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| **Spaceborne Forest Disturbance Detection in Central Europe using Transformers** |
| **Introduction:** Central European forests provide important ecosystem functions like climate regulation and carbon storage. Yet, climatic extreme events, which are becoming more frequent in times of climate change, led to major forest damage in recent years. The hot drought of the years 2018 until 2020, for instance, resulted in signs of damage in almost 80% of the trees in German forests. The weakened trees, then, are more susceptible to co-morbidities such as bark beetle infestations. This vast extent of forest damage cannot be monitored efficiently using ground data alone, and multispectral satellite image time series (SITS) may be an alternative. Most existing remote sensing-based forest disturbance detection methods follow one of two main approaches: Firstly, near real-time monitoring tools (e.g. BFAST Monitor, CCDC, Fordead) use an undisturbed reference period for model fitting and try to detect deviations from model predictions in the subsequent monitoring period. These methods, thus, rely on the assumption that the training period does not exhibit disturbance. Secondly, temporal segmentation algorithms identify break points and trend changes retrospectively. The segmentation is usually done on interpolated (e.g. BFAST) or seasonally aggregated (e.g. LandTrendr) univariate time series.  **Methods:** Here, we use a third type of approach, known from machine learning: time series classification. These methods classify the whole time series into undisturbed or disturbed forest pixels. A potential advantage is that the trained models do not need an undisturbed reference period for each pixel, as they have been fitted on a large amount of training data. In this study, we apply transformers, a state-of-the-art Deep Learning (DL) architecture, which have evolved as a promising tool for time series classification in remote sensing, on Sentinel-2 (S2) time series. Transformers are capable of establishing (the strength of) temporal links between satellite observations (such as lag effects between drought stress and subsequent tree dieback) by applying the so-called *self-attention* algorithm. Our Transformer model can process multivariate time series as input and does not need interpolation or gap filling. We train the model in two steps: *pre-training* was conducted with a high amount of time series with labels of medium accuracy of disturbances in German forests, while *fine-tuning* contained a smaller amount of highly accurate forest damage labels of Germany and Luxembourg. We compare three setups: *DL base* (using ten S2 bands as model input), *DL IND* (using ten vegetation indices) and *DL +IND* (using both).  **Results:** Preliminary results show that DL is capable of detecting dieback events of as small as 20 m² in the 100 m² pixels. Explainable AI indicates that DL base can distinguish between signal and noise in SITS expressing lag effects. Since DL base performs similar to the other DL setups, our results indicate that DL methods are capable of disentangling a complex signal given by ten different S2 bands instead of relying on handcrafted vegetation indices.  **Conclusion:** We conclude that using S2 time series in combination with Transformers are a viable approach to effectively provide timely and small-scale forest disturbance information in Central European forests. |