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Balancing Spatial, Spectral, and Temporal Information: Which Dimension Drives Deep Learning Performance in Forest Disturbance Classification?

Franziska Müller[1], Ana Bastos[1], and Gustau Camps-Valls[2]
[1]Institute for Earth System Science and Remote Sensing, University Leipzig, Leipzig, Germany
[2]Image and Signal Processing Laboratory, Universitat de València, València, Spain

Monitoring forest disturbances is essential for sustainable forest management. Remote sensing provides a powerful tool to detect and quantify such disturbances across large spatial and temporal scales, but separating different types of disturbances, such as wind-throw and insects, remains a challenge. In this study, we investigate how different types of information — spatial, spectral, and temporal — contribute to accurate classification of wind, bark-beetle and defoliator insect disturbances using modern machine learning (ML) and deep learning (DL) models. We rely on a comprehensive multimodal dataset based on multi-temporal optical, radar, and forest inventory data to evaluate several different ML/DL approaches for distinguishing between three disturbance agents.

A central focus of this work is to assess which dimensions of the data — spatial structure, spectral information, or temporal dynamics — are most informative for reliable classification.

Preliminary results suggest that (1) temporal information is highly important when combined with time-series–based deep learning architectures, which effectively capture disturbance trajectories and achieve F1-scores above 0.90 for wind and bark beetle disturbances; (2) spectral features alone achieve F1-scores of up to 0.86 when used with a multilayer perceptron (MLP), with SWIR bands and Sentinel-1 backscatter playing a key role in distinguishing disturbance agents; and (3) the combination of temporal and spectral information through multispectral temporal learning yields an overall F1-score of up to 0.95.

This work highlights the importance of carefully selecting appropriate data formats and choosing models that can effectively leverage the available information. We discuss methodological challenges, data limitations, and the potential of time-series–based deep learning approaches to improve forest disturbance monitoring across diverse forest types and disturbance regimes.