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Integrating Human Domain Knowledge into Artificial Intelligence for Hybrid Forest Fire Prediction: Case Studies from South Korea and Italy

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Forest fires pose a growing global threat, exacerbated by climate change-induced heat waves. The intricate interplay between changing climate, biophysical, and anthropogenic factors emphasizes the urgent need for sophisticated predictive models. Existing models, whether process-based for interpretability or machine learning-based for automatic feature identification, have distinct strengths and weaknesses. This study addresses these gaps by integrating human domain knowledge, crucial for interpreting forest fire dynamics, into a machine learning framework. We introduce FLAM-Net, a neural network derived from IIASA's wildfire Climate impacts and Adaptation Model (FLAM), melding process-based insights of FLAM with machine learning capabilities. In optimizing FLAM-Net for South Korea, new algorithms interpret national-specific forest fire patterns, and multi-scale applications, facilitated by U-Net-based deep neural networks (DN-FLAM), yield downscaled predictions. Successfully tailored to South Korea's context, FLAM-Net and DN-FLAM reveal spatial concentration near metropolitan areas and the east coastal region, with temporal concentration in spring. Performance evaluation yields Pearson's r values of 0.943, 0.840, and 0.641 for temporal, spatial, and spatio-temporal dimensions. Projections based on Shared Socioeconomic Pathways (SSP) indicate an increasing trend in forest fires until 2050, followed by a decrease due to increased precipitation. During the optimization process of FLAM-Net for Italy, optimal parameters for sub-areas are identified. This involves considering biophysical and anthropogenic factors at each grid, contributing to improved localized projection optimization by utilizing various sets of optimal parameters. There by, this process illuminates the intricate connections between environmental factors and their interpretation in the dynamics of forest fires. This study demonstrates the advantages of hybrid models like FLAM-Net and DN-FLAM, seamlessly combining process-based insights and artificial intelligence for interpretability, accuracy, and efficient optimization. The findings contribute scientific evidence for developing context-specific climate resilience strategies, with global applicability to enhance climate resilience.