

Post-print of Burned Area Change Detection Based on Multi-feature Combinations of Sentinel-1 and Sentinel-2

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Abstract

Against the backdrop of intensifying global warming, extreme high-temperature events occur frequently, leading to exacerbated droughts and the accumulation of combustible materials, which significantly increases the risk of wildfires. Increasingly frequent wildfires pose a serious threat to ecological security and sustainable development. Currently, burned area identification methods primarily rely on single spectral features, which are susceptible to interference from vegetation phenology, topography, and atmospheric conditions, resulting in problems of misclassification and omission. To address this, a multi-feature collaborative identification strategy is proposed, aiming to improve the accuracy of burned area detection and provide technical support for precise wildfire prevention and control. Based on SHAP feature importance calculated by random forest and XGBoost models, 20 feature combinations were designed by fusing various spectral index features, polarization features, and original features. Combining bi-temporal Sentinel-2 multispectral and Sentinel-1 polarimetric remote sensing images from before and after the fire, a Transformer-based bi-temporal image change detection model (BIT_{CD}) was used to identify burned areas in China and its surrounding regions. The results indicate that: (1) The improved model achieved an overall accuracy (OA) of 92.7% on the test set, an increase of 2.36% over the original model, and an increase in Intersection over Union (IoU) of 5% to 14%, significantly enhancing the model's ability to identify burned areas. (2) By synthesizing various indicators of the model, the optimal feature combination was determined to be the fusion of the Normalized Burn Ratio Plus (NBR_{PLUS}), Sentinel-1 backscattering coefficients (VV, VH), the red-edge band (RE4), and the Sentinel-2 short-wave infrared bands (S2, S1). The multi-feature integrated BIT_{CD} model proposed in this study can effectively identify burned areas, providing a methodological reference for post-fire disaster

identification, burned area assessment, post-disaster reconstruction, ecological restoration, and sustainable development.

Full Text

Burned Area Change Detection Using Multi-Feature Combinations Based on Sentinel-1 and Sentinel-2

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Abstract

Under the background of intensifying global warming, the frequency of extreme high-temperature events has increased significantly. This trend has led to exacerbated drought conditions and the accelerated accumulation of combustible fuel loads, creating highly favorable conditions for the occurrence and spread of large-scale wildfires. The increasing frequency of wildfires poses a severe threat to ecological security and sustainable development. Currently, methods for identifying burned areas primarily rely on single spectral features, which are susceptible to interference from vegetation phenology, topography, and atmospheric conditions, leading to issues with false positives and missed detections.

To address these challenges, this study proposes a multi-feature collaborative identification strategy aimed at improving the accuracy of burned area detection. Based on SHAP feature importance calculated using Random Forest and XGBoost models, this approach integrates various spectral index features, polarization features, and original spectral bands. Twenty distinct feature combinations were designed. By integrating bi-temporal Sentinel-2 multispectral imagery and Sentinel-1 polarimetric radar imagery from both pre-fire and post-fire periods, a Transformer-based Bitemporal Image Transformer for Change Detection (BIT_{CD}) model was employed to identify burned areas across China and its surrounding regions.

The results indicate that: (1) The improved model achieved an Overall Accuracy (OA) of 92.7% on the test set, representing a 2.36% increase compared to the original model. Furthermore, the Intersection over Union (IoU) improved by 5% to 14%, significantly enhancing the model's capability to identify burned areas. (2) By synthesizing various model performance metrics, the optimal feature combination was determined to be the Normalized Burn Ratio Plus (NBR_{PLUS}), Sentinel-1 backscattering coefficients (VV, VH), and specific Sentinel-2 bands (RE4, S2, S1). This approach provides a methodological refer-

ence for post-fire disaster identification, burned area assessment, and ecological restoration.

Keywords: Burned areas; Change detection; Feature combination; Deep learning; Transformer

1. Introduction

Forest fires represent a significant threat to global ecosystems, biodiversity, and atmospheric composition. Accurate mapping of burned areas is essential for post-fire recovery assessment, carbon cycle modeling, and forest management. Traditional change detection methods often struggle with the spectral complexity of post-fire landscapes and the interference of seasonal vegetation changes.

Traditional remote sensing identification of burned areas primarily relies on the Normalized Burn Ratio (NBR), calculated using the Near-Infrared (NIR) and Short-Wave Infrared (SWIR) bands. The NBR index leverages the characteristic spectral response of vegetation following a fire: a significant decrease in NIR reflectance due to the destruction of chlorophyll and leaf structure, coupled with a substantial increase in SWIR reflectance due to the loss of moisture and the exposure of charred soil. By comparing pre-fire and post-fire NBR values—the differenced Normalized Burn Ratio (dNBR)—researchers can delineate the extent of burned areas. However, traditional spectral indices often struggle to distinguish burned areas from other land cover types with similar spectral signatures, such as harvested agricultural fields or dark soil surfaces, particularly in regions with complex terrain.

With the rapid development of remote sensing technology, its extensive coverage capabilities have become increasingly significant. For fire monitoring, various satellite platforms have been utilized, including Landsat [?], Sentinel [?], and MODIS [?]. While optical remote sensing is highly susceptible to environmental interference, Synthetic Aperture Radar (SAR) imagery, such as Sentinel-1, offers all-weather, day-and-night observation capabilities. SAR backscattering is sensitive to changes in forest structure and surface roughness caused by fire. Despite these advantages, SAR data can be noisy and influenced by soil moisture. Therefore, integrating Sentinel-1 and Sentinel-2 data presents a promising strategy to leverage the strengths of both sensors.

2. Materials and Methods

2.1 Study Area and Data Acquisition

The study area covers China and several neighboring countries in the Asia-Pacific region, spanning a geographical range from 1°37'S to 62°04'N and 46°56'E to 144°05'E. This region encompasses diverse climate zones and

vegetation types, including the temperate forests of Northeast China, the Inner Mongolian grasslands, and Southeast Asian tropical rainforests.

The Sentinel-1 and Sentinel-2 imagery utilized in this study covers the period from May 2017 to September 2021. Sentinel-2 provides 13 spectral bands with spatial resolutions of 10 m, 20 m, and 60 m. Sentinel-1 provides C-band SAR data with VV and VH polarizations. All data were processed using the Google Earth Engine (GEE) platform.

2.2 Feature Construction and Selection

To enhance the precision of burned area identification, this study constructed 15 spectral index features based on original Sentinel-2 bands, including NBR, NDVI, EVI, and BAIS2. Additionally, Sentinel-1 backscattering coefficients (VV, VH) were integrated.

Sentinel-2 spectral bands and abbreviations used in the study.

Sentinel-1 polarization features.

To investigate the relative importance of various features, SHAP (SHapley Additive exPlanations) values were calculated using Random Forest (RF) and XG-Boost models. Based on the importance ranking, 20 distinct feature combinations were designed to evaluate the impact of different variables on model performance.

2.3 BIT_{CD} Model Architecture

This study employs the Bitemporal Image Transformer for Change Detection (BIT_{CD}) model. The model utilizes a convolutional neural network (CNN) backbone to extract features from bi-temporal images, which are then processed by a Transformer encoder-decoder to capture long-range spatiotemporal dependencies. The final prediction head generates the change map.

The NBR is defined as:

$$\text{NBR} = \frac{\rho_{\text{NIR}} - \rho_{\text{SWIR}}}{\rho_{\text{NIR}} + \rho_{\text{SWIR}}}$$

The differenced NBR is:

$$\text{dNBR} = \text{NBR}_{\text{pre-fire}} - \text{NBR}_{\text{post-fire}}$$

The loss function used during training is a combination of cross-entropy loss and dice loss:

$$L_{\text{total}} = \lambda_1 L_{\text{ce}} + \lambda_2 L_{\text{dice}}$$

3. Results and Discussion

3.1 Performance of Feature Combinations

The performance of the 20 feature combinations was evaluated using Overall Accuracy (OA), Intersection over Union (IoU), Precision, Recall, and F1-score. The RGB combination exhibited the poorest performance (OA: 90.56%). In contrast, combinations integrating spectral indices and SAR data consistently achieved OA values above 91%.

Performance of 20 feature combinations on the test set.

The optimal combination was determined to be $\text{NBR}_{\{\{\{\text{PLUS}}\}\{\{\text{VV}}\}\}\{\text{VH}\}}\text{RE4_S2_S1}$, which achieved an OA of 92.92% and a Precision of 76.95%. This configuration leverages the complementary advantages of vegetation indices, SAR structural information, and original spectral bands.

3.2 Model Training and Stability

Analysis of the F1-scores during training and validation indicates that the $\text{NBR}_{\{\{\{\text{PLUS}}\}\{\{\text{VV}}\}\}\{\text{VH}\}}\text{RE4_S2_S1}$ combination provides the most stable and efficient training process. The inclusion of the Red Edge (RE4) and SWIR (S2, S1) bands significantly improved the model's ability to distinguish burned areas from background noise, such as topographic shadows and harvested croplands.

[Figure 7: see original paper] Prediction results for various feature combinations.

4. Conclusion

This study proposed a multi-feature collaborative identification strategy for burned area change detection using a Transformer-based model. The main conclusions are:

1. The integration of multi-source data (Sentinel-1 and Sentinel-2) significantly improves the accuracy of burned area extraction compared to single-source data.
2. The $\text{BIT}_{\{\text{CD}\}}$ model, enhanced with optimized feature combinations, achieved an OA of 92.7%, outperforming the baseline model.
3. The optimal feature set includes the $\text{NBR}_{\{\text{PLUS}\}}$ index, SAR polarizations (VV, VH), and specific optical bands (RE4, S2, S1).
4. This methodology provides a robust technical framework for rapid wildfire monitoring and post-fire ecological assessment.

Future research will focus on expanding the dataset to include more diverse fire scenarios and optimizing the model structure for real-time monitoring.

Note: Figure translations are in progress. See original paper for figures.

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