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From fire danger to fire risk: an integrative framework for near-term wildfire risk forecasting

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Abstract

Wildfires are a common global disturbance. Many of these fires fill important ecosystem roles but others must be suppressed to prevent loss of life or property. Decision support tools can provide critical information to support effective wildfire management, but the many components of these tools lack a supporting framework to integrate risk components to produce effective and useful wildfire risk forecasts. Here we present a framework to support wildfire preparedness and response decision making that incorporates both static and dynamic components of wildfire hazard to produce risk forecasting. Static model components provide a time-invariant ignition probability for both human and natural caused ignitions and are developed using topographic and fuel quantity metrics. Dynamic model components are evaluated using a combination of fire danger rating indices from the new US National Fire Danger Rating System Version 4.0 released in 2016 and the newly derived Severe Fire Danger Index. Fire danger forecasts can be normalized to percentiles using an appropriate climatology and then used to assess the dynamic, temporally varying wildfire hazard. We show that a simple model using Energy Release Component and Burning Index from the USNFDRS captures the majority of the temporally variability in wildfire occurrence (AUC = 0.823). When combined, we demonstrate the effectiveness of this model forecast system to predict the spatial and temporal locations of new wildfire ignitions across large areas using a blend of high, moderate and low-resolution spatial terrain, fuels and weather forecast data. We demonstrate various components of this framework across the United States and Northern South America specifically across Colombia, Ecuador, and Peru. This work will improve our ability to leverage modern fire danger rating systems with over conventional wildfire risk assessments to provide better decision support products throughout the world and these products have the potential to reduce wildfire impacts to firefighters and communities.

1. Introduction

Wildfires are a common global disturbance. Many of these fires fill important ecosystem roles but others must be suppressed to prevent loss of life or property. Many traditional and / or emerging tools are available to provide effective decision support for wildfire preparedness and response, but these tools are often developed in isolation without an effective framework for integrating the various components of wildfire hazard and risk together to produce meaningful and useful metrics of wildfire potential over the next several days or weeks. Such information is critical to informing resource needs or effectively pre-positioning limited fire response resources in areas of highest potential.

2. A Dynamic Wildfire Risk Forecasting Framework

Wildfire risk has been defined as the product of hazard and vulnerability. However, different types of wildfire risk assessments have never been considered in the context of a larger framework. For example, most spatial wildfire risk assessments only use static factors or scenarios to assess spatial risk and those risks can be assumed static for most purposes. However, when considering the spatial and temporal likelihoods of new wildfire ignition, some of the important factors may be static, such as accessibility from roads or navigable rivers, fuel availability, slope, aspect, elevation and other variables. Dynamic factors generally track seasonal weather severity and are best assessed using fire danger indices from systems such as the Canadian Forest Fire Danger Rating System (Stocks et al., 1989), the US National Fire Danger Rating System (Figure 1) (Jolly et al., 2019) or other global fire danger metrics. When static and dynamic factors are combined, one can produce spatio-temporal maps of wildfire hazard.

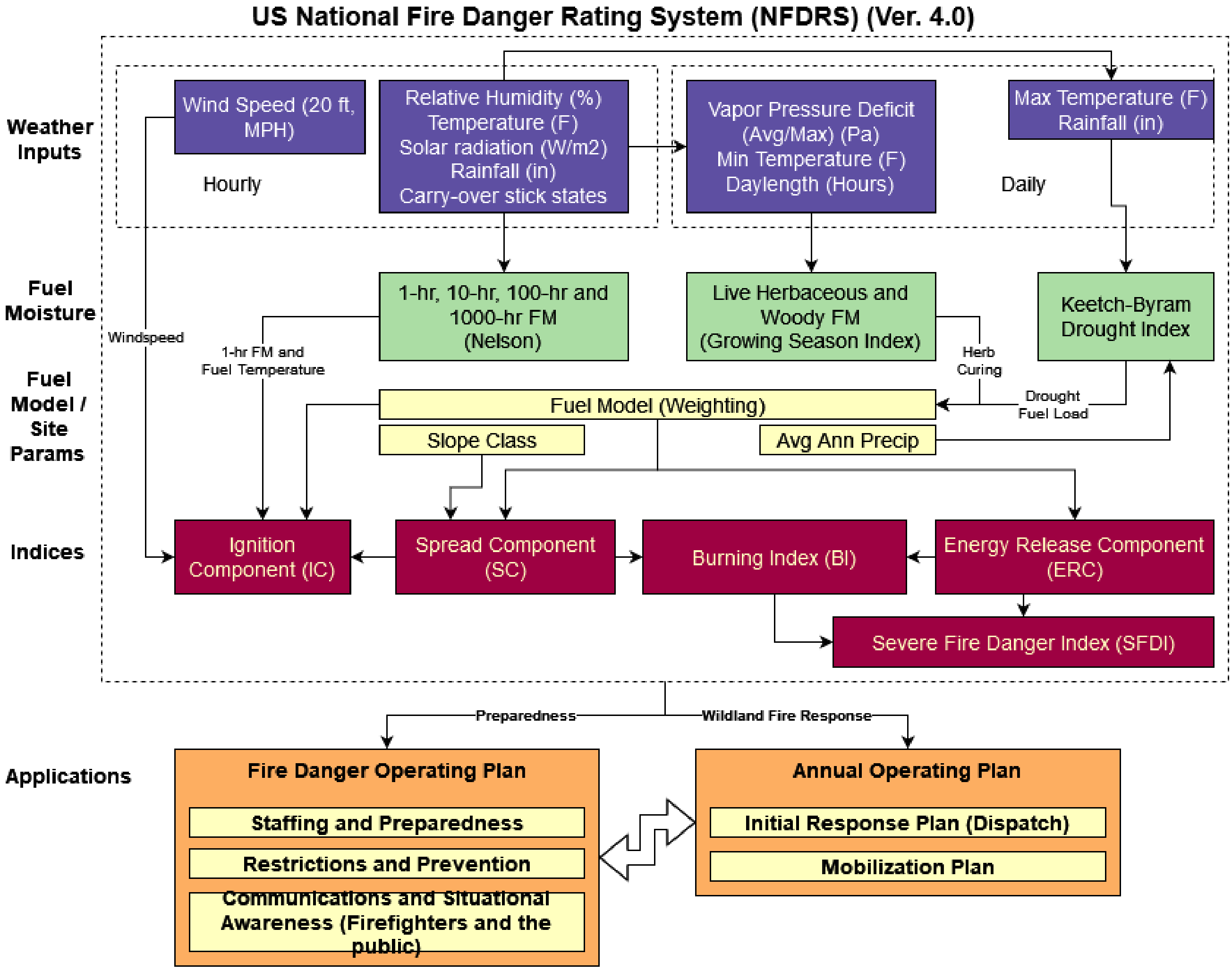

***Figure 1** - The new US National Fire Danger Rating System Version 4.0 is one option for modelling and forecasting the dynamic components of wildfire risk. These forecasts can be produced for up to two weeks out.*

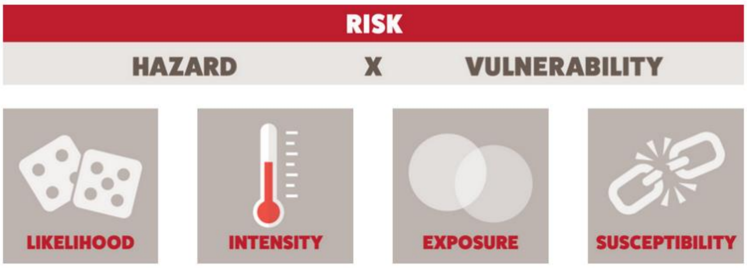

***Figure 2** – Definition of Wildfire Risk from the Wildfire Risk to Communities (US Forest Service)*

Vulnerability is more difficult to assess but it is generally considered the product of susceptibility and exposure but even these two components have both static and dynamic. Susceptibility is the propensity of a home or community to be damaged if a wildfire occurs and exposure is the spatial coincidence of wildfire likelihood and intensity with communities (Wildfire Risks to Communities[4]) (Figure 2). Static vulnerability is an instantaneous measure, while dynamic vulnerability recognizes that both exposure and susceptibility can be modified over time to reduce overall risk.

To clarify linkages between static wildfire risk assessment products and dynamic components of risk that vary from day to day or week to week, we need a clearly defined conceptual model of how each piece fits together in the wildfire risk assessment spectrum. Essentially, fire danger rating is a major component of a dynamic wildfire hazard forecast but it can build on some static assessment of ignition risk. For example, terrain variables such as elevation and slope don't vary much over time except when large, geologic events occur and can thus be assumed static. Further, road networks are known to influence the spatial locations of new wildfire ignitions (Monjarás et al., 2020) but road density doesn't vary drastically from year to year except in places with extensive land-use changes.

Two separate models of wildfire hazard were developed. The first was a 'static' ignition hazard model that produces a spatial ignition probability and the second was a 'dynamic' model that include temporally variants factors from NFDRS. The static ignition model was developed separately for human and natural ignitions using slope, distance from roads, maximum NDVI and spatial locations. Fuel availability has been shown to affect fire probabilities in other studies (Briones et al., 2019). The dynamic model used Energy Release Component and Burning Index percentiles. Both models had very high AUC > 0.82. An example ROC for the dynamic model is shown in Figure 5.

The final framework is shown in Figure 6 and an example spatial assessment of dynamic wildfire hazard is shown in Figure 7. This conceptual framework can be used to better characterize the types of wildfire risk products produced for various applications. For example, typical wildfire risk mapping products are static and used for spatial planning. In contrast, fire danger assessment either in real-time or forecast are best used for characterizing dynamic wildfire hazard because they vary over time. When combined, these static and dynamic components of wildfire hazard and vulnerability form a framework that can guide how to leverage the combined components to produce effective wildfire risk forecasts that can support decision making at fine spatial and temporal scales or that can be scaled to larger areas over summarised over time to support longer-term decisions. Finally, we present an example spatial, normalized forecast for three countries in South America (Figure 8).

This framework demonstrates that a unified description of wildfire risk can be obtained when we consider the dynamic and static components of both the hazard and vulnerability. Future work will expand these assessments to the entire Continental United States, will leverage vulnerability assessments from the Wildfire Risk to Communities project across the United States and build on the forecasting system for Latin America to produce similar products and forecasts for Peru, Ecuador and Colombia.

[4] https://wildfirerisk.org/understand-risk/

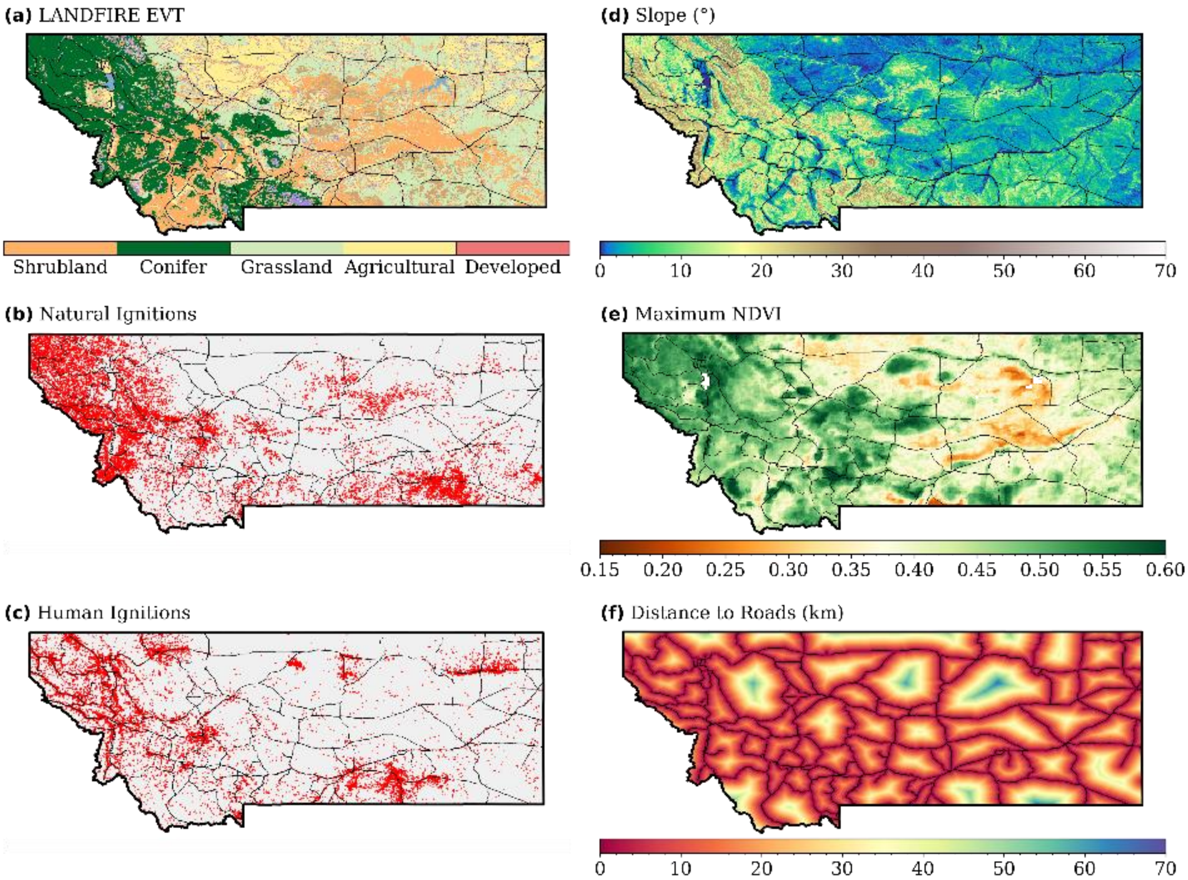

Figure 3 – Spatial inputs to a static ignition probability model. These variables are used to model the temporally invariant aspects of ignition risk.

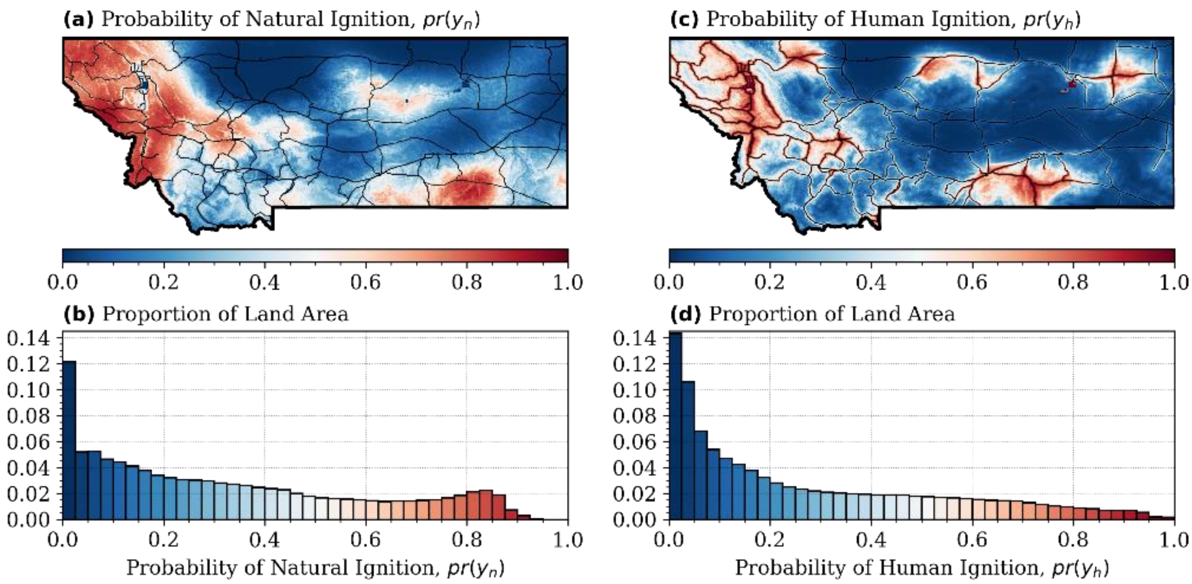

Figure 4 – Final model predicts of ignition risk at 30m resolution across Montana, USA. These maps combine distance to roads, maximum NDVI, slope and spatial location into a static predictive map of ignition risk. These maps can be combined to provide assessments

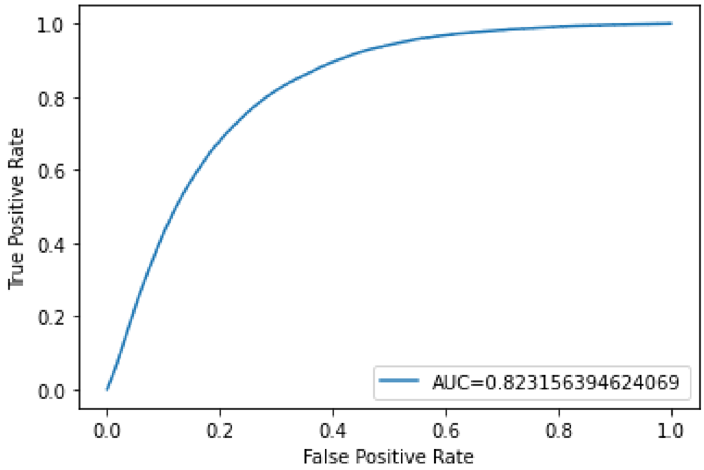

Figure 5 – ROC for dynamic wildfire hazard assessed spatially over Montana, USA. This model uses ERC and BI percentiles from the US National Fire Danger Rating System as inputs. This simple, temporal-only model is very effective at predicted the times when wildfires have historically occurred.

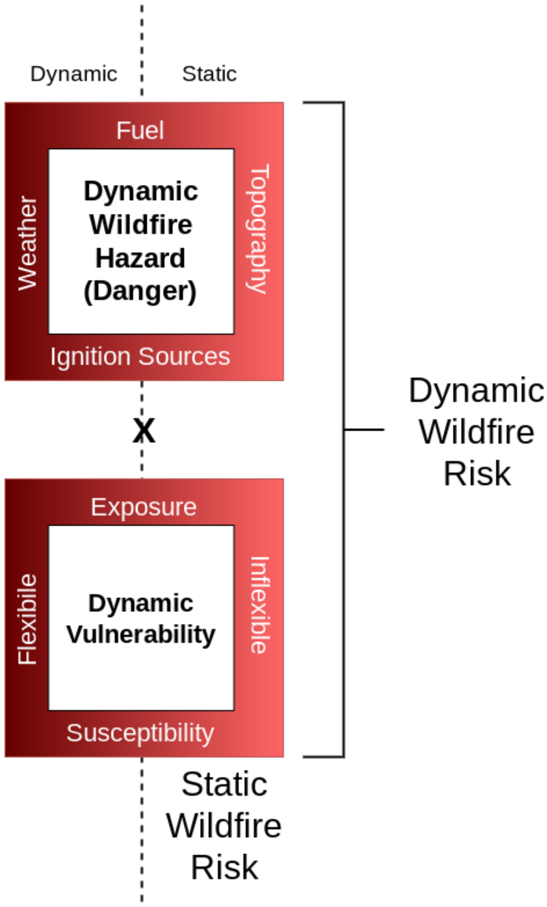

Figure 6 - The conceptual framework linking various static and dynamic wildfire hazard, vulnerability and risk components. Effective forecasts can combine both static and dynamic hazards with snapshots of vulnerability to forecast wildfire risk.

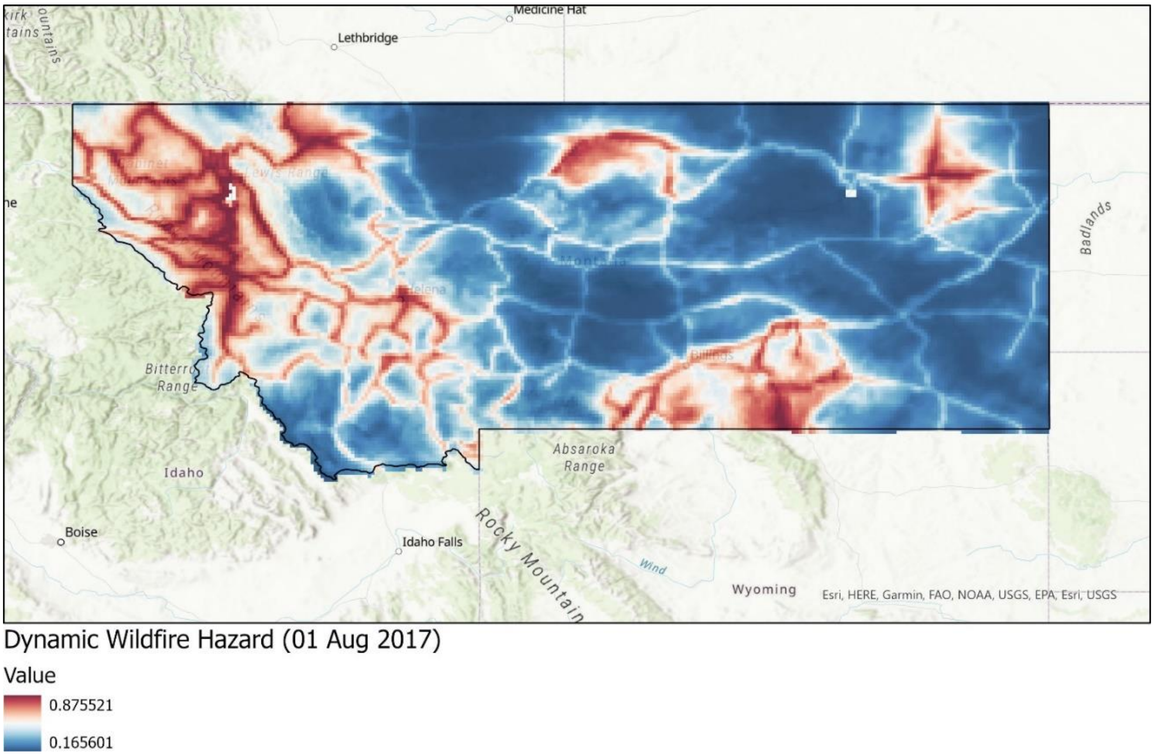

Figure 7 – Final combined dynamic fire hazard assessment for Montana by combining the static human ignition probability with the dynamic wildfire probabilities using the Energy Release Component and Burning Index percentiles from the US NFDRS.

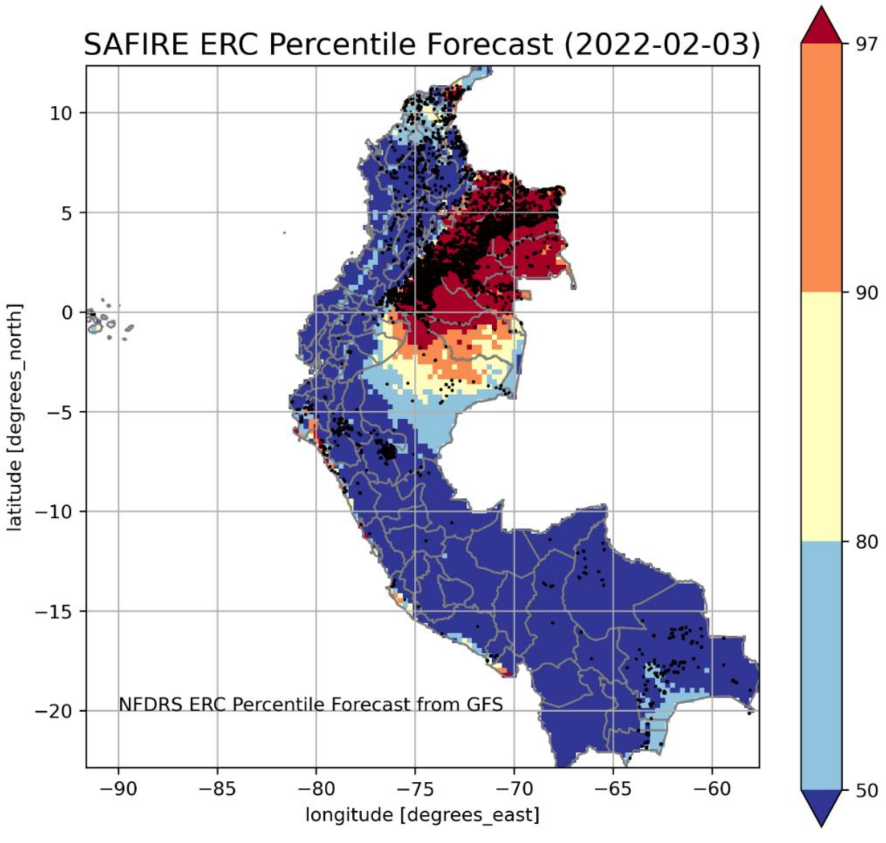

Figure 8 – An example forecast of the Energy Release Component for Peru, Ecuador and Colombia using the Global Forecast System (GFS) with a short climatology of the GFS.

3. References

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