dynamics, leading to the large E_som flux?
  This is an interesting question – it is true that our understanding of fire interactions is incomplete and challenged by the scales over which fire operates. As noted, biomass loss depends on both tissue combustion completeness (*K*) and vegetation biomass resilience (*r*). The biomass resilience parameter is constrained also by the interactions between burned area and LAI dynamics – not just woody dynamics. This constraint arises because resilience is a parameter that applies to all live pools (a property of vegetation), whereas combustion completeness is specific to each live pool. LAI data are more frequent and extend over a longer period that biomass data, so there is a stronger constraint on the resilience parameter from LAI. K_{wood} is constrained largely by biomass observations, not by LAI. Thus, equifinality between *r* and *K* is reduced due to their differential constraint from independent observations.
  The massive ensemble calibration approach using multiple chains means that any equifinality is robustly characterised in the posteriors generated by the analysis. It is clear in Figure 3 that the uncertainty on the individual *Mort* fluxes and *E_som* fluxes are relatively large. We can include clearer discussion and emphasis of fire flux uncertainty in the discussion.

Section 4.1 provides limited information about how parameters, including fire and combustion parameters, are constrained or how model performance is validated.

We can add figures to the SI showing the direct comparison of analytical outputs for LAI, biomass and soil C to the assimilated observations, to support the summary statistics presented on P13 L14.
We do refer to Table 1 (L 7) which quantifies the constraint on each parameter relative to parameter priors. We could add further text in this section to summarise the degree of constraint shown in detail in the Table.
This section (L 24) also refers to Figure 2 which is an independent validation of the calibrated model's capacity to simulate biomass accumulation over decades at two SAW sites.

To address this, the following questions should be clarified:

- On Page 13, Lines 20–21, it is stated that "fire emissions fell at the lower end of the range of fire emissions products," yet this appears to contradict the lower panel of Figure S2.

The text should read that the analysed median fire emissions were broadly "within the range of fire emissions products". We apologise for not revising the text after an update to the analysis.

- Page 13, Lines 21–22, mentions that "uncertainties were much larger than the products' range." Why is this the case, and what are the implications for interpreting emergent functional and causal relationships?

The calculation of regional fire emissions uncertainties from the CARDAMOM analysis is conservative. We assume that uncertainties are uncorrelated and so there is no effect of cancelling errors from combining multiple pixel analyses. In fact, there is likely to be some error correlation and therefore some reduction in errors at the regional scale. The analytical errors are large as a result of cascading uncertainties in C stocks in live and dead pools, and their interactions with fire (combustion completeness). These uncertainties are directly tracked by the CARDAMOM approach and shown in the fluxes displayed in Figure 3.

The high uncertainty in fire-driven emissions is not an important factor in the interpretation of causal relationships because the causal analysis was confined to dynamics of live pools, and focused mostly on C_{wood} dynamics, not emissions. This focus was deliberate to align with data availability (e.g. LAI and biomass observations) and thus rich information for calibration and inference of causation, using links to disturbance and climate data. There is no causal analysis of fire emissions or soil C dynamics. We can adjust the text to note these points.

Given the challenges in constraining fire and combustion parameters and the resulting large uncertainties in fire emissions, which hinder interpretation of ecosystem-level model outputs, it would be informative to compare CARDAMOM emissions with emissions from the prognostic fire models in the TRENDY LSM dataset. On Page 25, Line 30, it is suggested that "inconsistencies in C emissions from respiration and fire" account for mismatches in NBP, and this claim should be substantiated with more information on TRENDY model emissions in Section 4.5.

This comparison has been made in Figure S 11, which shows the different patterns of fire emissions within the TRENDY ensemble, and TRENDY variations from the CARDAMOM analysis.

We can add this figure reference at this point in the text to support our conclusion about inconsistencies.