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Abstract
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Data-Driven Wildfire Spread Modelling Of European Wildfires

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Challenge

Human-induced climate change is causing wildfires to intensify and become more frequent across the globe, as evidenced by recent extreme events in Greece (2023), Canada (2023), and Chile (2024). To effectively manage these risks, wildfire spread models play a crucial role in planning timely suppression efforts. Historically, wildfire spread models have been developed using semi-empirical approximations based on experimental burnings. Although used in an operational context, such models suffer from inaccuracies and transferability issues outside of their development region. Recent advances in the availability of remote sensing data, artificial intelligence, and computational resources allow for a new data-driven perspective on wildfire spread modelling that offers the opportunity to overcome the limitations of established semi-empirical models.

Methodology

We developed a novel data-driven wildfire spread modelling approach using a Spatio-Temporal Graph Neural Network (STGNN) trained on the historic burned area time series of European wildfires retrieved from Copernicus Sentinel-3 imagery. A training dataset was built by populating individual burned area perimeters with dynamic (e.g. meteorological data, Fire Weather Index (FWI), hotspots) and static (e.g. fuel map, land cover, topography) auxiliary datasets in a discrete, hexagonal grid system (H3), which allows to include neighbourhood relationships into the dataset. Each wildfire time series was then transformed into a spatio-temporal graph representation which formed the input for the model. The STGNN can simultaneously process and learn the spatial and temporal dependencies in the data by combining a Graph Convolutional Network (GCN) with a Gated Recurrent Unit (GRU). The model was iteratively trained on each time step of individual wildfire time series and can predict the next day's burned area. Testing was done by feeding the first day of an unseen wildfire time series and predicting the wildfire's burned area on the four following days. Validation was achieved by calculating the weighted macro-mean Jaccard Index (IoU) between the predicted daily burned area and the Sentinel-3 reference burned area. A first model was developed on Portuguese wildfires to test the ability of the STGNN to capture the spatial and temporal evolution of wildfires. To assess the generalization ability of the wildfire spread model, the STGNN was then trained and tested with Mediterranean wildfire time series from different countries with varying environmental conditions.

Expected results

Both the Portugal and Mediterranean models were able to predict the next day's wildfire spread with an overall weighted macro-mean IoU of 0.37 and 0.36, subsequently. Both models could capture the general temporal trend of a wildfire but suffered from an overprediction bias. A robust performance was achieved across all fire seasons from 2017 to 2022, indicating that the extent of a fire season does not significantly affect the results. The results show an increase in IoU values with an increasing fire spread size up to an optimum of approx. 5 km^2. The lowest accuracies were achieved on days without any fire spread, which occur frequently in the reference dataset, explaining the overall moderate performance metrics resulting from the overprediction bias. The prediction performance of both models increased with ongoing prediction days, resulting in the highest IoU values on the last day of the testing time series. The Mediterranean model was able to generalize well over varying environmental conditions and fire regimes in different countries. Wildfires in Spain were predicted most accurately with an overall weighted macro mean IoU of 0.44, closely followed by Greece (0.43), and Portugal (0.39). These countries also experienced the largest and most intense wildfires in Europe. Countries with smaller and less intense wildfires (e.g. Italy) were predicted with lower accuracies (IoU < 0.34).

Outlook for the future

This work demonstrated a novel, data-driven approach to model wildfire spread based on historical burned area time series and environmental variables. Our results show that the spatial and temporal dimensions of a wildfire greatly influence the model performance. This supports the usage of a spatio-temporal graph-based modelling framework. Overall, the statistical evaluation showed only mediocre results in predicting the next day's wildfire spread but are in line with similar studies highlighting the complexity of this modelling domain. This lack of accuracy probably results from insufficient reference data quality. While not intended as a replacement for conventional semi-empirical wildfire spread models, a data-driven approach showed a promising way forward to potentially overcome the prevailing transferability issues. Therefore, the focus of future work should be on improving the reference data basis by creating datasets describing individual wildfire fire events with an improved temporal and spatial resolution.

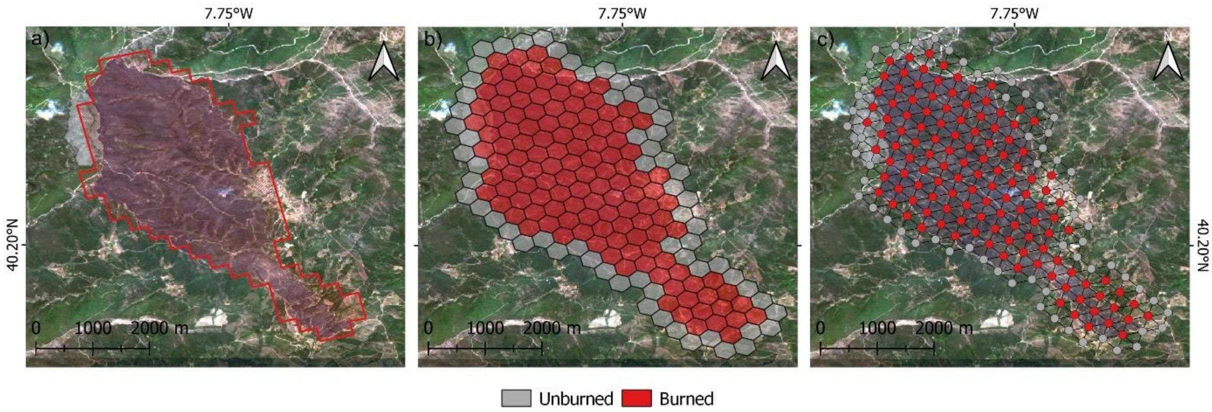

Figure 1 Different data representations of the burned area on the 07.08.2020 of a wildfire in Portugal. Background: Sentinel-2 RGB image from the 07.08.2020. (a) Burned area perimeter as derived from Sentinel-3. (b) Burned area perimeter displayed in H3 cells. (c) Burned area perimeter displayed as graph structure.

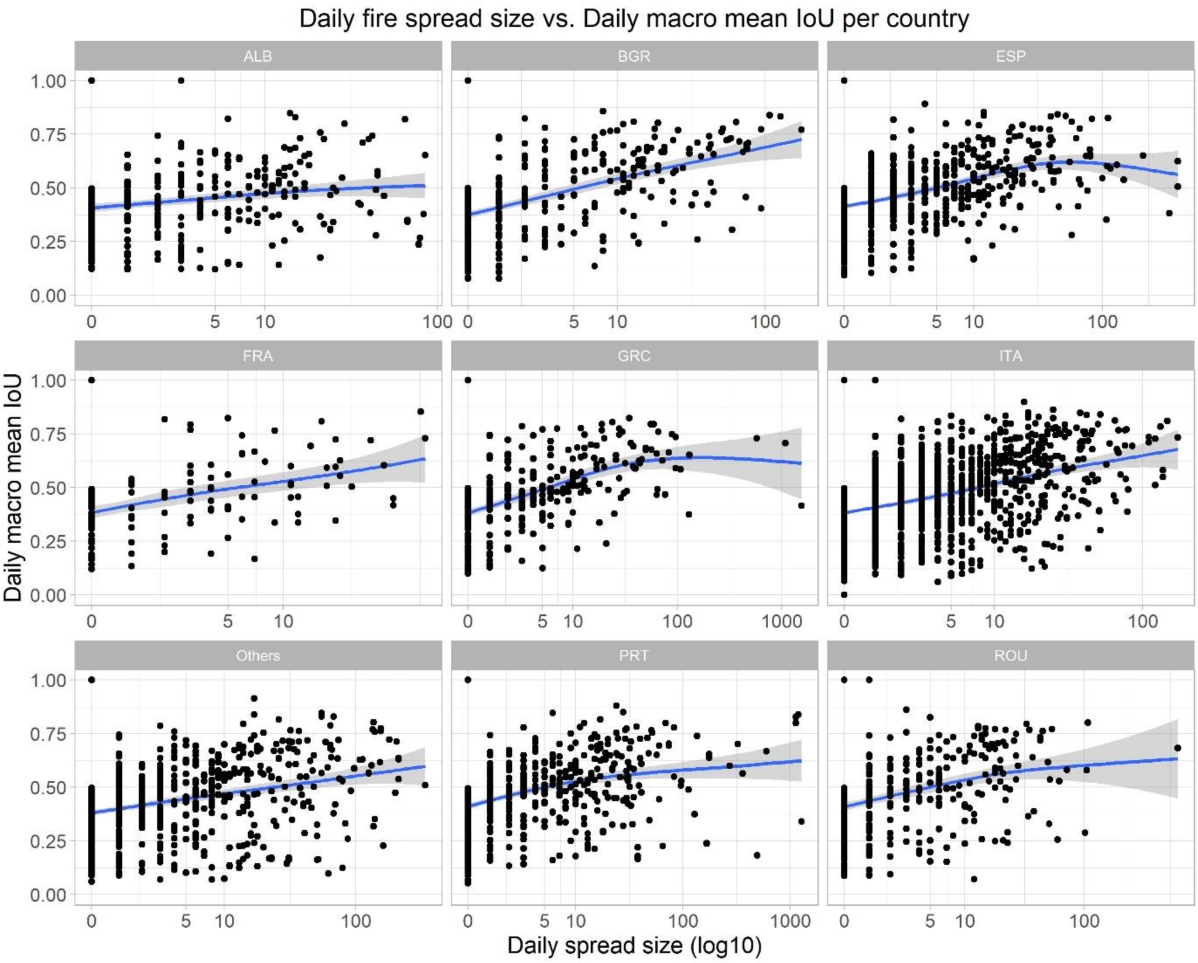

Figure 2 Daily macro mean IoU of the Mediterranean model per country and daily spread size. The daily wildfire spread is defined as the number of new burned H3 cells (one H3 cell equals approx. 0.1 km²).