Using artificial intelligence to monitor live fuel moisture content across France, based on a high-resolution land surface analysis

Referee #2

Commentary 2.1: Table 2 lists ten predictors selected for the model, but it is not clear how vegetation type or species composition is represented. In this study, LFMC measurements from multiple plant species at the same observation site appear to be averaged to represent shrub-layer LFMC. However, without information on the relative abundance, fractional coverage, or biomass contribution of each species, it is difficult to determine whether a simple arithmetic mean adequately represents the actual moisture condition of the shrub fuel layer. This issue may be particularly important when species at the same site exhibit substantially different seasonal or drought-response characteristics. In such cases, an unweighted species average may not accurately represent the LFMC of the actual fuel mixture at the site. The authors should clarify how vegetation type and species composition are represented in the model and discuss this as a potential source of uncertainty.

Response 2.1:
We thank the reviewer for highlighting this important issue. We agree that an unweighted arithmetic mean of LFMC measurements across species does not necessarily represent the actual fuel mixture's moisture content at a site, particularly when species differ in abundance. In this study, vegetation type is represented indirectly through predictors derived from the LDAS-AROME model. The operational configuration uses twelve vegetation types rather than individual plant species. The relevant vegetation type groups are temperate broadleaf vegetation and shrublands. Consequently, the model estimates LFMC using environmental and vegetation state variables at this aggregated functional level without explicitly accounting for species composition or relative species abundance. The observational dataset does not provide consistent information on species fractional cover. We therefore averaged the available species-level LFMC measurements to construct a site-level reference value. As the number of species sampled varies between sites, the resulting average may not accurately represent the actual LFMC of the local fuel mixture at all sites. We acknowledge that this aggregation introduces uncertainty into the model target, particularly where species exhibit contrasting responses to seasonal drying and water stress. We will revise the manuscript to clarify how vegetation is represented in the model, and to acknowledge the limitations associated with unweighted averaging of species-level observations.

Commentary 2.2: The manuscript repeatedly refers to modeled LFMC values as "predictions." However, it is not clear whether these values are truly predictions in the forecasting sense. Prediction generally implies estimation of a future state using information available prior to that time. In the present study, the LFMC appears instead to be diagnosed or estimated from land-surface model variables and other environmental predictors. If future meteorological forcing is not used, the term "LFMC estimation" would be more appropriate than "LFMC prediction."

Response 2.2:
We thank the reviewer for raising this relevant point. We agree that the term 'prediction' may imply the forecasting of future LFMC conditions using information available at an earlier time. As our model estimates LFMC based on environmental and land-surface variables rather than forecasting its future state, we will replace 'predictions' with 'estimates' throughout the manuscript, including in

the figures, tables and supplementary material where applicable.

Commentary 2.3: Line 302: The manuscript states, "The drop in NSE for the FC in 2020 is due to the first substantial expansion of observation sites beyond the Mediterranean basin, which occurred in 2020." If the spatial expansion of the observational network has an important impact on model evaluation, this change should also be reflected in Figure 1.

Response 2.3:
We thank the reviewer for this comment. We acknowledge that our original statement was inaccurate: the ONF observation network did not first expand beyond the Mediterranean basin in 2020. This actually occurred in 2023. The decrease in NSE observed that year may be related to the limited number of observations available during the initial years of the FC experiment. This NSE metric requires a sufficient number of observations. We will highlight this in the revised manuscript.

Commentary 2.4: Section 3.2: Section 3.2 compares LFMC maps for individual dates, including the date corresponding to the lowest LFMC in 2022, with the same calendar date in another year. However, comparison of two individual days may not be sufficient to demonstrate a robust climatological or interannual spatial gradient. A single-day LFMC field can be strongly influenced by short-term meteorological variability. If the authors intend to demonstrate persistent spatial differences or anomalous LFMC conditions in 2022 relative to 2023, monthly or weekly mean fields would provide a more robust comparison. In addition, overlaying observed wildfire locations or burned areas on these maps could provide useful context regarding the potential relevance of the LFMC product to fire-danger applications. This point is further discussed in Comment 6 below.

Response 2.4:
We thank the reviewer for this helpful suggestion. We agree that comparisons between individual dates can be affected by short-term meteorological variability, meaning they are not sufficient for establishing persistent spatial patterns or robust interannual differences. Our initial objective was to demonstrate the model's capacity to depict spatially and temporally fluctuating LFMC conditions rather than to consistently reproduce the same spatial distribution year on year. In particular, the comparison between 2022 and 2023 was intended to demonstrate how the estimated LFMC maps respond to contrasting annual conditions. However, we acknowledge that this comparison alone does not demonstrate the persistence or climatological significance of these differences. We will clarify this in the manuscript and complement the analysis with mean LFMC fields to provide a more robust assessment of spatial patterns. See also Response 2.6.

Commentary 2.5: Section 3.3: The manuscript attributes the relatively large uncertainty primarily to the limited representation of temperate deciduous broadleaf forest within the observational dataset. While this explanation is plausible, it may not be the only contributing factor. Other sources of uncertainty could include complex terrain, spatial heterogeneity in soil moisture, uncertainties in meteorological forcing, differences in vegetation species composition, limitations in the land-surface model's representation of plant water stress, and etc. Without an independent analysis that separates or evaluates these effects, it is difficult to attribute the poor model performance mainly to the under representation of a specific forest type. The authors should discuss other plausible sources of uncertainty.

Response 2.5:
We thank the reviewer for this insightful comment. We agree that the relatively large uncertainty

cannot be attributed solely to the limited representation of deciduous broadleaf forests in the observational dataset. Other factors may contribute to the observed errors, including complex topography, spatial heterogeneity in soil moisture, uncertainties in meteorological forcing, differences between species in LFMC responses and limitations in the representation of vegetation water stress within the LSM. These factors may interact, and it is not possible to separate their respective contributions using the analyses presented in this study. In accordance to the reviewer's comment, this will be acknowledge in the corrected version of the manuscript.

Commentary 2.6: Section 4.2: LFMC is an important component of wildfire danger because it influences fire behavior. However, LFMC alone does not determine whether a wildfire will occur. Ignition is a separate and essential component by natural or anthropogenic sources. Even under extremely low-LFMC conditions, a wildfire will not occur without an ignition source. Therefore, LFMC should be interpreted as an indicator of the potential for successful ignition and subsequent fire spread, rather than as a direct predictor of fire occurrence at a specific location and time. For this reason, correspondence between simulated low LFMC and a single observed fire event is insufficient to demonstrate consistency with real fire occurrence. A more appropriate evaluation would include a larger sample of fire cases and assess whether observed fire occurrence, fire spread, or burned area systematically corresponds to low-LFMC conditions identified by the model.

Response 2.6:
We thank the reviewer for this important clarification. We agree that LFMC alone does not determine fire occurrence; this also depends on the availability of an ignition source (whether natural or anthropogenic) and other environmental factors, such as wind conditions. The objective of this analysis was not to predict fire occurrence, but rather to examine the temporal evolution of simulated LFMC around reported fire outbreaks, and to assess its relationship with the established LFMC danger threshold. We acknowledge that this analysis does not establish a causal relationship between LFMC and fire occurrence, nor does it demonstrate that low LFMC alone explains the timing or location of individual fires. This analysis does not consider other factors influencing ignition and fire spread, including meteorological conditions and human activities. We will therefore revise the manuscript to clarify the exploratory nature of this benchmark, and avoid interpreting the temporal correspondence between low LFMC and reported fire outbreaks as evidence of fire prediction skill.

Minor Comments:

- Table 1: The sum of the training and validation samples does not appear to match the reported total number of observations. Please clarify the reason.
- Line 101: “LMFCdry from LMFCfresh” should be corrected to: “LFMCdry from LFMCfresh”

Response 2.7:
Thank you for noting this. It will be corrected in the revised version of the paper.