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To cite this article before publication: Chris Huntingford *et al* 2025 *Environ. Res. Lett.* in press https://doi.org/10.1088/1748-9326/adf12b

Perspective Article

A Call to Refine Fire Attribution: Expanding the FAR Statistic to Capture the Complexity of Los Angeles Extreme Fires.

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Keywords: Wildfires, Attribution, Climate change, Los Angeles, Global Warming, Fire Suppression

The January 2025 wildfires in Los Angeles resulted in a tragic loss of life and major damage to homes, infrastructure, and public health. Two key questions are: to what extent did climate change increase the likelihood of the event, and what role did direct human actions play? Direct human actions could encompass expanding urban developments into wildlands, unattended campfires, sparks from faulty equipment such as powerlines, or deliberate changes to land cover that may slow wildfire spread. Attribution studies generally address the first climate-related question by using the Fraction of Attributable Risk (FAR), a metric based on changes in meteorological conditions. However, this approach can oversimplify the complex drivers of fire, especially in regions like Los Angeles, where topography, vegetation, and ignition sources interact with large-scale climate signals. This suggests a need to extend FAR statistics to incorporate these factors and to translate them into more meaningful quantities such as fire emissions, health and air quality impacts, and economic losses. We use "FAR" as a general term throughout to refer to either that specific statistic or its derivatives, such as risk ratio or probability ratio.

To include human action and address the second question raised above, recent studies have begun to include coarse metrics of direct human influence, such as population density and broad land-use types, in attribution frameworks (Burton *et al*., 2024). These developments represent a promising shift beyond climate effects alone, particularly through initial attempts to attribute changes in direct fire quantities, such as burned area. However, these approaches remain limited in terms of detail and scope. Our perspective emphasises the need to routinely incorporate human factors, such as land management practices, into attribution calculations. An extended FAR statistic that encompasses all processes related to climate and fire risk, while also quantifying the effects of direct human actions, would illustrate whether direct human drivers are offsetting or exacerbating the impacts of climate change on fire events. The main suggestion and rationale are for statistics that quantify any role of climate change on fire events, accounting for land ecosystem interactions and human interventions, to create a more complete summary of how an evolving climate influences wildfire characteristics and their frequency.

To fully determine the extent to which climate change has raised the chances of a Los Angeles 2025-like fire event, it is necessary to assess (1) whether fine-scale changes, such as local wind direction and speed, are occurring, as these may have smaller spatial scales than the grid boxes of Global Climate Model (GCM) or Earth System Model (ESM) ensembles; (2) the role of vegetation growth, including inter-seasonal and inter-annual memory, which may respond to changing rainfall characteristics; and (3) how vegetation state, in tandem with local meteorological conditions, translates to natural fire risk (e.g. Di Giuseppe *et al*., 2025). Importantly, (4) we emphasize the need to quantify the interaction between climate and direct human impacts for inclusion in attribution analysis. Such changes include land management practices, fire suppression policies, and the expansion of the wildland-urban interface, all of which may modulate both fire behaviour and its impacts. Decades of fire suppression in California may have contributed to fuel buildup (Steel *et al*., 2015), although recent controlled burns have helped reduce fuel loads, illustrating the complex interplay between human decisions and fire risk. All these factors can be evaluated as modifying factors for any atmospheric-derived FAR statistic. We also propose a broader derivation of FAR-based statistics that extends beyond changes to fire event probabilities to include attribution statements that link more directly to people. Such metrics could encompass air pollution-related health effects, economic damage, or even loss of life, providing more actionable insights for preparedness and mitigation benefits. Expanding the current large-scale GCM or ESM-based numerical attribution systems to include these factors will result in a more accurate mapping between changes to atmospheric composition including climate-altering Greenhouse Gas (GHG) levels, fire impacts and local direct human influence. Developing this enhanced knowledge may help to create better early warning systems for any approaching higher wildfire likelihood.

The world looked on with deep concern regarding the recent Los Angeles wildfires, which extensively penetrated residential areas, affecting over ten thousand houses[1], and resulted in many deaths. As with many environmental extremes, examining their causes can lead to multiple candidate explanations. Alternatively, multiple perturbed forcings may combine, some driven by climatological changes and others not. Viewed in its simplest form, wildfires are often associated with high temperatures, and the Californian event has been suggested to result directly from global warming and so climate change ("*LA wildfires more likely because of climate change, says attribution study*"[2]) However, wildfire is a complex phenomenon shaped by climate, vegetation, and human activity. Thus, even climatic forcing may be manifested by adjusting several drivers to create extreme situations, leading to dependence between these forcings. This complexity necessitates a thorough attribution analysis that accounts for all direct and indirect climate forcings.

Globally, the total area burned each year has likely declined (Andela *et al*., 2017), largely due to human land use, and particularly the expansion of agriculture and grazing lands. However, these reductions are generally confined to flammable African savannah regions, disproportionately affecting the global trend. While land use has dampened fire activity in these areas, climate change has the opposite effect on many others, and it is in this context that fire attribution work has demonstrated its strength. Recent global attribution studies have revealed that climate change is actively increasing the burnt area in many locations (Burton *et al*., 2024), driving more burning in certain ecosystems through enhanced vegetation growth (i.e., greening) and hotter, drier conditions (Forkel *et al*., 2019). Simultaneously, extreme fire events are becoming more frequent and intense (Cunningham *et al*., 2024; UNEP, 2022[3]), and the length of fire seasons is extending (Jones *et al*., 2022). These advances in global-scale attribution represent a considerable step forward, offering strong evidence that climate change is not merely associated with fire weather conditions but also directly influences fire activity itself.

Attribution statements that determine whether climate change has increased the risk of a particular event, such as a climate extreme, often utilise two sets of simulations produced by GCMs or ESMs (Liu *et al*., 2022a; Liu *et al*., 2022b) or two large ensembles of a single model (Jones *et al*. 2024). One set comprises calculations, or proxies, for atmospheric gas composition at preindustrial levels, whereas the second set pertains to contemporary levels, including raised GHGs. Comparing these simulations

[1] https://laedc.org/wpcms/wp-content/uploads/2025/02/LAEDC-2025-LA-Wildfires-Study.pdf
[2] https://www.imperial.ac.uk/news/260633/la-wildfires-more-likely-because-climate/
[3] *Spreading like wildfire - the rising threat of extraordinary landscape fires.* A UNEP Rapid Response Assessment https://www.unep.org/resources/report/spreading-wildfire-rising-threat-extraordinary-landscape-fires

allows for deriving the FAR statistic, first proposed by Allen (2003) and initially applied to characterise the year 2003 European heatwave (Stott *et al*., 2004). Specifically, the FAR statistic determines the fractional change in the likelihood of an extreme event of a certain magnitude or higher due to human-induced altered atmospheric properties, including raised atmospheric GHGs. In the context of wildfires, Jones *et al*. (2024) and Burton *et al*. (2024) adopted the FAR approach, with the latter quantifying the contribution of climate change to changes in burned area across major regions, including causing a 16–62% rise in this quantity in western North America.

The tools in Jones *et al*. (2024) marked a significant advance by integrating large-scale meteorological changes with Bayesian statistical methods to identify the impact of climate change. However, although these newer studies link rising atmospheric GHGs to changes in wildfire risk, attribution research remains incomplete. FAR calculations often lack the necessary resolution to capture the nuances of specific fire events, such as fine-scale regional features that respond to local meteorological changes or their impacts. The accuracy of these calculations is also likely to improve with enhanced ecosystem modelling, many aspects of which might respond to climate change and contribute to fire susceptibility in different ways. Hence, to fully understand the role of climate change in fire risk, multiple climate-driven impacts must be considered (UNEP, 2022[2]). Furthermore, beyond quantifying changes in Fire Weather Indices (FWI) and burned area, there is a gap in human-relevant attribution linking fire impacts to societal and ecological consequences. Consequently, understanding how changes in fire risk translates to risks for people, economies, and ecosystems suggests a need for novel FAR statistics explicitly related to such quantities. Most attribution studies rely on general definitions of events, such as broad-scale changes in fire weather, rather than conditioning on the specific atmospheric, ecological, or anthropogenic factors that shaped the observed fire. This raises the framing issue: to what extent should an attribution analysis be event-specific? For instance, in Southern California, wind patterns, recent drought-driven vegetation drying, and ignition sources like power line failures can critically influence fire behaviour and impact. Similarly, land-use patterns, such as the expansion of wildland–urban interfaces (Radeloff *et al*. 2018), often determine exposure and losses. Although event-specific attribution calculations may sacrifice some measure of generalisation, we suggest this is more than compensated by capturing location-specific cascades of non-climate drivers and human decisions that can strongly interact with climate change.

Fig. 1 schematically illustrates the extension of climate-related FAR calculations of altered fire risk to include local meteorological and ecological factors, and whether risks are mitigated by human actions to suppress or contain wildfires, or potentially exacerbated by other planning decisions. Illustrating this last need, when the findings of Burton *et al*. (2024) were presented to the public soon after the Los Angeles fires, notable was the absence of information on the role of human management, such as local land-use decisions or preparedness measures, prompting criticism from some[4]. Many argued that human factors, rather than climate change, were to blame, highlighting the challenges of communicating complex scientific findings to the public eager for definitive explanations. Our proposal of FAR statistics that quantify both the contribution of climate change and the more direct human factors to wildfire risk could be useful in these circumstances, allowing comparison to calculations characterising only climate forcings. Many additional factors may need to be linked within a combined FAR statistic. For instance, society witnessing repeated fires may lead to stronger calls for better

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[4]See sample of comments on social media releases that may represent public perception: https://x.com/metoffice/status/1879872480992530620; https://www.linkedin.com/posts/met-office_does-climate-change-play-a-role-in-the-los-activity-7285638187438243840-Xfga/

wildfire preparedness measures, or alternatively, factors may compound, such as any ongoing land use changes that aggravate fire events.

In particular, for Los Angeles, regional-scale wind features exist (second layer from top, Fig. 1), characterised by notable periods of the presence or absence of Santa Ana winds. The impact of these winds on wildfires has been well documented (Dye *et al*., 2020; Jin *et al*., 2014). Nesting a Regional Climate Model (RCM) within known historical large-scale climate forcings reveals in detail the mechanisms of these winds (Hughes & Hall, 2010). Additionally, there are studies using GCMs and ESMs that aim to understand how climate change may alter these wind properties (Guzman-Morales & Gershunov, 2019). We recommend simulating the Los Angeles region with the routine operation of RCMs, or even finer-scale atmospheric models, embedded in coarse-scale GCM and ESM calculations, the latter associated with modelling different GHG levels. Such a structure could be similar to the United Kingdom Convection-Permitting simulations (UKCP18; e.g. Kendon et al., 2020), and with diagnostics distilled to generate FWI values (arrows A and C of Fig. 1).

The next computational challenge is to model ecosystem responses to climate change. Early climate simulations treated vegetation as static in size, simply providing a lower boundary condition to the atmosphere of the partitioning of available energy into upward heat and vapour fluxes. However, initially motivated by the need to understand the global carbon cycle, changing vegetation carbon stores are emulated by Dynamical Global Vegetation Models (DGVMs) (e.g. Sitch *et al*., 2008). DGVMs can project vegetation growth, competition, and different biome compositions in response to imposed climate change (arrow B, Fig. 1), thus potentially supporting researchers in determining whether extra growth or altered composition (third layer, Fig. 1) can elevate fire risk (Fig. 1, Arrow D) (Allen *et al*., 2024; Di Giuseppe *et al*., 2025). Yet vegetation composition and related wildfire risk are not solely shaped by meteorology but are also influenced by direct human interactions with the landscape (Andela *et al*., 2017). Furthermore, human-driven changes to land use, such as the expansion of agriculture and the growth of wildland-urban interfaces, alter fire dynamics. As noted above, Radeloff *et al*. (2018) argued that the recent expansion of urban regions has substantially raised wildland-urban interfaces, heightening fire risk. Other direct factors suggested as possible contributors to the wildfires in Los Angeles include electrical arcing from utility provisions, careless disposal of cigarettes, or even vandalism through the intentional setting of fires. Since each additional process or impact introduces uncertainty, FAR-type statistics that aim to capture linked effects would ideally be derived with uncertainty bounds that quantify any compounding errors. Some of these non-atmospheric, or fine-scale atmospheric contributions, may currently have large uncertainties, preventing decisive overall attribution-based statements, although this might encourage more detailed research into such components.

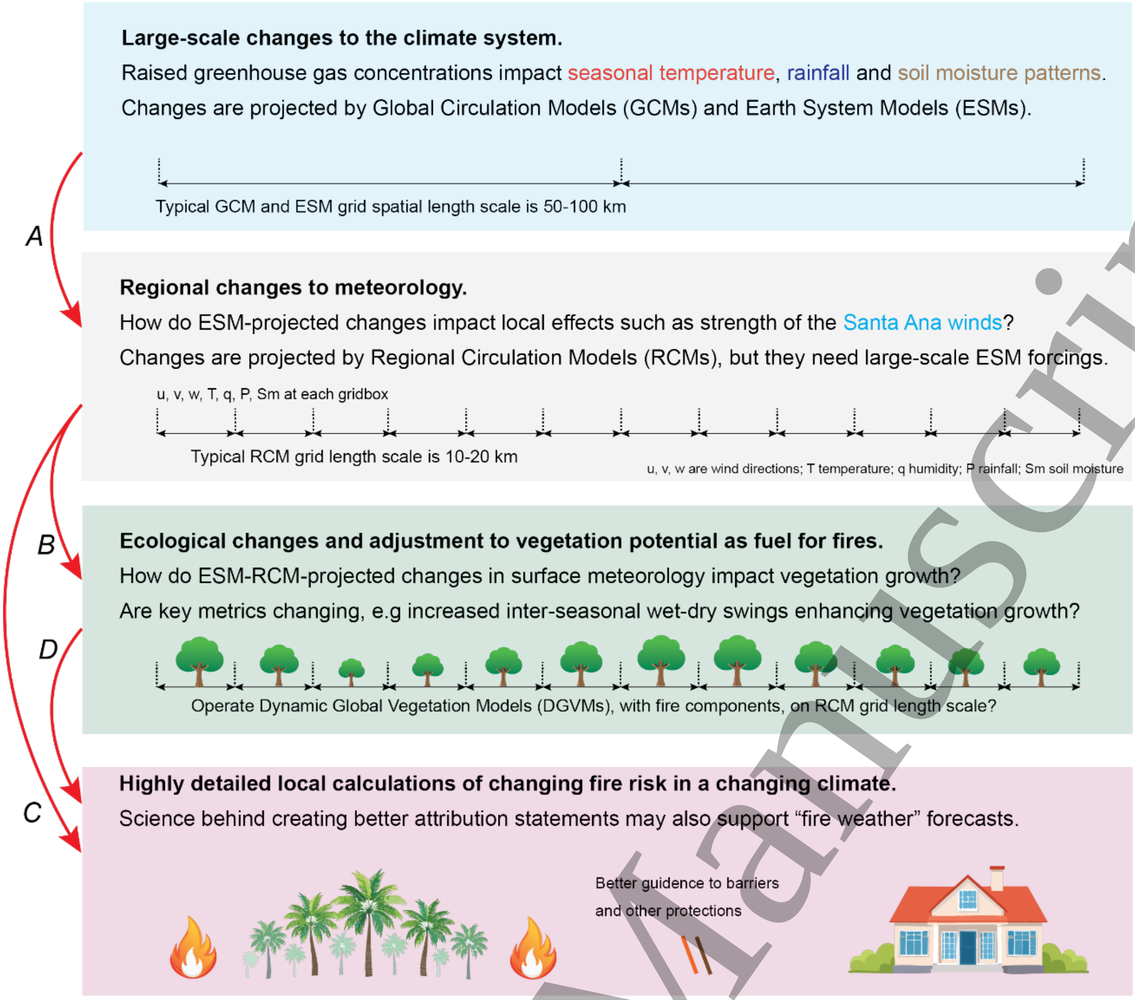

Fig 1. Schematic of the proposed chain of linked simulation activities that may extend current attribution statements, which are generally atmospheric only (top rectangle). The extension would include local high-resolution modelling of atmospheric currents with attributes specific to the Los Angeles region (second rectangle), explicit vegetation growth modelling (third rectangle), and how these all translate into fire risk (fourth rectangle). The last rectangle also allows for the possibility of modulating attribution statistics to include non-climate methods designed to protect residential areas from wildfires. The links (shown by arrows) are by A: driving RCMs for the Los Angeles region with GCM or ESM outputs, B, C: using these finer-scale RCM estimates to drive vegetation growth simulations and provide fire-risk weather projections respectively and D: characterising how changes to vegetation structure (e.g. higher CO_2-induced "greening") also raise fire risk. All components together may generate what is sometimes referred to as a full "end-to-end" attribution structure.

The year 2025 Los Angeles fires caused major loss of life and property, prompting calls for a clearer understanding of wildfires, assessing whether climate change was a major factor, and the impact of any direct societal interventions. We argue that advancing attribution statements regarding wildfire events and their impacts necessitates moving beyond traditional metrics such as the FWI and burnt area. Although valuable, these measures fail to capture the full complexity of fire behaviour and its cascading impacts. Fire intensity, size, and rate of spread are critical variables, particularly for firefighting operations and resource allocation, while the impacts extend to how the destruction of housing stock compounds pre-existing housing crises, pushing more people into homelessness and deepening social inequalities. We advocate the development of flexible FAR statistics that directly quantify changes in these variables. Accurate "end-to-end" attribution of any climate change signal to altered frequency or magnitude of fire-related quantities requires a better understanding of local meteorological changes and the role of changing ecosystem dynamics as atmospheric greenhouse gases rise. Ideally, these factors will be included in FAR calculations as submodels improve their predictive capabilities. If performed carefully, this approach should also account for nonlinearities and potential time delays between any extreme climate-based forcings and impact (a concern raised by Perkins-Kirkpatrick *et al.*, 2022). Critically, we propose a further extension to FAR statistics that includes quantifying direct human activities, such as fire suppression measures or other potential actions that raise fire risk, and their interaction with climate change. Then, with this more complete attribution capability, we suggest applying it to various impacts, as the statistics may differ depending on whether quantifying indices of fire-driven changes in public health outcomes, economic losses, or ecosystems disruption. Such an approach may support a more accurate and refined characterisation of individual events in the broader media. This approach also aligns the view of Jézéquel *et al*. (2024) that, in general, a much better understanding of the causes of disasters emerges when attribution statements prioritise characterising the impact itself while also quantifying additional non-climatic causal factors. These extensions to the FAR statistic have the potential to reduce any polarised debate regarding whether all issues arise from climate change or local planning matters, including situations in which both factors may be significant for fire risk. We hope that these suggestions may be generic, for use in different locations to understand wildfire events.

Conflict of Interest Statement

The authors declare that they have no conflicts of interest.

Ethics Statement

To the best of our knowledge, this manuscript does not raise any ethical issues.

Data Availability Statement

This article is a perspective concerning future research directions, and so no use is made of data.

Acknowledgements

Chris Huntingford and Douglas I Kelley were supported by the NC-International programme (NE/X006247/1) delivering National Capability. Maria L.F. Barbosa was supported by UKRI NERC as part of the LTSM2 TerraFIRMA project.

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