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20 **Preprint Statement:**

21 This manuscript is a non-peer-reviewed preprint submitted to EarthArXiv.

Rapid satellite assessment of the 2026 High Fens fire

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Abstract

Climate change is altering fire regimes across Europe, contributing to longer periods of favorable fire weather. In August 2026, the High Fens nature reserve experienced one of the largest wildfires in Belgium's recorded history. This event is ecologically and biogeochemically significant because the fire affected a landscape dominated by carbon-dense peatlands, where prolonged smouldering can cause substantial carbon (C) loss and greenhouse-gas emissions. This study provides a rapid satellite-based assessment of the 2026 High Fens Fire and uses the pre-fire hydro-climatic conditions as an empirical benchmark for examining their occurrence across northern high latitudes. Using Sentinel-2 imagery, we mapped a 25.43 km² burn scar with substantial spatial heterogeneity in spectral severity. A regional analysis based on Visible Infrared Imaging Radiometer Suite (VIIRS) active fire detections indicated that the High Fens event was the only peatland-dominated cluster among the six largest fire clusters identified in our Western European VIIRS record between 2012 and 2026. To contextualize the severe hydro-climatic conditions preceding ignition, we combined anomalies in maximum air temperature, vapor pressure deficit, and surface soil moisture to define an empirical pre-fire benchmark. Upscaling this benchmark across the High Northern Latitudes (HNL) showed that comparable combinations of temperature, atmospheric dryness, and surface soil moisture occurred across a broad geographic footprint, particularly along the southern margins of the HNL, including parts of southern Canada, Europe, and Siberia. Intersecting this benchmark exceedance footprint with global peatland and Moderate Resolution Imaging Spectroradiometer (MODIS) MCD64A1 burned-area datasets identified ~253,000 km² of peatland with no MCD64A1-detected burned area during 2001–2025 and ~84,000 km² with detected burned area during the same period. The unburned peatland area contains an estimated 35.9 Gt C of soil organic carbon stock. An additional 10.1 Gt C was contained within peatland areas that had MCD64A1-detected burned area during 2001–2025. Translating this widespread meteorological exposure into reliable estimates of potential carbon emissions requires a precise understanding of belowground fire behavior. Because substantial uncertainty remains in estimating peat combustion and post-fire ecosystem recovery, the accessibility of the High Fens reserve and the availability of nearby peatland observations provide an opportunity for future field-based validation and long-term monitoring.

Keywords: wildfire, Belgium, remote sensing, climate change, peatland

1. Introduction

Wildfire risk is increasing across Europe as climate change drives hotter, drier fire weather, more frequent heatwaves, and more severe drought conditions, although realized burned area also depends on fuels, ignitions, and fire management (Giannaros and Papavasileiou 2023; Grünig et al. 2023; Jones et al. 2024; Santos et al. 2024). Extreme fire weather is expanding beyond the Mediterranean into central, temperate, and some boreal regions, while fire seasons are projected to lengthen across much of Europe, including northern areas (Carnicer et al. 2022; El Garroussi et al. 2024; Hetzer et al. 2024). Model projections indicate that burned area is likely to increase substantially, with Mediterranean Europe projected to see roughly 40% to 100% more summer burned area as warming rises from 1.5 to 3°C, and with temperate forests becoming increasingly susceptible to damage under emerging fire regimes (Patacca et al. 2026; Turco et al. 2018). Regions that have historically experienced fewer large wildfires may therefore increasingly encounter periods of extreme fire weather in coming decades (Calheiros et al. 2021; El Garroussi et al. 2024; Miller et al. 2025).

Against the backdrop of these broader continental trends, a large wildfire ignited in the High Fens (Hautes Fagnes) nature reserve in eastern Belgium on August 14, 2026. The fire spread rapidly across the reserve, eventually becoming one of the largest wildfires in Belgium's recorded history and requiring a massive emergency response involving more than 250 personnel, aerial support, and the activation of the Copernicus Emergency Management Service (EU Space 2026; Reuters 2026; The Brussels Times 2026). Furthermore, the fire forced the evacuation of hundreds of residents from surrounding Belgian municipalities and triggered transboundary smoke alerts and evacuations in the neighboring German municipality of Monschau (Associated Press 2026; DW News 2026; Reuters 2026).

Beyond its geographic extent, the High Fens wildfire represents an important ecological and biogeochemical event because it occurred in a landscape dominated by peatland (Henrion et al. 2024). Peatlands are carbon-dense wetland ecosystems that occupy a small fraction of Earth's land surface yet store about one-third of global soil carbon (Dargie et al. 2017; Wilkinson et al. 2023). During drought or under chronic drainage, peatlands can become more vulnerable to fire as drying lowers water tables and increases the depth of oxygenated peat available for combustion (Kettridge et al. 2015; Turunen et al. 2025). Unlike predominantly flaming forest fires, peat fires can involve prolonged smouldering combustion, a low-temperature process that can spread laterally and downward through organic soil (Hu et al. 2018; Rein and Huang 2021). This belowground combustion can rapidly oxidize legacy carbon that accumulated over centuries to millennia, releasing disproportionate volumes of greenhouse gases. Furthermore, such deep combustion can fundamentally alter peat properties and hydrology, threatening post-fire ecosystem recovery (Harris et al. 2021; Hu et al. 2019; Kettridge et al. 2015; Wooster et al. 2018) and degrading critical services provided by landscapes like the High Fens, including water filtration, long-term carbon storage, and biodiversity support (Bonn et al. 2016; Kimmel and Mander 2010; Milner et al. 2026).

Despite their potential importance for the global carbon cycle, peatland wildfire impacts remain difficult to quantify because estimates of carbon loss require information on pre-fire carbon stocks, peat properties, and post-fire burn depth all of which are difficult to characterize across heterogeneous landscapes (Ballhorn et al. 2009; Konecny et al. 2016; Nelson et al. 2026;

Reddy et al. 2015; Wilkinson et al. 2023). Baseline peat thickness, bulk density, carbon content, and moisture conditions vary substantially across space and are often unavailable at the resolution needed to quantify combustion, especially in remote peatlands where field access is limited (Ballhorn et al. 2009; Hu et al. 2024; Lin et al. 2021). Burn depth and the extent of belowground smouldering are also difficult to determine directly after fire, even though smouldering can consume large volumes of carbon-rich organic soil and vary strongly within a burn scar (Konecny et al. 2016; Lin et al. 2021; Nelson et al. 2026). Remote sensing provides spatial information on burned area and surface spectral change, but optical data do not directly measure peat consumption, burn depth, or carbon loss, and satellite products often miss or poorly represent belowground combustion without complementary field data (Nelson et al. 2026; Vetrìta et al. 2021). Paired pre- and post-fire LiDAR surveys (whether airborne or unmanned aerial vehicle (UAV)-based) can help constrain burn-related elevation change and, where measurement conditions permit, estimate changes in surface elevation associated with peat combustion, but such observations remain costly, spatially limited, and uncommon (Konecny et al. 2016; Reddy et al. 2015; Simpson et al. 2016). This uncertainty matters because carbon-loss estimates are highly sensitive to burn depth and related assumptions. In a study conducted by Rodríguez Vásquez et al. (2021) on Indonesian peatland wildfires, depth of burn was found to explain 94.2% of variance in emissions. The scarcity of spatially explicit pre- and post-fire observations therefore limits the quantification of subterranean smouldering, weakens validation of remote-sensing estimates of soil combustion, and leaves regional carbon emissions from peatland fires highly uncertain (van der Werf et al. 2010).

The 2026 High Fens Fire provides an opportunity to characterize an unusually large peatland fire in a temperate western European landscape and characterize the broader exposure of northern peat carbon stocks to hydro-climatic conditions comparable to those preceding the fire. The primary objectives of this study are to: (1) quantify the spatial footprint and spectral burn severity of the event using high-resolution Sentinel-2 observations; (2) benchmark the fire within the regional historical record using Visible Infrared Imaging Radiometer Suite (VIIRS) active-fire detections; and (3) determine whether the compound hydro-climatic preconditions preceding this fire recur across broader northern peatland regions. Specifically, we use event-specific pre-fire anomalies to construct an empirical index and evaluate where comparable conditions occurred across the High Northern Latitudes (HNL) between 2016 and 2026. By intersecting this exceedance footprint with global peatland and MCD64A1 burned-area datasets, we quantify the soil organic carbon stocks residing in unburned peatlands exposed to analogous hydro-climatic conditions. In doing so, this study provides an empirical benchmark to identify where comparable extreme conditions have occurred across historically unburned, carbon-dense northern ecosystems.

2. Study area

The High Fens nature reserve (Figure 1) is a protected area of about 40 km² in eastern Belgium, on the Stavelot-Venn Massif within the Ardennes region near the German border (Goemaere et al. 2016). The region has a humid and cold climate and a pronounced topographic gradient (Mormal and Tricot 2004), and its highest point reaches 694 m above sea level, which represents the highest elevation in the country (Henrion et al. 2024; Keulen et al. 2005).

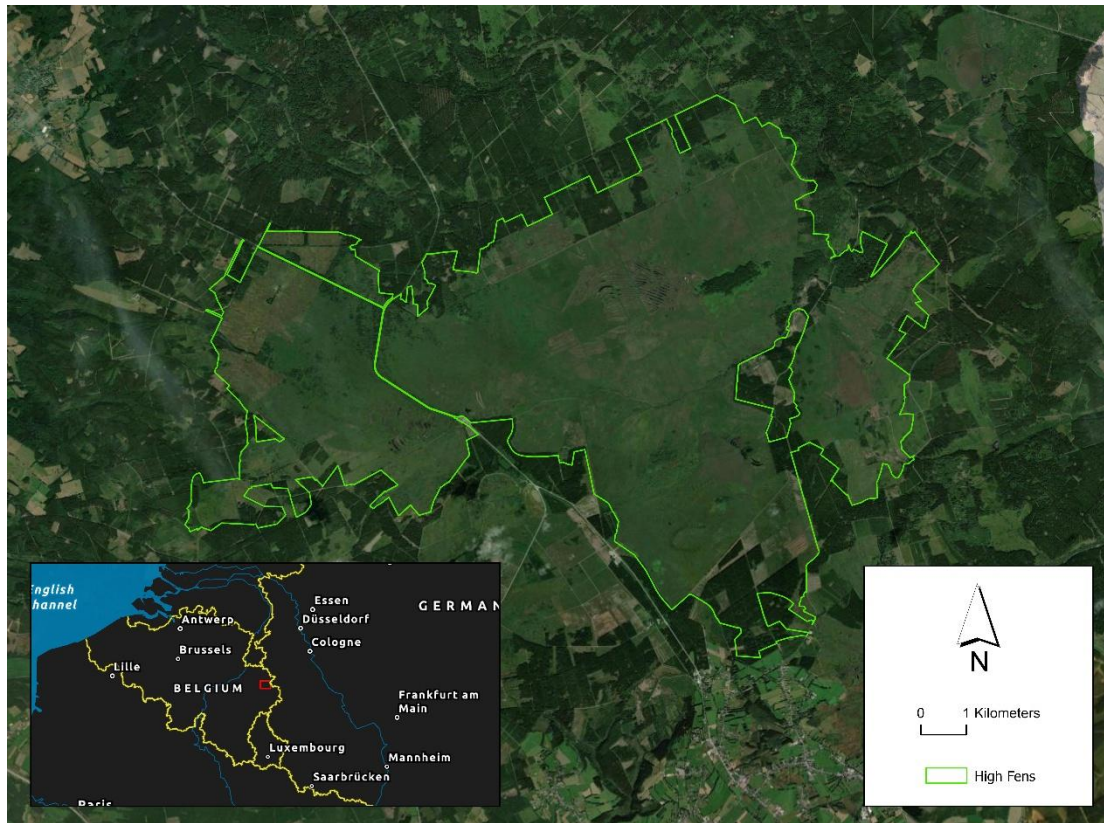


Figure 1. The study area. The boundary of the High Fens Nature Reserve is adopted from the World Database on Protected and Conserved Areas dataset (UNEP-WCMC and IUCN 2026). The location of the study area relative to Belgium and surrounding regions is indicated by the red box in the inset.

The reserve is dominated by peatland ecosystems, especially raised bogs, alongside wet moors linked to peat-bog degradation (Keulen et al. 2003; Li et al. 2024). These environments support vegetation adapted to acidic, waterlogged conditions, including peat-forming Sphagnum mosses, dwarf shrubs, and graminoids such as *Molinia caerulea* (Hindryckx 1999; Keulen et al. 2003). Created in 1957 to protect peatlands from further degradation, the High Fens is one of Belgium's most important peat-bog landscapes and a significant site for ecological and peatland research (Goemaere et al. 2015).

To place the High Fens Fire in a broader regional context, we defined the Western European analysis domain using the United Nations Geospatial Database (<https://www.un.org/geospatial/>) regional classification. The domain includes Austria, Belgium, France, Germany, Liechtenstein, Luxembourg, Monaco, the Netherlands, and Switzerland. This domain was used only for the historical VIIRS fire-cluster comparison. For the circumpolar analysis, we defined the HNL as all land areas north of 50°N.

3. Methodology

3.1. Burn scar mapping and severity classification based on Sentinel-2 imagery

To estimate the spatial extent of the High Fens Fire, we mapped its burn scar at a 20 m spatial resolution using paired Sentinel-2 Level-2A surface reflectance images. Specifically, we selected one pre-fire and one post-fire Sentinel-2 Level-2A surface reflectance image

representing the closest sufficiently cloud-free observations available for the analysis. The selection criteria required the two images to be as close together temporally as possible while also being as cloud-free as possible. Ultimately, relative to the fire's August 14, 2026 ignition date, the pre-fire image was acquired on July 25, 2026, and the post-fire image was acquired on August 26, 2026. Although the two images were separated by 32 days, the August 26 image was the closest sufficiently cloud-free post-fire observation available after the main fire was brought under control. The Normalized Burn Ratio (NBR) was calculated separately for the pre- and post-fire images, followed by calculation of the differenced Normalized Burn Ratio (dNBR) using the formula provided by Key and Benson (2006) and Delcourt et al. (2021):

$$NBR = \frac{Band\ 8A - Band\ 12}{Band\ 8A + Band\ 12}$$

$$dNBR = NBR_{pre} - NBR_{post}$$

Burned and unburned reference polygons were manually identified from the post-fire imagery, and dNBR values were extracted from these reference areas. We evaluated candidate dNBR thresholds using receiver operating characteristic (ROC) analysis, calculating the true-positive rate (TPR) and false-positive rate (FPR) across the range of observed dNBR values. Youden's J statistic ($J = TPR - FPR$) (Youden 1950) was used to identify the threshold providing the maximum separation between the reference burned and unburned samples. The resulting threshold was then applied to the full dNBR image to delineate the mapped burn scar.

3.2. VIIRS fire-cluster footprint calculation for historical wildfire context in Western Europe

The High Fens Fire was unusually large for Belgium (EU Space 2026), but its regional significance is best evaluated by comparing its fire-associated footprint with other events identified using a consistent detection method. Although the European Forest Fire Information System (EFFIS) maintains a historical fire database suitable for such comparisons, our data request had not been fulfilled in time for this analysis. Consequently, we developed a workflow that derives a fire-associated spatial footprint from VIIRS active-fire detections. Leveraging the near-real-time availability and low latency of VIIRS data provided by NASA's Fire Information for Resource Management System (FIRMS), this approach enables the rapid estimation of wildfire event sizes within hours of containment.

VIIRS 375 m Collection 2 active-fire detections from the Suomi National Polar-orbiting Partnership (S-NPP) were compiled for 2012–2026. To distinguish landscape wildfires from persistent thermal anomalies, such as continuously burning gas flares and industrial heat sources, we developed a spatiotemporal clustering and duration-filtering approach. Active-fire detections were represented by their spatial coordinates and acquisition dates, and candidate links were identified between detections occurring within 750 m and 14 days of one another. A k-d tree algorithm (Bentley 1975) was used to recursively partition this data space, enabling efficient identification of localized detection pairs without exhaustive comparisons among all observations. Because the k-d tree identifies pairwise connections rather than complete fire events, a graph connected-components analysis (Hopcroft and Tarjan 1973) was subsequently used to identify the full extent of each event. In this approach, individual fire detections were treated as network nodes, while their spatial and temporal proximity defined connecting edges.

The connected-components algorithm then traced transitive connections among detections, allowing spatially expanding and multi-day fires to be grouped into discrete fire events. These algorithms were implemented in Python using the `scipy.spatial` (Virtanen et al. 2020) and `NetworkX` (Hagberg et al. 2008) modules, respectively. To reduce repeated detections associated with persistent thermal anomalies or prolonged burning of the same 375 m cell, detections occurring more than seven days after the first detection within the same event and grid cell were excluded. The filter was applied at the cell level rather than to the event as a whole, allowing spatially expanding fire activity to be retained. After filtering, clusters were retained only when they contained at least three active-fire detections. This criterion was used to reduce isolated detections and transient thermal anomalies but may exclude small fires represented by fewer detections. To derive an approximate areal footprint from the point detections, each retained VIIRS detection was represented by a 375 m $\times$ 375 m cell centered on the detection location, and overlapping cells within each cluster were dissolved into a single event footprint.

To evaluate the regional scale of the High Fens wildfire within a broader spatial and temporal context, we applied the aforementioned active fire clustering method to all VIIRS S-NPP active fire detections across Western Europe. The size of the cluster representing the High Fens Fire was compared with those of all other clusters in terms of total area and land cover, with land cover information derived from the 100 m European Environment Agency (EEA) Coordination of Information on the Environment (CORINE) Land Cover dataset for 2018 (European Environment Agency 2020). Because CORINE Land Cover 2018 provides a static land cover classification, the resulting land cover composition represents the 2018 classification applied to all VIIRS fire clusters in the 2012–2026 analysis period and does not account for land cover changes during that period. To resolve the high thematic detail of the 44 native CORINE Level 3 classes and minimize classification noise during regional wildfire comparisons, the land cover classes were reclassified and grouped into a simplified eight-class system: Forests, Grassland, Peatland, Wetland, Water, Cropland, Urban, and Others. Under this unified classification scheme, artificial and developed surfaces (CLC codes 111–142, representing continuous/discontinuous urban fabric, industrial sites, mines, and artificial vegetated areas) were aggregated as “Urban”. Agricultural lands (CLC codes 211–244, including arable land, pastures, and complex heterogeneous agricultural patterns) were consolidated as “Cropland”. Tree-covered areas (CLC codes 311–313, covering broad-leaved, coniferous, and mixed forests), along with transitional woodland-shrub communities (CLC code 324), were grouped under “Forests”. Natural grasslands (CLC code 321) and moors and heathlands (CLC code 322) were consolidated into the “Grassland” class to represent open herbaceous and shrubby fuels. Peat bogs (CLC code 412) were classified as “Peatland”, while other wet ecosystems, including inland marshes (CLC code 411) and coastal wetland systems (CLC codes 421–423), were grouped under a distinct “Wetland” class. Continental and marine water bodies (CLC codes 511–523) were consolidated under “Water”. Finally, structurally sparse, barren, or transient land covers (including sclerophyllous vegetation 323, bare rock, beaches, and burnt areas 331–335) were aggregated as “Others”.

3.3. Pre-fire hydro-climatic conditions and High Fens Fire Index construction

To characterize the multivariate hydro-climatic conditions preceding the High Fens Fire, we

initially examined five hydro-climatic variables during the pre-fire period. Daily meteorological variables were derived from the ERA5-Land reanalysis dataset (Muñoz-Sabater et al. 2021) at a spatial resolution of 0.1 degrees and an hourly resolution and aggregated daily over the summer season (June, July, and August; JJA) spanning a 10-year historical baseline (2016–2025) and the 2026 fire year. These variables included maximum air temperature (T_{max}), maximum vapor pressure deficit (VPD_{max} , computed by calculating the maximum hourly VPD value across each 24-hour interval), accumulated precipitation, and mean wind speed. To capture substrate moisture dynamics, daily mean surface soil moisture (SSM) at 0-5 cm was obtained from the NASA SMAP Level-4 Soil Moisture active-passive product at a 9 km spatial resolution (Reichle et al. 2025). The selection of these five variables was based on their documented associations with wildfire occurrence and fire-conducive conditions across different ecosystems (Brown et al. 2023; Goss et al. 2020; Jain et al. 2022; Jones et al. 2024; Mueller et al. 2020; Yang et al. 2021). All these variables were processed in Google Earth Engine and exported at their native spatial resolutions. Because ERA5-Land is a continuous reanalysis model and SMAP Level-4 is a gap-filled data assimilation product, the datasets provide continuous spatial coverage, allowing for the direct extraction of the time series at the reserve's centroid without requiring additional spatial gap-filling.

All five variables were systematically analyzed across the 2026 pre-fire buildup window (June 1 to August 13, 2026) to characterize their respective anomalies relative to the 10-year historical JJA baseline. This multivariable screening revealed T_{max} , VPD_{max} , and SSM as the three variables showing the most pronounced anomalies relative to their respective summer baselines (see Section 4.3). Based on this assessment, these variables were selected to characterize the multivariate hydro-climatic conditions preceding the fire. The three variables exhibited pronounced anomalies immediately prior to the fire, indicating the combination of anomalously high atmospheric heat and dryness and low surface soil moisture that characterized the pre-fire conditions at High Fens. Together, these variables provide an empirical representation of the pre-fire hydro-climatic conditions at the study site. It is important to emphasize, however, that this representation is not intended to constitute a predictive fire-susceptibility model. Rather, it is an empirical characterization derived solely from observed environmental conditions at the High Fens site and does not incorporate the broader spatial, temporal, physical, and statistical parameterization required for a robust fire prediction model. Its purpose is instead to provide a consistent framework for characterizing the multivariate hydro-climatic conditions preceding this extreme fire event.

To quantitatively characterize these pre-fire hydro-climatic conditions, summer daily baseline statistics, including means (μ) and standard deviations (σ), for the three selected variables were computed over the 2016–2025 baseline period at the centroid coordinates of the nature reserve. Daily summer values across the study period (2016–2026) were then standardized into standard anomalies (Z-scores):

$$Z_{T_{max}} = \frac{T_{max} - \mu_{T_{max}}}{\sigma_{T_{max}}}$$

$$Z_{VPD_{max}} = \frac{VPD_{max} - \mu_{VPD_{max}}}{\sigma_{VPD_{max}}}$$

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$$Z_{SSM} = (-1) \times \frac{SSM - \mu_{SSM}}{\sigma_{SSM}}$$

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The SSM anomaly (Z_{SSM}) was calculated directly as the negative of the standardized deviation to invert the scale, ensuring that positive anomalies uniformly represent desiccated, fire-favorable conditions. To assess environmental susceptibility on any given summer day, the scalar High Fens Fire Index (HFFI) was computed directly as a weighted combination of these daily anomalies, utilizing the specific target anomalies recorded on August 13, 2026 (the day immediately preceding wildfire ignition), as weights:

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$$HFFI = \frac{Z_{T_{max}} \cdot Z_{T_{max},target} + Z_{VPD_{max}} \cdot Z_{VPD_{max},target} + Z_{SSM} \cdot Z_{SSM,target}}{(Z_{T_{max},target})^2 + (Z_{VPD_{max},target})^2 + (Z_{SSM,target})^2}$$

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where $Z_{T_{max},target}$, $Z_{VPD_{max},target}$, and $Z_{SSM,target}$ represent the standardized anomalies recorded on August 13, 2026. Under this formulation, an HFFI value of 1.0 represents a daily state where the compounding atmospheric and substrate dryness has a normalized projection equal to that of the August 13 anomaly vector. Daily HFFI trajectories and multi-year summer HFFI matrices (2016–2026) were constructed using this formulation to quantify daily HFFI trajectories and identify periods during which HFFI reached or exceeded the benchmark value of 1.0 (HFFI ≥ 1.0) across the historical record.

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3.4. High Northern Latitude upscaling of HFFI

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To assess the geographic extent of areas across the HNL that experienced hydro-climatic conditions comparable to or exceeding those observed at High Fens before the 2026 fire, the HFFI framework was expanded across the circumpolar HNL. Daily grids of the three selected variables (T_{max} , VPD_{max} , and SSM) were extracted for the summer months (JJA) from 2016 to 2026 using Google Earth Engine for all landmasses north of 50°N. To overcome computational memory limitations and processing failures when aggregating daily multi-year records across the entire circumpolar domain, these variables were resampled and extracted at a coarser 50 km spatial resolution. The daily hemispheric rasters were standardized using the summer baseline statistics (μ and σ) calculated specifically at the centroid of the High Fens Nature Reserve from the 2016–2025 baseline period, establishing a consistent benchmark for comparison with the High Fens Fire. These common reference statistics were applied to every 50 km pixel across the circumpolar domain. Consequently, HFFI values represent similarity to the hydro-climatic conditions observed at High Fens rather than anomalies relative to the local climate at each HNL pixel. For each pixel, daily Z-scores were calculated against this common reference following the formula given in Section 3.3. The daily HFFI value was then calculated using the specific pre-fire target anomalies observed at High Fens ($Z_{T_{max},target}$, $Z_{VPD_{max},target}$, and $Z_{SSM,target}$).

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To identify geographic hotspots where hydro-climatic conditions comparable in the HFFI metric to those preceding the High Fens Fire occurred, the daily HFFI time series was summarized as the cumulative number of days per year during which conditions met or exceeded the threshold (HFFI ≥ 1.0) across the HNL. This temporal aggregation produced annual HFFI exceedance-count rasters, with higher values indicating a greater frequency of days during which the combination of temperature, atmospheric dryness, and surface soil moisture reached or exceeded the High Fens pre-fire benchmark.

To quantify the peatland area and soil organic carbon stock within the HFFI exceedance footprint and characterize their mapped fire history, we integrated PEATGRIDS Global Peat Thickness and Carbon Stock data (Widyastuti et al. 2025) with MCD64A1 Collection 6.1 burned-area data (Giglio et al. 2018). PEATGRIDS provides global 1-km resolution estimates of total peat carbon stock, expressed as Mg C per pixel and calculated from predicted peat thickness over the entire peat profile. We used the PEATGRIDS to define the peatland analysis domain and quantify the total peat carbon stock within each analysis category. MCD64A1 was used to identify peatland pixels with detected burned area during 2001–2025. A cumulative burned-area mask was generated by assigning a peatland pixel as burned when MCD64A1 detected burned area in at least one year during this period. Peatland pixels without MCD64A1-detected burned area during 2001–2025 were classified as having no detected fire during the observation period. The resulting burned and no-detected-fire peatland categories were then intersected with the $HFFI \geq 1.0$ exceedance footprint to quantify their spatial extent and associated peat carbon stocks.

For the purposes of this study, we define “HFFI-exposed peatland” as peatland area that experienced hydro-climatic conditions meeting or exceeding the High Fens pre-fire benchmark ($HFFI \geq 1.0$). For each HFFI-exposed peatland pixel, surface area and associated soil organic carbon stocks were quantified using the PEATGRIDS per-pixel carbon mass datasets. The total carbon stock was calculated by summing the mean carbon mass of all exposed pixels. Specifically, for a given peatland category, total carbon mass ($C_{mass,total}$) was calculated as:

$$C_{mass,total} = \sum_{i=1}^N C_{mass,i}$$

where N is the number of 1 km PEATGRIDS pixels within the respective HFFI-exposed peatland category. This approach provides an estimate of the total peatland carbon stock for peatlands exposed to hydro-climatic conditions with a projection onto the High Fens benchmark equal to or greater than 1.0. The calculation was performed separately for burned and unburned peatlands, allowing the carbon pools already affected by fire to be distinguished from those remaining unburned but exposed to similarly extreme fire-conducive conditions. Because pixel-level errors in global soil models are highly spatially autocorrelated, aggregating pixel-level standard deviations under the assumption of statistical independence results in severe underestimation of regional uncertainty. Therefore, we report the aggregated mean carbon stocks as best-estimates without bounding them by propagated pixel-level variance, acknowledging that actual regional uncertainties are substantially larger and scale with the global uncertainties reported by the baseline PEATGRIDS dataset.

4. Results

4.1. Spatial extent and dNBR-based burn severity of the High Fens Fire

The Sentinel-2 imagery captured a pronounced change in surface conditions across the High Fens between the pre-fire and post-fire observations (Figure 2). The pre-fire image acquired on July 25, 2026, shows a continuous mosaic of vegetated surfaces across the study area, whereas the post-fire image acquired on August 26, 2026, shows a large and contiguous area of altered surface reflectance corresponding to the fire-affected landscape. Applying the dNBR threshold of 0.192 that maximized Youden's J for the manually delineated reference polygons, the resulting

burn scar covers an estimated 25.43 km² (2,543 ha). The mapped fire footprint extends across a substantial portion of the central and eastern parts of the reserve, with several elongated extensions along its perimeter. Within the mapped burn scar, dNBR values show substantial spatial variability, with areas of higher positive values interspersed with patches of lower values. The spatial heterogeneity in dNBR indicates substantial spatial variation in the magnitude of surface spectral change within the mapped burn scar.

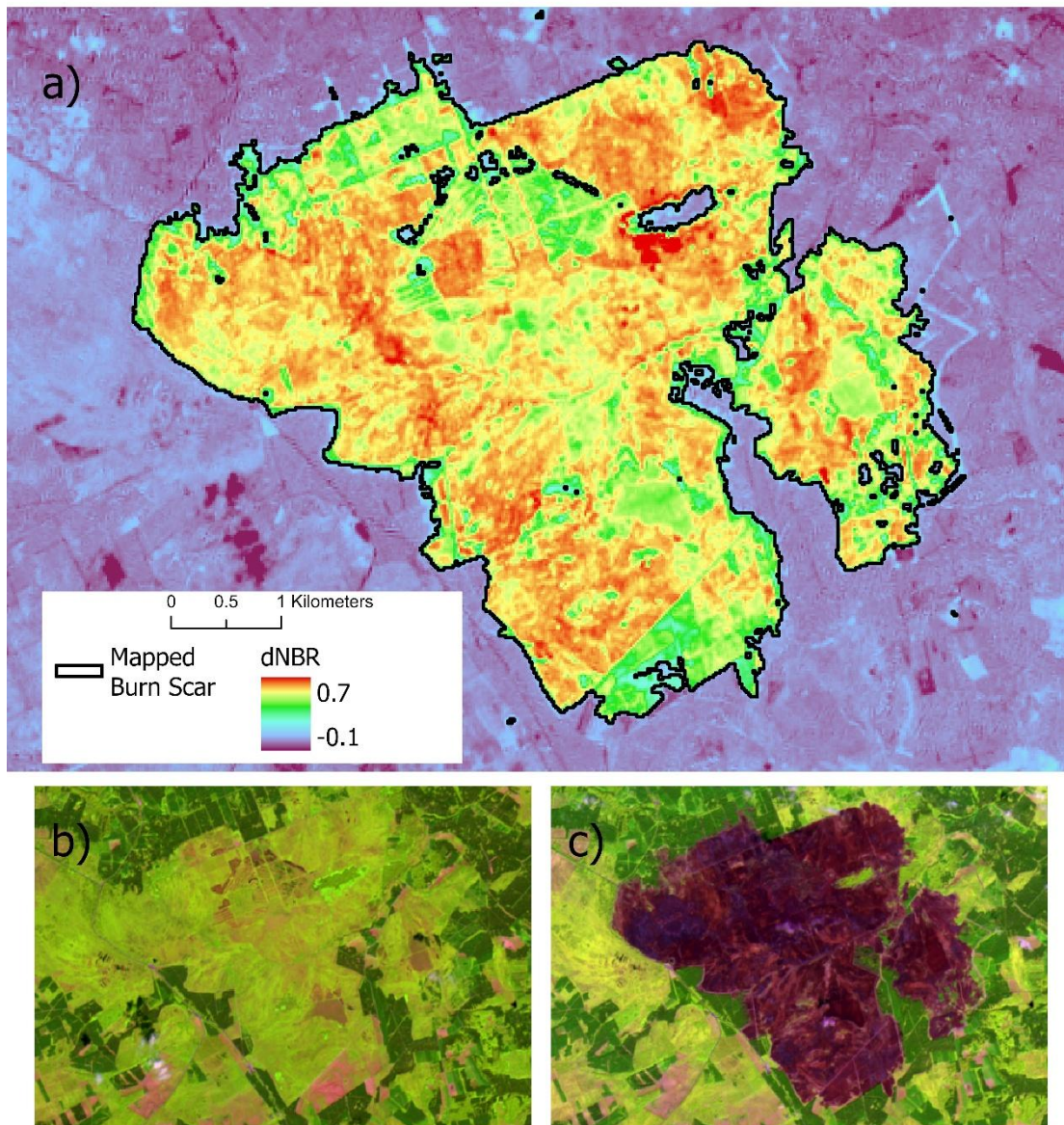


Figure 2. Spatial extent and spectral severity of the 2026 High Fens Fire. (a) Differenced Normalized Burn Ratio (dNBR) derived from Sentinel-2 imagery, with the mapped burn scar outlined in black. The color scale represents dNBR values, with higher positive values indicating greater spectral change between the pre- and post-fire observations. (b) Pre-fire Sentinel-2 image acquired on July 25, 2026. (c) Post-fire Sentinel-2 image acquired on August 26, 2026.

4.2. Regional context of the High Fens Fire

The VIIRS active-fire clustering identified the High Fens Fire as a 35.20 km² fire-associated footprint, compared with a 25.43 km² burn scar mapped from Sentinel-2 imagery. The two

estimates show broadly similar spatial patterns, but the VIIRS-derived footprint extends beyond the Sentinel-2 mapped scar, particularly along the western side of the fire-affected area (Figure 3).

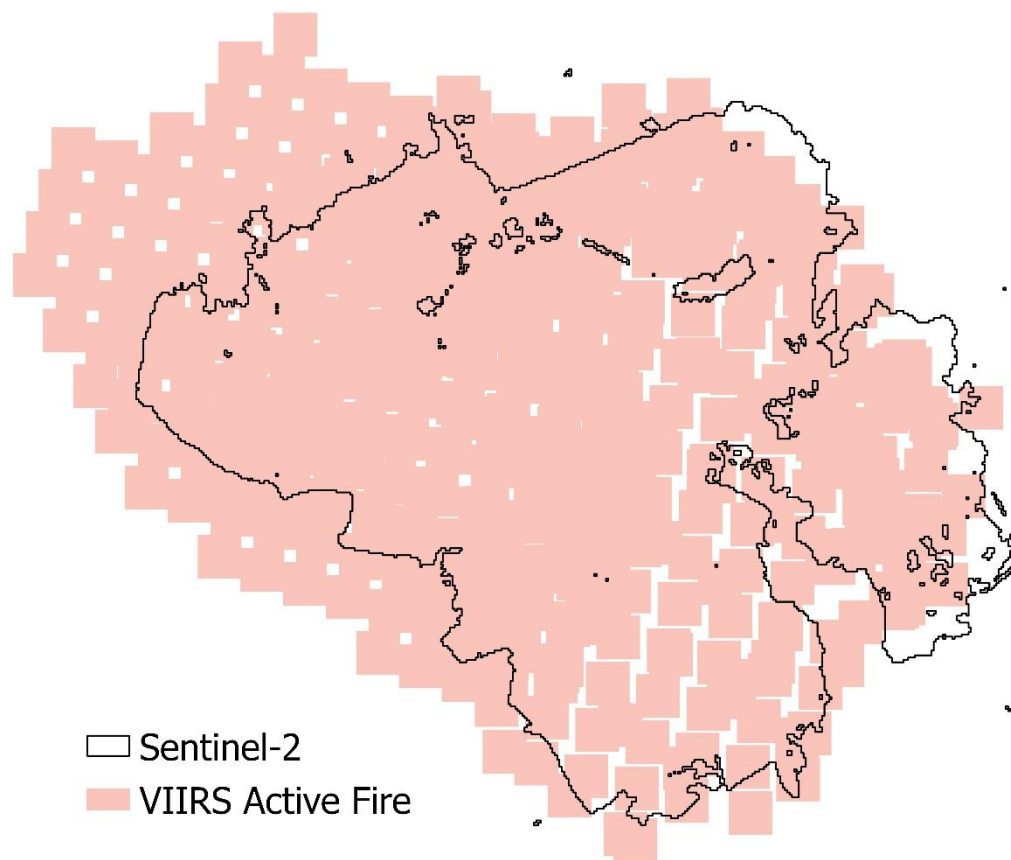


Figure 3. Spatial extent of the 2026 High Fens Fire derived from VIIRS SNPP active fire detections and comparison with the Sentinel-2 mapped burn scar. The pink area represents the VIIRS active-fire-derived fire footprint, while the black outline represents the Sentinel-2 mapped burn scar. The VIIRS-derived footprint extends beyond the Sentinel-2 mapped scar, particularly along its western side.

In the broader Western European fire-cluster perspective, the High Fens Fire ranked sixth in terms of cluster size since 2012 (Table 1). The five larger clusters were all located in France, with areas ranging from 39.41 to 172.17 km². The largest cluster covered 172.17 km² and occurred in southwestern France from July 20 to 27, 2026, while the second-largest covered 121.80 km² and occurred in France from July 13 to 20, 2022. The remaining three larger clusters had areas of 41.23, 40.82, and 39.41 km². The High Fens Fire was therefore the largest VIIRS fire cluster identified in Belgium during the analysis period and ranked among the largest events identified across the broader Western European domain.

The land cover composition of the High Fens Fire event differed markedly from that of the five larger regional clusters (Table 1). Within the High Fens VIIRS-derived event footprint, 63% of the area was classified by CORINE Land Cover 2018 as peat bog, 36% as forest, and 1% as grassland. In contrast, the five larger clusters were dominated by forest, which accounted for 81–

96% of their respective footprints. The High Fens event was therefore the only active fire cluster among the six largest regional disasters between 2012 and 2026 in which peatland constituted the majority of the VIIRS-derived fire-associated footprint. Although ranking sixth in absolute size across the regional analysis, the 2026 High Fens Fire was the only peatland-dominated cluster among the six largest VIIRS fire clusters identified in the analysis.

Table 1. The six largest VIIRS active fire clusters identified across Western Europe during 2012–2026, ranked by cluster area. For each fire cluster, the table reports the centroid location, country, year, start and end dates, area, and land cover composition.

Rank by Size	Centroid Latitude	Centroid Longitude	Country	Year	Start Date	End Date	Area (km ²)	Land Cover Composition
1	44.86190	-1.081320	France	2026	07-20	07-27	172.17	Forest (95%), Urban (3%), Cropland (1%), Others (1%)
2	44.52230	-0.527275	France	2022	07-13	07-20	121.80	Forest (96%), Cropland (2%), Urban (1%), Others (1%)
3	44.48970	-0.734756	France	2022	08-11	08-13	41.23	Forest (93%), Cropland (4%), Urban (3%)
4	44.75310	-0.896140	France	2026	07-25	07-29	40.82	Forest (92%), Cropland (4%), Urban (4%)
5	44.40250	-1.124730	France	2026	07-23	07-29	39.41	Forest (81%), Urban (14%), Cropland (3%), Water (1%), Wetland (1%)
6	50.52700	6.093840	Belgium	2026	08-14	08-17	35.20	Peatland (63%), Forest (36%), Grassland (1%)

4.3. Pre-fire hydro-climatic anomalies and HFFI trajectories

To characterize the environmental conditions preceding the August 14, 2026, wildfire, five daily hydro-climatic variables were monitored across the summer buildup phase from June 1 to August 13, 2026, revealing pronounced multi-week departures from their respective 10-year historical summer baselines (JJA 2016–2025; Figure 4).

Daily maximum vapor pressure deficit (VPD_{max}) was characterized by persistent positive anomalies relative to the historical summer average of 1.1 kPa (Figure 4a). Following a cool, humid period in early June where VPD_{max} remained below the baseline, values crossed above the mean in mid-June and remained consistently elevated through July and August. The daily time series exhibited three distinct peaks exceeding the baseline, including an initial peak in late June, a second peak in late July, and a third peak in early August, before reaching its seasonal maximum of 4.0 kPa on August 13, one day before the reported fire onset. Daily maximum air temperature (T_{max}) followed a similar temporal pattern relative to its historical summer baseline (Figure 4b). During the first half of June, daily temperatures remained well below the 10-year summer mean of 21.0 °C, reaching a seasonal minimum of 14.1 °C in mid-June. Temperatures crossed above the historical baseline on June 16, rising rapidly to establish the absolute seasonal maximum of 33.6 °C on June 26. Subsequent high-temperature anomalies of lower magnitude occurred in late July and early August, before returning to near-maximum levels on the eve of the wildfire. SSM obtained from SMAP began the summer of 2026 in a wet, well-watered state that sat

comfortably above the historical summer average (Figure 4c). Soil moisture crossed below this baseline in mid-June and entered a prolonged, continuous decline that persisted throughout July and August. The shallow substrate reached its absolute seasonal minimum of $0.05 \text{ m}^3/\text{m}^3$ in late July and remained near this low level through the first half of August. Daily mean wind speed fluctuated dynamically above and below its historical summer average (Figure 4d). The highest wind speeds of the summer were recorded during the wetter phase in early June, with a final, late-summer peak occurring in late July. Throughout most of July and August, mean wind speeds remained near or below the baseline, showing no persistent anomaly during the weeks preceding ignition. Daily accumulated precipitation was heavily concentrated in early and mid-June relative to its historical summer average (Figure 4e). This initial period was characterized by three major rainfall events, including a primary maximum of 164.9 mm in early June, after which precipitation was characterized by an extended dry spell with only minor, isolated trace events up to the August 14 ignition. Based on the persistence and coherence of their pre-fire anomalies, VPD_{max} , T_{max} , and SSM were selected for the subsequent HFFI analysis, whereas wind speed and precipitation were not included in the final index, as their drying influence is largely integrated into the resulting surface soil moisture and VPD trajectories.

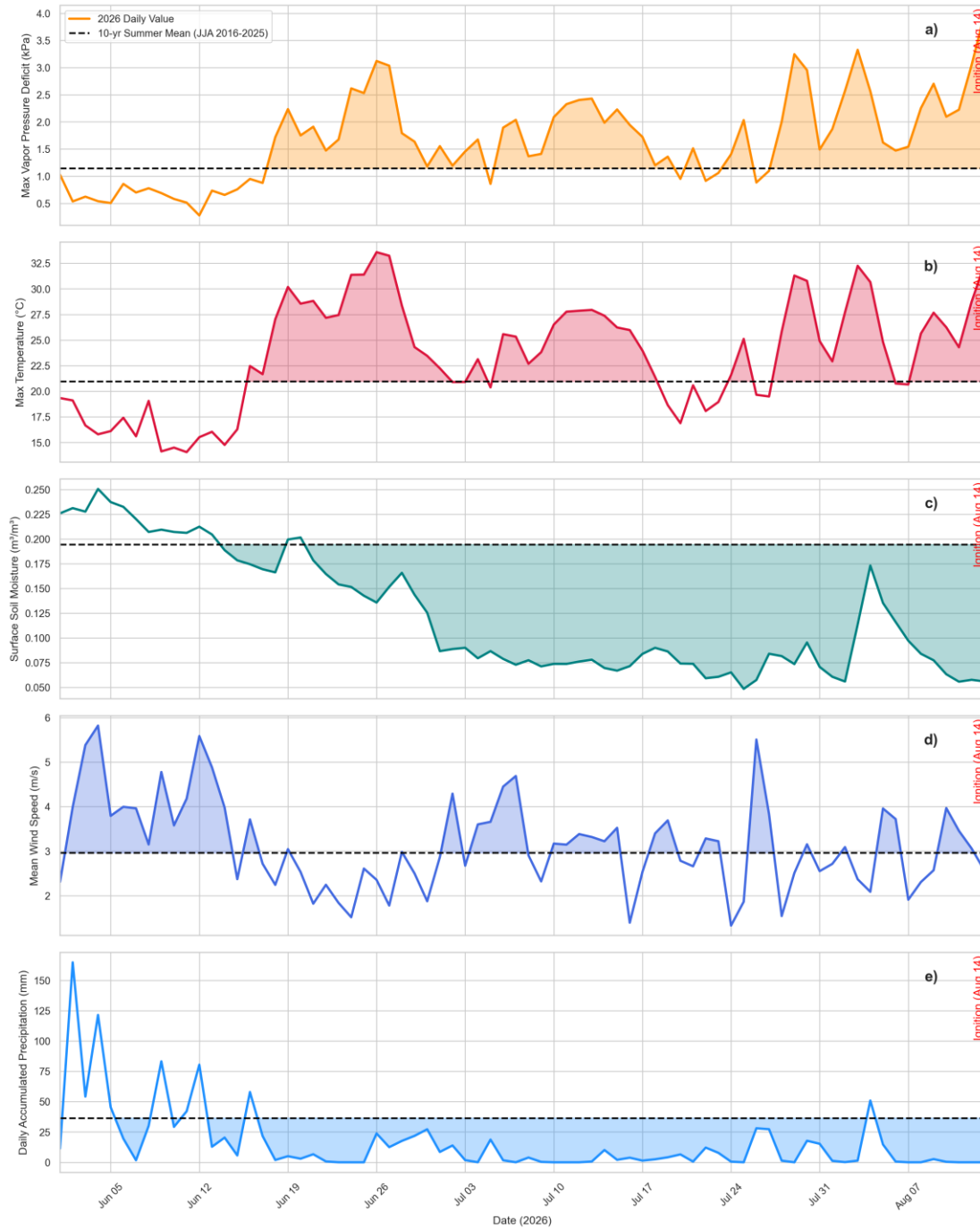


Figure 4. Pre-fire hydro-climatic trajectories at the High Fens Nature Reserve centroid during the summer of 2026. Panels display (a) daily maximum vapor pressure deficit (VPD_{max} , kPa), (b) daily maximum air temperature (T_{max} , °C), (c) surface soil moisture (SSM, m^3/m^3), (d) daily mean wind speed (m/s), and (e) daily accumulated precipitation (mm). The red vertical line indicates the wildfire ignition date (August 14, 2026), and black dashed horizontal lines represent the 10-year historical summer mean (JJA 2016–2025). Shaded regions denote daily departures from the long-term baseline.

The temporal progression of the combined hydro-climatic anomalies is summarized by the HFFI, which projects daily three-variable anomaly states onto the August 13 benchmark vector

(Figure 5). Under this formulation, $HFFI = 1.0$ represents the August 13 benchmark state, while values above 1.0 indicate daily anomaly combinations whose projection onto the benchmark direction exceeds that of the August 13 state. The daily summer HFFI matrix spanning the 11-year record (2016–2026) reveals that HFFI values approaching or exceeding the HFFI benchmark threshold ($HFFI \geq 1.0$) are exceptionally rare within this humid, temperate landscape. Notably, no active fire detections were recorded within the High Fens nature reserve by VIIRS between the beginning of the sensor record in 2012 and the ignition of the August 2026 event. Excluding the 2026 benchmark day itself, conditions reached or exceeded the HFFI threshold ($HFFI \geq 1.0$) during only a single discrete event in the historical record: a three-day window during the historic European heatwave of July 24–26, 2019 (Figure 5).

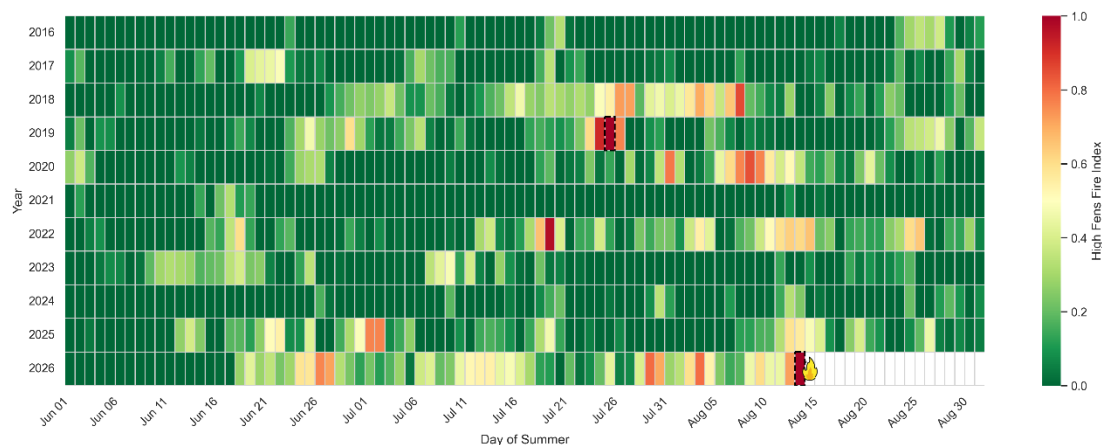


Figure 5. Summer daily susceptibility heatmap of the High Fens Fire Index (HFFI) from 2016 to 2026. Daily HFFI values are shown from lower to higher similarity to the High Fens pre-fire benchmark. Black dashed boxes outline days meeting or exceeding the HFFI benchmark threshold of 1.0, and the flame icon on August 14, 2026, marks the August 14, 2026, fire ignition date.

4.4. Circumpolar HFFI upscaling and peatland fire-history overlap

To evaluate the geographic distribution of hydro-climatic conditions comparable to those preceding the High Fens Fire, the HFFI was upscaled to all HNL spanning the summer months of 2016 to 2026 (Figure 6). This hemispheric projection mapping reveals that the hydro-climatic conditions recorded immediately prior to the High Fens Fire are not uniform across the HNL, but are geographically restricted. Regions experiencing at least one day meeting or exceeding the HFFI benchmark threshold ($HFFI \geq 1.0$) occupy a distinct latitudinal belt concentrated along the southern margins of the high-latitude domain (highlighted in pink in Figure 6). HFFI exceedances were concentrated primarily across southern Canada, central and eastern Europe, and the southern transition zones of Siberia. In contrast, the vast majority of the high-latitude domain, including Alaska, northern and central Canada, Scandinavia, and northern Siberia, did not experience a single day of critical exceedance (represented in blue, denoting 0 days, in Figure 6).

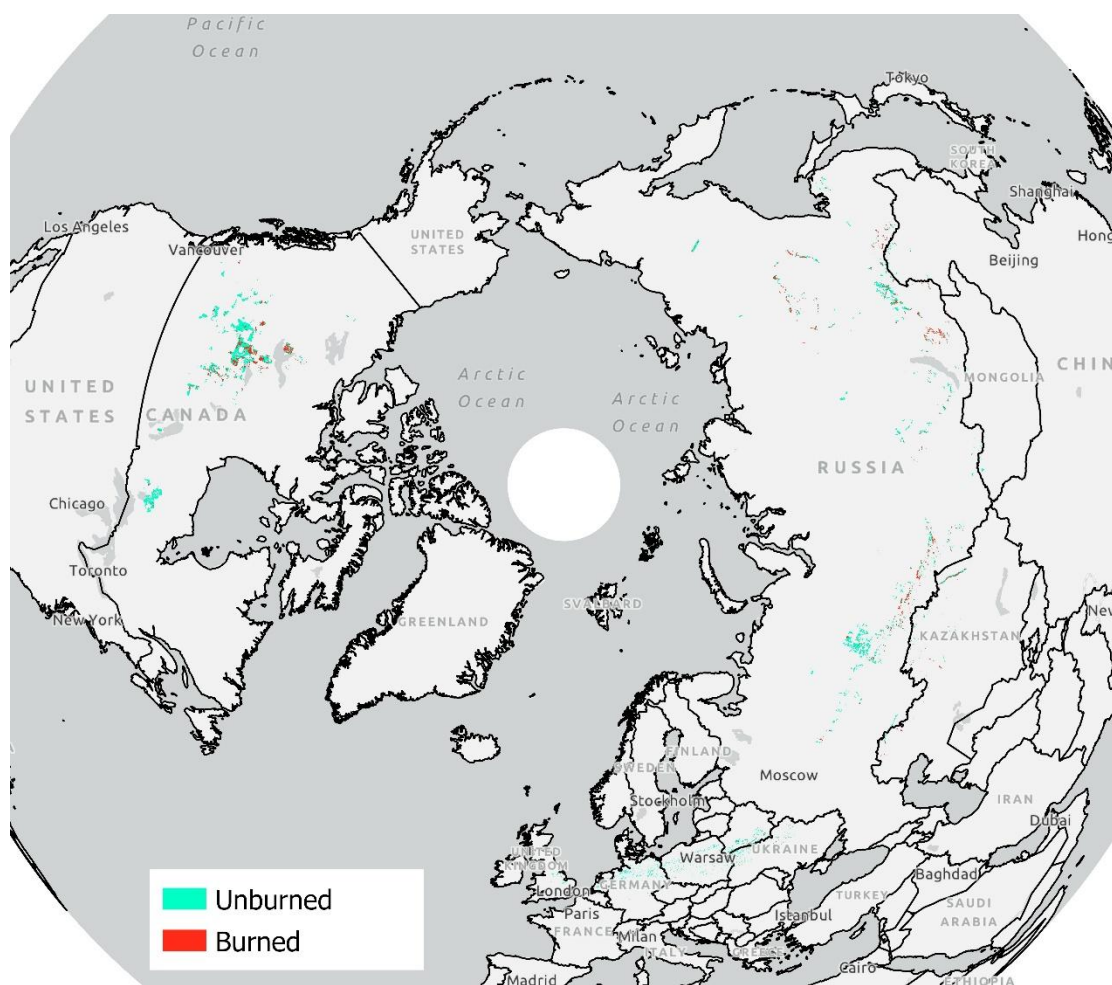


Figure 7. Spatial overlay of circumpolar peatland ecosystems intersecting the severe HFFI exceedance footprint. HFFI-exposed peatland areas are categorized into unburned peatlands (cyan) and peatlands with MCD64A1-detected burned area during 2001–2025 (red).

The total area and absolute soil organic carbon pools for these circumpolar peatland scenarios are quantitatively summarized in Table 2. Across the HNL domain, peatlands without MCD64A1-detected burned area during 2001–2025 covered 6,051,266 km² and contained an estimated 802.9 Gt C of soil organic carbon. Peatlands with MCD64A1-detected burned area covered 570,240 km² and contained 75.9 Gt C. Within the HFFI exceedance footprint, 252,771 km² of peatland had no detected burned area during 2001–2025 and contained 35.9 Gt C, whereas 84,158 km² had detected burned area and contained 10.1 Gt C. Across the HNL peatland domain, 8.6% of the mapped peatland area had MCD64A1-detected burned area during 2001–2025. Within the HFFI exceedance footprint, 25.0% of the mapped peatland area had detected burned area.

Table 2. Quantitative summary of peatland area and soil organic carbon stocks across the HNL and within the HFFI exceedance footprint. Burned and unburned categories are based on MCD64A1-detected burned area during 2001–2025.

Scenario Category	Area (km ²)	Total Soil Carbon (Gt C)
Total HNL Land Unburned	6,051,266	802.9
Total HNL Land Burned	570,240	75.9
Severe HFFI Exposed Unburned	252,771	35.9
Severe HFFI Exposed Burned	84,158	10.1

5. Discussion

5.1. The High Fens Fire as an important peatland-fire case

The significance of the 2026 High Fens Fire extends beyond its mapped extent. Sentinel-2 imagery identified a 25.43 km² burn scar with substantial spatial variation in dNBR across the reserve. While the fire occurred primarily within a peat-covered landscape, satellite surface reflectance cannot partition combustion between aboveground vegetation and the underlying organic soil. High dNBR values reflect severe canopy consumption, vegetation scorch, and surface charring, but they do not provide direct evidence of the depth or mass of peat consumed below the surface. Consequently, field measurements of post-fire residual organic layer thickness remain essential to determine the extent to which the peat deposit itself, rather than overlying biomass, served as the primary fuel source.

Unlike predominantly aboveground forest fires, peatland fires can involve prolonged subterranean smouldering that triggers massive carbon loss and severe ecological shifts (Harrison et al. 2024; Turetsky et al. 2015). This subterranean dynamic presents a unique challenge for post-fire assessment. Within the High Fens burn scar, we observed substantial spatial heterogeneity in the dNBR footprint (Figure 2), indicating a highly variable surface response. However, because optical sensors only capture surface-level reflectance, this dNBR heterogeneity cannot directly quantify the depth of the organic-soil combustion or the total volume of carbon consumed.

While optical satellite data cannot directly quantify subterranean carbon loss, the High Fens landscape offers an exceptional opportunity to address these data gaps through existing resources and local accessibility. Previous work has characterized peat thickness and carbon storage using field surveys, airborne LiDAR, UAV-based remote sensing, and ground-penetrating radar in the Belgian High Fens (Li et al. 2024), as well as in situ (Li et al. 2025) and potential (Li et al. 2026) gaseous carbon loss in the form of soil respiration. Although these specific observation sites are located outside the mapped burn scar and cannot serve as direct pre-fire measurements of the burned pixels, their proximity (within 2 km of the High Fens burn scar) provides valuable environmental context. Combined with the high accessibility of the reserve, repeated satellite observations, and the potential for targeted post-fire field assessments, this event provides a robust framework to investigate how surface burn severity relates to actual carbon emissions and long-term ecosystem recovery over time.

5.2. A broader context for circumpolar peatland exposure

The High Fens pre-fire benchmark was uncommon at the site during 2016–2026, with the exception of a three-day period in July 2019. When applied across the HNL, comparable HFFI conditions were concentrated primarily along the southern margins of the domain, including southern Canada, central and eastern Europe, and southern Siberia. This spatial pattern indicates

that the hydro-climatic combination observed before the High Fens Fire has occurred elsewhere across northern peatland regions, but its occurrence alone does not imply fire susceptibility.

The peatland overlay provides a further perspective on the magnitude of this exposure, demonstrating that approximately three-quarters of the HFFI-exposed peatland area had no detected burned area during the MCD64A1 observation period. The size of this unburned, yet meteorologically exposed, peatland carbon pool highlights a potential vulnerability. If extreme fire weather facilitates novel ignitions and subsequent deep smouldering in these ecosystems, the resulting carbon release could be substantial, though estimating actual emissions is beyond the scope of this study.

While this intersection of extreme fire weather and vast recently unburned carbon stocks highlights a severe latent risk, these results demonstrate that the hydro-climatic conditions represented by the High Fens pre-fire benchmark occurred across a substantial area of northern peatlands, including extensive areas without a detected fire history during the study period. The potential carbon implications nevertheless warrant further investigation because carbon loss from peat combustion is highly sensitive to the depth of burning. Previous work has shown that burn depth can dominate uncertainty in peat-fire emission estimates. For example, Rodríguez Vázquez et al. (2021) found that burn depth accounted for 94.2% of the variance in their estimated emissions from Indonesian peatland fires. Consequently, the carbon stocks reported here provide an estimate of the amount of carbon present within peatlands exposed to the HFFI benchmark, rather than an estimate of future fire emissions.

5.3. A long-term opportunity for studying peatland recovery

The High Fens Fire provides an opportunity to examine peatland recovery following a large disturbance in a landscape where nearby pre-fire observations are available. Li et al. (2024) characterized peat thickness and carbon storage at field sites approximately 2 km from the mapped burn scar, documenting substantial spatial variation in these properties over relatively short distances. The spatial variation in dNBR within the Sentinel-2 burn scar (Figure 2) similarly indicates a heterogeneous surface response to fire, but the ecological and biogeochemical consequences of this variation cannot be determined from the initial post-fire observations alone. Future monitoring could examine whether differences in fire-related spectral change are associated with subsequent variation in vegetation recovery, surface moisture, water-table dynamics, peat subsidence, and carbon or greenhouse-gas fluxes. Measurements from the adjacent unburned sites, together with the spatial patterns documented by Li et al. (2024), could help assess whether pre-existing spatial variation in peat properties is associated with differences in fire effects and subsequent recovery across the burn scar.

Hydrological change is likely to be particularly important. Previous peatland research has shown that lowering of the water-table depth can increase the vulnerability of peatlands to post-fire ecological regime shifts (Kettridge et al. 2015). Repeated observations of soil moisture, water-table conditions, vegetation composition, and surface elevation could therefore help determine whether the High Fens Fire produces persistent changes in ecosystem structure or hydrological functioning. The relatively accessible setting of the reserve makes such repeated observations more feasible than in many remote northern peatlands. The combination of satellite observations with field measurements, and potentially airborne observations such as UAV

surveys, would be especially valuable. While spaceborne LiDAR such as the Global Ecosystem Dynamics Investigation (GEDI) can characterize pre-fire aboveground biomass, its discrete orbital track spacing is generally too coarse to continuously map localized burn-scar elevation changes. However, active L-band Synthetic Aperture Radar (SAR) missions, such as the recently launched NASA-ISRO Synthetic Aperture Radar (NISAR) and the upcoming European Space Agency (ESA) Radar Observing System for Europe in L-band (ROSE-L), offer a transformative capability. These sensors penetrate vegetation canopies and can utilize interferometric SAR (InSAR) to track continuous surface subsidence, providing a spatially comprehensive proxy for peat combustion depth and post-fire compaction that moderate-resolution optical sensors cannot resolve.

5.4. Remote sensing enables rapid characterization of unexpected wildfire events

Our study illustrates how complementary satellite observations can support rapid characterization of unexpected wildfire events. VIIRS active-fire observations can provide information on fire activity within hours, and in some cases minutes, of satellite acquisition (Orland et al. 2025; Schroeder et al. 2014), making them particularly valuable for the initial detection and characterization of an emerging or recently occurred fire. In the case of the High Fens Fire, the VIIRS cluster identified a 35.20 km² fire-associated footprint and allowed the event to be placed within a broader regional context shortly after the event, before a complete official fire record was available. As shown in Table 1, the High Fens Fire ranked sixth in cluster area among the events identified in our analysis. Thus, active-fire observations can provide both near-real-time information on fire activity and a means of contextualizing an unexpected event within the regional fire record before the official fire record becomes available.

Post-fire optical observations from Sentinel-2, and similarly from Landsat, provide an important complement to active-fire observations because their higher spatial resolution allows the spatial extent and surface characteristics of the affected area to be delineated in greater detail. For the High Fens Fire, Sentinel-2 imagery acquired on August 26, 2026 identified a 25.43 km² burn scar, providing a more spatially detailed delineation of the surface burn scar than the VIIRS active-fire footprint (Figure 3). Coupled with pre-fire observations, the optical imagery also captures the spatial pattern and relative heterogeneity of surface change following the fire. Together, the two types of observations provide complementary information: VIIRS enables rapid identification and characterization of fire activity, whereas Sentinel-2 and Landsat provide more spatially detailed observations of the resulting surface disturbance.

The difference between the VIIRS-derived footprint and the Sentinel-2 burn scar also illustrates the uncertainty associated with interpreting either observation as a direct measure of burned area. The VIIRS footprint extends beyond the Sentinel-2 scar, particularly toward the west (Figure 3), likely reflecting the 375 m detection footprint and our 375 m cell dilation, among other factors. Conversely, optical burn-scar mapping can be affected by clouds, smoke, viewing conditions, and image acquisition timing. These differences underscore the value of combining active-fire and post-fire optical observations rather than treating either product as a complete representation of fire extent. More broadly, the rapid availability of active-fire observations, followed by the higher spatial resolution of optical imagery, provides an effective framework for characterizing unexpected wildfire events shortly after they occur.

5.5. Interpretation and limitations of the HFFI framework

The HFFI should be interpreted as an empirical benchmark derived from the High Fens Fire rather than as a general predictive fire-susceptibility model. The index represents the combination of $T_{\max}$, $VPD_{\max}$, and surface soil moisture anomalies observed immediately before the fire, and $HFFI \geq 1.0$ identifies days whose combined anomaly state reached or exceeded the magnitude represented by the High Fens benchmark. The temporal results in Figure 5 therefore show when conditions comparable to those preceding the fire occurred at High Fens, while the circumpolar results in Figure 6 show where comparable conditions occurred elsewhere.

This interpretation also highlights an important limitation of the circumpolar analysis. The HFFI reference statistics derived from High Fens were applied uniformly across HNL, meaning that HFFI values at other locations represent similarity to the environmental conditions associated with the High Fens Fire rather than anomalies relative to local climate conditions. A high HFFI value therefore indicates similarity to the hydro-climatic conditions observed before the High Fens Fire, but it does not indicate that conditions are unusually extreme relative to the local climate or that fire is likely to occur. Also, the benchmark threshold is event-derived. Because $HFFI = 1.0$ was defined from the conditions immediately preceding a single fire, the threshold has not been independently validated against an independent set of fire events. The rarity of HFFI exceedance at High Fens shown in Figure 5 is therefore informative about the historical occurrence of this particular combination of conditions at the study site, but it should not be interpreted as validation of a universal fire threshold. For example, the HFFI benchmark was exceeded in July 2019 without a VIIRS-detected fire in the High Fens, illustrating that extreme weather alone is insufficient to cause fires without ignitions and favorable underlying fuel conditions.

Furthermore, the selection of the three hydro-climatic variables and their target anomalies was determined post-hoc based on their extreme departure from the baseline prior to this specific event. The additive nature of the HFFI equation also mathematically allows an extreme anomaly in one variable to compensate for a less fire-conducive state in another. Finally, utilizing a point-based centroid baseline to standardize coarser 50 km hemispheric grids introduces a scale mismatch that may smooth localized climatic extremes.

Spatial resolution is another important limitation. The circumpolar HFFI analysis was conducted at 50 km resolution, which is appropriate for identifying broad regional patterns but cannot resolve the fine-scale heterogeneity of peatland hydrology, vegetation, topography, or fuel structure. In addition, the peatland dataset used to estimate exposure operates at 1 km resolution and is itself subject to uncertainty in both peatland delineation and estimates of peat carbon storage. The 252,771 km² of peatland without MCD64A1-detected burned area during 2001–2025 identified in Figure 7 and Table 2 should therefore be interpreted as a regional-scale estimate of potentially HFFI-exposed peatland area and carbon, rather than a precise delineation of individual peatlands or their carbon stocks and susceptibility to burning. Furthermore, the use of SMAP surface soil moisture limits the representation of peatland hydrological conditions, as the 0–5 cm surface layer does not directly characterize deeper peat moisture or water-table position, which strongly influences smouldering combustion.

Similar caution is required when interpreting the fire-history layer. The circumpolar

burned/unburned classification was derived from MCD64A1 burned-area data for 2001–2025 rather than from the VIIRS active-fire footprints used in the Western European comparison. While the MCD64A1 layer provides a consistent global record, moderate-resolution surface reflectance algorithms often struggle to map peatland fires; for instance, recent updates to the Global Fire Emissions Database (GFED5) noted that large omission errors prevent the direct use of the MCD64A1 product for accurately estimating burned area in tropical peatlands (Chen et al. 2023). Consequently, our classification of peatlands without MCD64A1-detected fire history likely includes some areas that experienced undetected low-intensity, small, or subterranean burning. Furthermore, this binary classification records whether burned area was detected at least once during the observation period but does not distinguish the number, timing, or severity of individual fire events.

The carbon estimates represent soil organic carbon stock contained within the mapped peatland areas. They do not represent carbon emissions, carbon loss, or the amount of carbon that would necessarily be combusted in a future fire. Actual carbon emissions would depend on ignition, fire behavior, water-table conditions, peat properties, burn depth, and combustion completeness, none of which are quantified by the HFFI exposure analysis.

Taken together, these limitations define the appropriate role of the HFFI in this study. Its principal value is not as a standalone forecasting tool, but as a consistent empirical benchmark linking the hydro-climatic conditions observed before the High Fens Fire with their occurrence elsewhere across the HNL. Combined with the satellite-based characterization of the fire itself, the regional fire comparison, and the peatland carbon overlay, this framework provides a way to place a single unexpected wildfire within a much broader environmental context.

6. Conclusions

The 2026 High Fens Fire was an unusually large wildfire in Belgium, demonstrating that extensive peatland fires can occur outside the traditionally studied boreal and Arctic regions. The strong spatial heterogeneity in the post-fire surface response highlights that the consequences of peatland fire cannot be inferred from burned area alone, particularly because combustion depth and associated carbon loss cannot be directly determined from Sentinel-2 surface reflectance observations.

The environmental conditions preceding the fire indicate the circumstances under which peatland fires may emerge in regions where they have historically been uncommon. The severe combination of high temperature, atmospheric dryness, and declining surface soil moisture preceding the High Fens Fire also occurred across extensive areas of southern Canada, Europe, and southern Siberia. Crucially, these conditions intersected with large areas of peatland that lacked detected fire activity between 2001 and 2025. The substantial carbon stocks within these exposed, unburned peatlands highlight a major vulnerability in the northern carbon pool as extreme hydro-climatic anomalies occur. However, because ignition, fuel conditions, and local hydrology ultimately dictate fire behavior and carbon release, the HFFI serves best as an empirical benchmark for identifying environments experiencing comparable pre-fire extremes, rather than as a standalone emissions model.

This study also demonstrates the value of multi-scale satellite remote sensing for responding to unexpected wildfires. Near-real-time VIIRS active-fire observations provide early indications

of fire activity and regional significance, while higher-resolution Sentinel-2 and Landsat observations rapidly delineate the affected footprint and characterize spatial burn severity. Moving beyond remote sensing, the High Fens event provides a uniquely accessible natural laboratory. Because historically wet, temperate peatlands are rarely exposed to such severe drying and combustion, this site offers a logistically feasible opportunity for ongoing, field-based ecological research. Long-term field monitoring of the High Fens burn scar, integrated with satellite observations, will yield foundational insights into how carbon-dense ecosystems respond to novel fire regimes, ultimately reducing uncertainties in biogeochemical modeling under a warming climate.

7. Acknowledgments

The authors acknowledge the use of Gemini Pro 3.1, a large language model developed by Google, to assist with data-analysis code development and manuscript language editing. The authors independently reviewed and verified the resulting analyses and text and take full responsibility for the accuracy, interpretation, and originality of the final manuscript.

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