利用歷史乾旱數據優化週尺度野火危險度：以混合式深度學習模型應用於臺灣潮濕副熱帶森林為例

Past Drought Memory Sharpens Weekly Wildfire Susceptibility Mapping: A Hybrid Deep Learning Approach in Humid Subtropical Taiwan

俞鉦文 [1] (Yu H.-W.) 柳婉郁 [2] (Liu W.-Y.) 王世宇 [3] (Wang S.-Y.) 周崇光 [1] (Chou C.-K.) 陳奕穎 [1*] (Chen Y.-Y.)

[1] 中央研究院環境變遷研究中心 [2] 國立中興大學森林學系 [3] 泰國農業大學農學系

[1]Research Center for Environmental Changes, Academia Sinica

[2]Department of Forestry, National Chung Hsing University

[3]Department of Agronomy, Kasetsart University

摘　要

即使在濕潤的副熱帶森林中，乾旱驅動的野火事件也正在加劇，然而這些地區的預警系統仍仰賴僅以氣象資料建構的靜態地圖，既無法掌握野火風險何時升高，也難以呈現不同山坡間野火風險之空間差異。基於臺灣野火容易受過去長期乾旱因子所主導的研究發現，本研究發展了一套混合式深度學習模型（Parallel CNN-LSTM Model），該模型能同時處理每個地點的地景脈絡資訊，以及過去環境水文與植被生長變化，藉此產出涵蓋全臺灣的週尺度野火危險度地圖。此外，本研究系統性測試了不同的空間資訊範圍（5×5 至 25×25 網格大小）與時間窗口長度（過去4 週至 24 週），以找出最佳的模型型態。在完全獨立的 2022 至 2024 年測試期間，本研究模型可達到 0.82 的 AUC-ROC，並成功標示 2023 年臺灣西南部發生的重大野火事件。本研究亦發現同時納入3公里之空間資訊、12週的歷史時間窗口時，模型對野火事件偵測表現達到高峰；若納入更長的歷史窗口僅增加模型雜訊，並未提升預測能力。值得注意的是，具備歷史記憶能力的模型能偵測僅憑當前資訊模型所遺漏的野火事件，且這些額外偵測的野火事件中往往歷經長期乾旱、植被逆境事件，成功證實了本研究的混合式深度學習模型，透過納入過去資訊來偵測臺灣森林緩慢乾燥過程，以提升模型對於野火危險度之偵測能力。本研究期望該成果能提供臺灣建構與精進地區性野火危險度預警模型，亦可作為其他野火好發地區之參考範例。

關鍵字：野火危險度；混合深度學習模型；卷積與遞迴網路；歷史乾旱記憶；亞熱帶濕潤氣候

Abstract

Drought-driven wildfire is intensifying even in humid subtropical forests, yet warning systems in these regions still rely on static maps built from weather alone, capturing neither when risk rises within a season nor how it varies from one hillside to the next. Building on evidence that wildfire in Taiwan is governed by antecedent drought, we developed a hybrid deep learning model, parallel CNN-LSTM, that jointly processes landscape context and recent moisture and vegetation histories at each location to produce weekly wildfire susceptibility maps across Taiwan. We systematically tested spatial patch sizes (5×5 to 25×25 grid cells) and temporal windows (4 to 24 weeks) to identify optimal input configurations. Over a fully independent 2022–2024 test period, the model achieved an AUC-ROC of 0.82 and flagged the major 2023 wildfire in southwestern Taiwan. Performance peaked with a roughly three-kilometre area and a 12-week antecedent window; longer history added noise rather than skill. Critically, the history-aware model detected fires that a snapshot of current conditions missed, events preceded by months of mounting moisture deficit and stressed vegetation, confirming that tracking gradual drying invisible to present-state indicators is the model's core advantage. Drought and vegetation stress dominated susceptibility during the fire season, while preconditioning factors, terrain and human access, mattered most once severe fire weather eased. By resolving the same drought memory previously seen only year to year into weekly pixel-level maps, this approach offers a dynamic susceptibility layer to strengthen Taiwan's national wildfire warning system and a reference for other humid subtropical regions.

Key words: wildfire susceptibility; hybrid deep learning; convolutional and recurrent networks; antecedent drought memory; subtropical humid climate