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Analysis of forest canopy land surface temperature along the Carpathian Mountains over the last two decades

KEYWORDS: thermal remote sensing, Landsat, forest canopy

Introduction

The application of satellite thermal remote sensing to the analysis of forest canopies can provide valuable insights into forest health and dynamics. By measuring temperature variations within forest canopies, satellite thermal imagery can help identify stressed areas caused by factors such as disease, drought, canopy moisture levels, or pest infestations. Forest canopy temperature is closely correlated with air temperature and follows similar seasonal trends (Guo et al. 2023), thereby complementing forest phenology analysis (Smigaj et al. 2024).

The Carpathian Mountains, spanning Central and Eastern Europe, play a crucial role in maintaining regional biodiversity, regulating climate, and providing ecological services. This study utilizes Landsat satellite (NASA) thermal time-series data to enhance the current analysis of Carpathian forest phenology from the project with observational data, offering reliable information on land surface temperature (LST) trends in the forest canopy.

Methods

The study examined eight forest sites with the area of 25 ha each, distributed along the Carpathian arc to allow for meaningful space-time substitution. These sites, ranging in elevation from 830 to 1038 meters above sea level, predominantly feature beech trees mixed with mature fir and spruce (see Adamič et al. (2023) and Čater et al. (2024)). The sites were listed from south to north, and named as Tismana, Arefu, Zagon, Soveja, Tarcau, Frumosu, Livovská Huta, and Salajka (Fig. 1).

The LST values were derived from thermal bands of Landsat satellites (5, 7, 8, 9) for each forest site, covering the period from 2003 to 2022. The number of LST averages available for each forest site varied monthly and yearly due to the extensive distribution of the sites, the arrangement of the satellite data collected, and cloud cover. LST values were estimated using the statistical mono-window algorithm developed by the Climate Monitoring Satellite Application Facility and the Google Earth Engine (GEE) online platform, which enables the analysis of extensive thermal satellite time series (Ermida et al. 2020).

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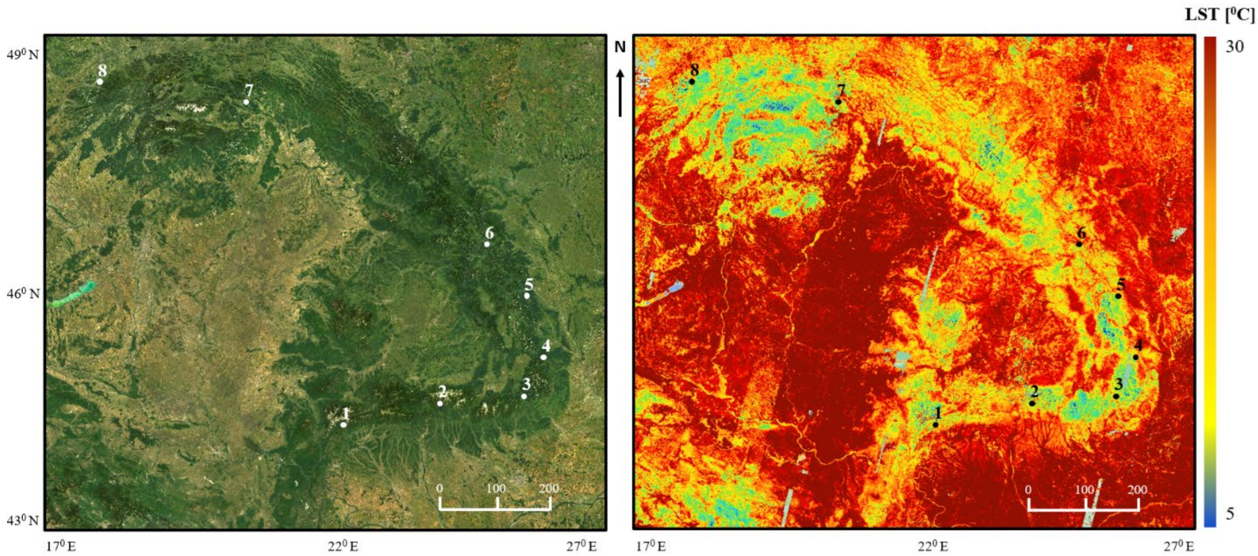

Fig. 1. Carpathian Mountains RGB composite (left), and Land Surface Temperature (LST) map (right) from Landsat 8 data (mosaic of cloudless images from 2021-05-01 to 2021-08-30) The study sites are numbered from south to north: 1 - Tismana, 2 - Arefu, 3 - Zagon, 4 - Soveja, 5 - Tarcau, 6 - Frumosu, 7 - Livovská Huta, and 8 - Salajka.

Results and Conclusions

Mean LST from Landsat time series revealed years with maximum and minimum canopy surface temperature for each study site (Table 1).

Table 1. Mean LST for study sites. Bold values are maximum and minimum mean LST

Mean LST [°C]	Tismana	Arefu	Zagon	Soveja	Tarcau	Frumosu	Livovska Huta	Salajka
2003	**4.1**	7.2	**3.4**	7.5	8.9	3.6	**4.8**	11.9
2004	9.7	11.6	13.3	15.0	12.7	6.6	11.8	13.0
2005	4.2	**6.2**	1.4	8.9	11.3	5.8	12.3	**3.2**
2006	8.0	9.7	9.8	11.9	7.2	5.3	15.3	9.4
2007	11.4	15.0	11.5	11.7	9.5	12.5	15.7	10.9
2008	**12.8**	**15.3**	14.9	14.9	16.3	**13.8**	12.3	12.2
2009	11.0	13.4	12.1	13.3	10.2	9.1	16.0	11.9
2010	9.7	8.6	10.0	12.3	6.2	**2.3**	11.2	11.2
2011	6.1	12.9	11.5	7.9	7.4	9.1	14.9	12.0
2012	12.1	13.3	9.7	11.5	16.3	12.1	12.8	10.1
2013	9.5	15.7	13.5	4.1	9.4	9.2	11.3	13.4
2014	9.7	10.8	7.9	4.0	**4.8**	8.4	9.9	6.2
2015	9.8	11.8	**16.1**	13.5	**16.5**	8.1	**16.1**	10.3
2016	5.6	10.0	12.5	**3.1**	9.9	4.4	13.7	10.7
2017	7.8	12.6	16.0	7.4	13.2	6.8	7.9	9.9
2018	9.2	11.4	13.3	13.7	7.8	8.4	15.8	**13.5**
2019	8.1	11.5	12.8	**15.1**	8.9	8.3	11.8	12.1
2020	9.2	13.9	15.3	10.4	4.6	9.5	12.5	9.9
2021	8.6	13.0	12.2	4.7	6.8	6.5	11.6	3.7
2022	7.7	7.1	5.5	10.2	5.1	4.9	6.6	10.3

The analysis of the forest canopy LST trend (Fig. 2) revealed a statistically significant increasing trend for Zagon and a significant decreasing trend for Soveja ($p < 0.1$). A non-significant increasing trend was observed for Arefu, while no trends could be confirmed for the other sites. Over the past 20 years, the canopy surface temperature in Zagon has increased by 3 °C, whereas it has decreased by 2°C in Soveja. The highest canopy surface temperatures were recorded at Livovská Huta, Arefu, and Zagon, with mean LSTs over the 20-year period being 13.5°C, 11.3°C, and 11.2°C, respectively. The coldest site was Frumosu, with a mean LST of 7.6°C for the same period.

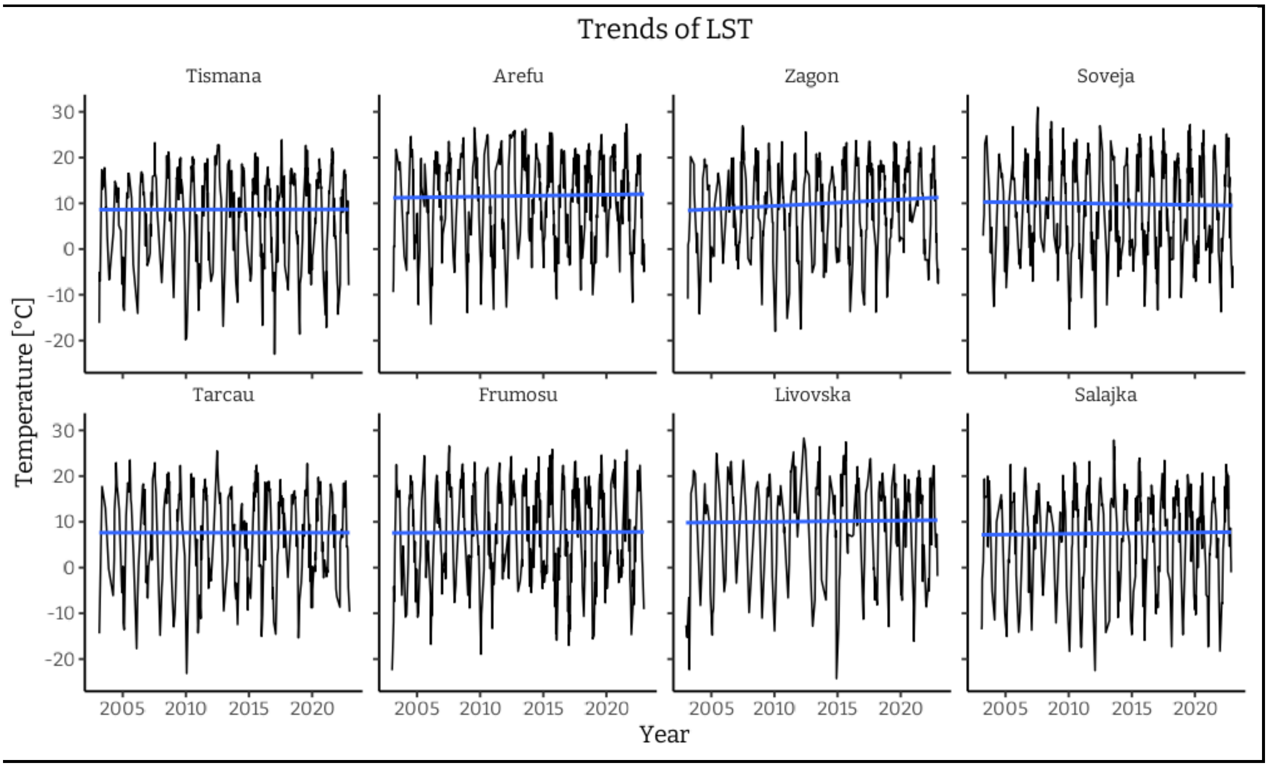

Fig. 2. Canopy land surface temperature (LST) trends for studied sites

Analysing maximum and minimum mean LST for each study site (Table 1) can provide the information about potentially extreme years, such as 2003, 2008 and 2015. Tismana, Zagon and Livovská Huta had a minimum mean LST in 2003. Tismana, Arefu and Frumosu had a maximum mean LST in 2008. Zagon, Tarcau and Livovská Huta had a maximum mean LST in 2015.

The increase in forest canopy surface temperature to 3^0C on Zagon did not lead to an earlier start of the growing season as might be expected, but may have contributed to the longer duration and late end of the growing season on Zagon's during the 20-year period studied. Schieber et al. (2017) reported that the growing season of European beech was extended by more than two weeks over the 21-year period within the increasing mean monthly air temperature.

Although the surface temperature of the forest in Soveja decreased by 2°C, this site had one of the highest surface temperatures, which is consistent with the highest air temperature among the study sites (Table 1). The decreasing trend in canopy surface temperature in Soveja can be attributed to the influence of colder winter months observed in the period from 2010 to 2015 (Figure 2). The lower LST in Soveja may also indicate cooling due to phenological shift. Park & Jeong (2023) demonstrated the sensitivity of LST to advanced phenological SOS (start of season) and delayed EOS (end of season) over northern deciduous forests and explained the cooling effect of the phenological shift by the reduced aerodynamic resistance of trees.

The LST of the canopy can be influenced by the intensity and duration of sunlight (Li et al. 2023), which affects the balance between absorbed and reflected solar radiation as well as ecophysiological processes such as evapotranspiration and shading. This aspect was not considered in our study and is suggested as an additional factor to be investigated in future research on canopy LST and forest phenology in the Carpathians. Using a Digital Elevation Model can be estimated the amount of solar radiation taking into account the slope, aspect, and shadows.

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