Spatial Trends in Tree Phenology in the Bohemian Forest Ecosystem over the Last Two Decades

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Tree phenology is a crucial proxy for ecosystem services such as biomass production and an important indicator for the impact of climate change on forests. Both traditional monitoring and phenological cameras (pheno cams) offer only few observation points, limiting the study of large-scale spatial patterns. Satellite time-series can provide the spatio-temporal extent needed, however, their agreement with in situ data is often unknown and uncertainties are high.

This study aims to fill these gaps for the Bohemian Forest, where traditional and pheno cam observations are available, but no full-scale spatio-temporal analysis of tree phenology has been conducted to date. The Bohemian Forest is a cross-border region including the German Bavarian Forest National Park (BFNP) and the Czech Šumava National Park. It contains a diverse forest composition and with both managed and unmanaged areas.

Forest phenology in satellite data is analyzed via an innovative method and validated with pheno cam data. Landsat 4-9 and Sentinel 2 data is harmonized before the EVI (enhanced vegetation index) is calculated. Six phenological timings per pixel and year are obtained: (1) start of the green up in spring, (2) point of fastest growth (spring inflection point (SIP)), (3) end of spring growth, (4) start of senescence in autumn, (5) point of fastest decline (autumn inflection point), (6) end of the autumn decline. This is achieved through a combination of smoothing and extraction methods. For smoothing, fitting and filtering is dynamically applied based on data quality. With limited data points for a year, a double logistics function is fitted and phenology is estimated based on it. If enough data is available, it is Savitzky-Golay-filtered and the inflection points are extracted directly. If filtering is insufficient, local logistic function fitting is used. Based on the inflection points, the other timings (1, 3, 4, 6) are obtained trough a geometric analysis of the curve's derivatives.

To validate the results, time series of 15 pheno cams are analyzed in a similar way. Here, the Green Chromatic Coordinate (GCC) is used instead of the EVI. To insure accuracy, the pheno cam images are pre-processed to exclude bad-quality images using both traditional and AI-driven methods.

First results show that phenological dates derived from satellite data correspond well with pheno cam data (Fig. 1). Satellite-derived SIPs occur later in the year than those of the pheno cams. For autumn inflection, the inverse is observed. These differences could be explained by the lower temporal resolution of the satellite data, suggesting that the new approach provides reliable phenology estimates. Furthermore, it successfully detects spatial differentiation between different forest stands of the same type (Fig. 2). Futher work will apply this approach to the full spatio-temporal data extents for both national parks over the last two decades, deriving temporal trends for different forest types.

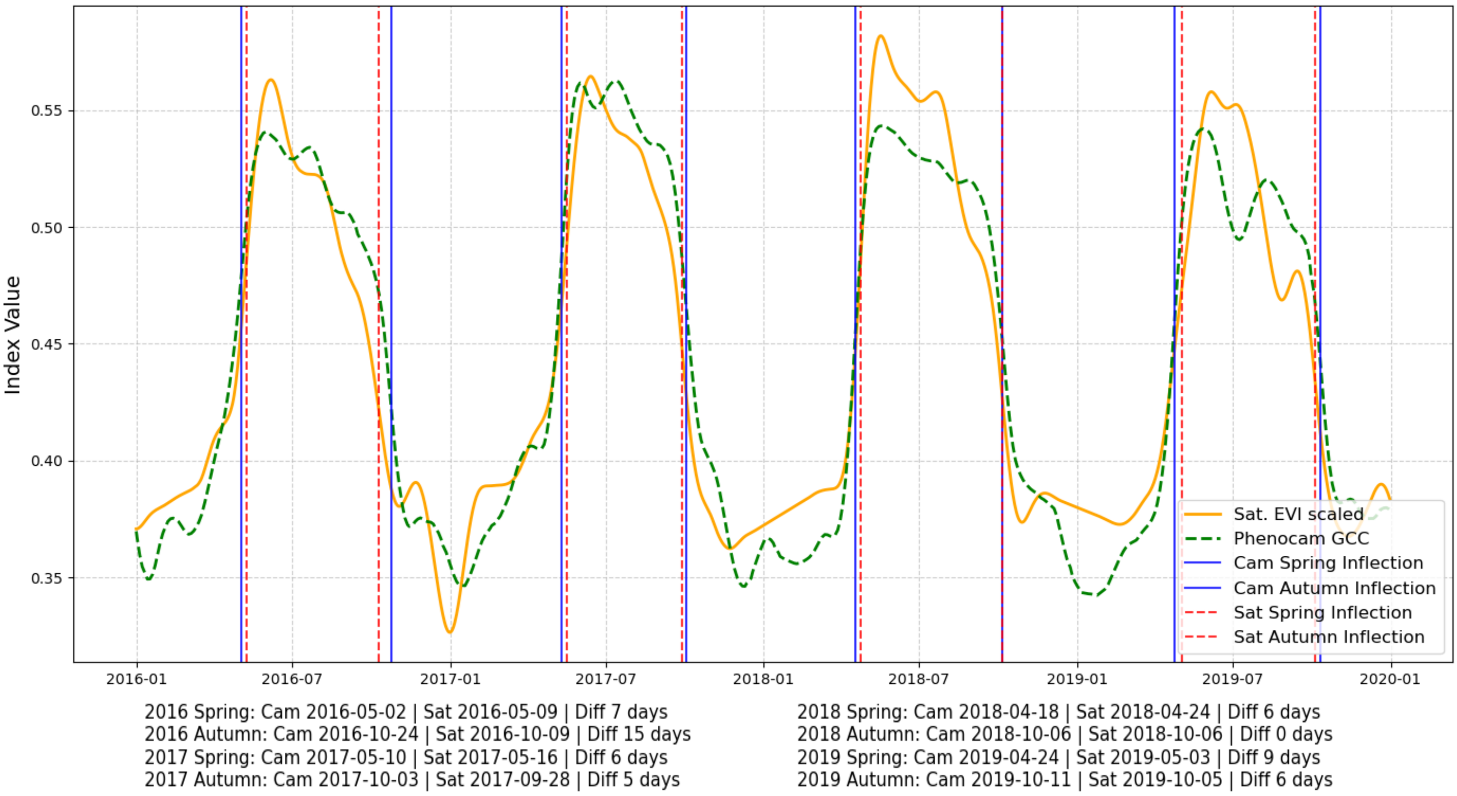

Fig. 1: Comparison of results for spring and autumn inflection timings between one pheno cam and the spatial mean of its collocated satellite pixels. The satellite-obtained EVI time series (orange) was scaled to the same value range as the pheno cam-obtained GCC time series to ease visual comparison. At the bottom, the obtained dates for each year and season are listed for each platform together with the absolute difference in days between the two.

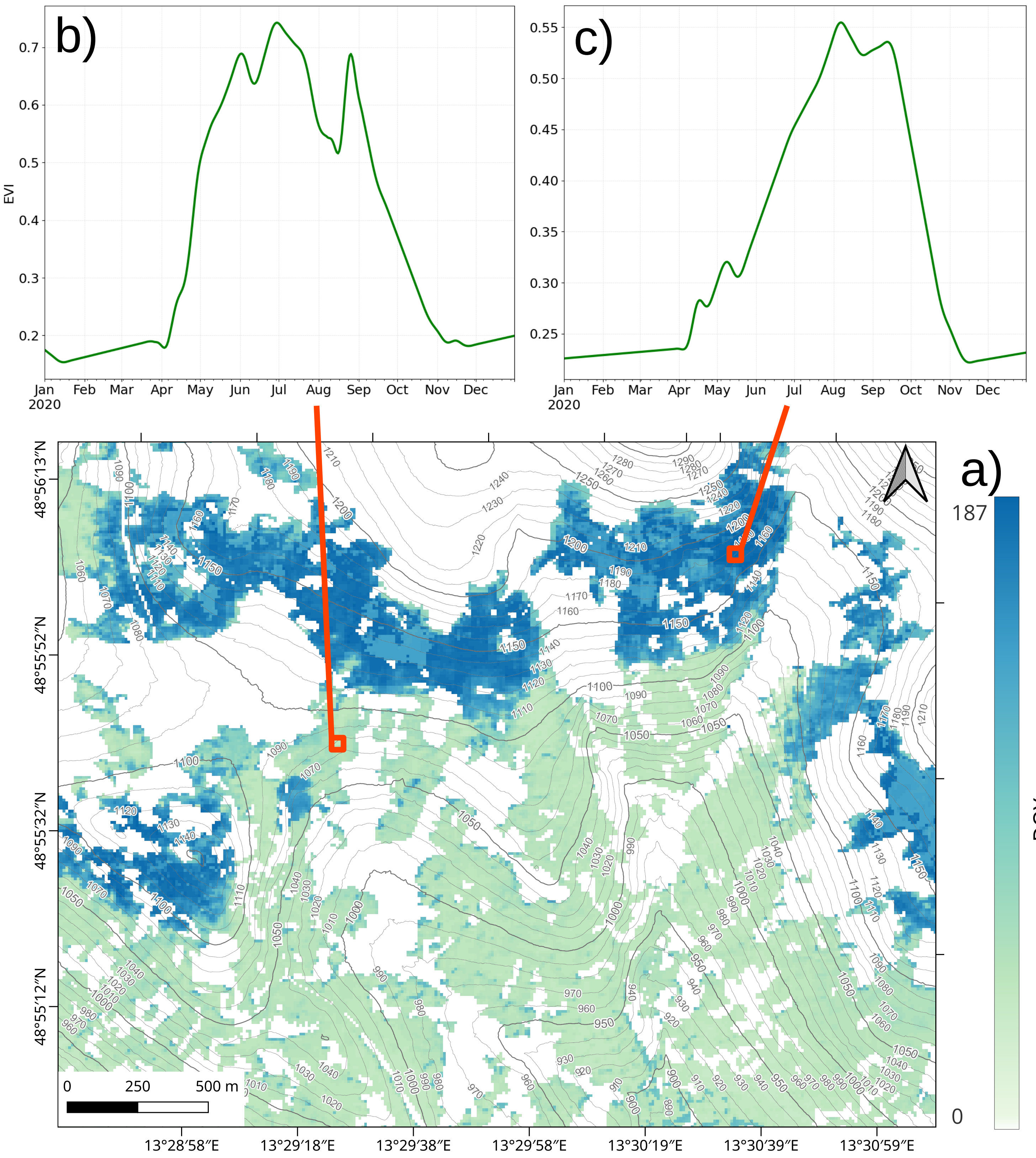

Fig. 2: SIPs of only mature deciduous forest stands in the year 2020 for an example area inside the BFNP. **a)** Calculated day of year (DOY) of the SIP. A clear distinction between clusters of late SIPs in higher elevations and earlier SIPs in lower elevations is visible. The division roughly follows the 1100 m elevation line and is quite abrupt, despite a continuous elevation gradient. The late SIPs in higher altitudes are interpreted as signs of a late frost event in the region in the year 2020. Clusters of affected trees might show delayed phenological development with trees over 1100 m elevation being disproportionately affected. Two representative time series of EVI development are shown. **b)** A pixel with forest unaffected by the late frost event. **c)** A pixel with forest affected by the late frost event. The differing EVI scale between b) and c) should be noted.