How are the satellite-derived and in situ observed phenological phases of beech stands affected by the biometeorological factors?

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Abstract. The response of vegetation to changing environmental conditions is the matter of plant phenology. One way how to study phenological phases from local to global scale is to employ satellite measurement based vegetation indices. We used Normalized Difference Vegetation Index (*NDVI*) derived from spectroradiometer MODIS as an indicator of changing phenological phases. We made *in situ* phenological observations in 13 beech stands (*Fagus sylvatica* L.) to validate satellite-derived phenology. The aim of our study was to evaluate how local meteorological conditions characterized with biometeorological factors (BMF) affect the onset dates of satellite-derived (SAT) and *in situ* observed (VIZ) phenological phases: onset of leaf unfolding (VIZ and SAT), and onset of leaf coloring (VIZ). Correlation analyses revealed statistically significant relationship between all used BMF and onset of leaf unfolding (VIZ and SAT). We also found out significant relationships between onset of leaf coloring VIZ and BMF, except of actual evapotranspiration of period from April to September.

Key words

phenology, leaf unfolding, leaf coloring, biometeorological factors, beech

Introduction

Plants are very sensitive to ambient environmental conditions. They reflect the overall impact of many environmental factors in each moment of their development (Kurpelová 1972). The limiting factor for the beginning of the growing season in temperate conditions is mainly temperature (Menzel 2002). There are several theories about which external factors cause the leaf senescence, e.g. Estrela & Menzel (2006) discovered that higher temperatures in autumn caused delayed onset of autumn phenophases, Priwitzer & Minďáš (1998) found out that cool and wet period with precipitation advanced leaf coloring. Škvarenina et al. (2002) considered climatic water balance as a suitable variable to characterize the climatic conditions of the area. In this study we analyzed, how were the spring and autumn phenophases affected by chosen biometeorological factors.

Material and methods

Phenological phases were observed in 13 stands (Fig. 1) with dominant incidence of beech and minimal incidence of evergreen conifers. Phenological observations were carried out in 8 stands from the year 2000 to 2012 and in 5 stands from 2011 to 2012. The phenological methods according Slovak Hydrometeorological Institute (1984) and Braslavská & Kamenský (1996) were used and unified. We observed one spring phenophase: beginning of leaf unfolding (*LU_10*) and one autumn phenophase: beginning of leaf coloring (*LC_10*).

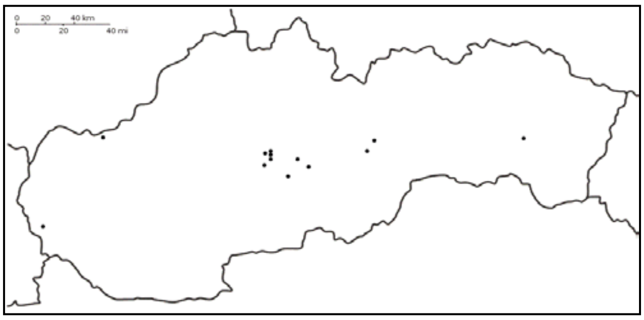

Figure 1. *Spatial distribution of monitored stands in Slovakia*

The biophysical indicator of changing phenological phases was Normalized Difference Vegetation Index (*NDVI*). Seasonal course of *NDVI* was modeled using software Phenological profile (Bucha & Koreň 2009) and here calculated local extremes of sigmoid logistic function identified individual phenological phases. Only the beginning of leaf unfolding could be identified by the local extreme of the phenological function – local extreme of the 1. derivative in the spring period. The beginning of leaf coloring couldn't be identified by any of the local extremes. We analyzed the relationship i) between beginning of leaf unfolding derived from satellite data and visual observation and spring biometeorological factors (Tab. 1), and ii) between visually observed beginning of leaf coloring and autumn biometeorological factors (Tab. 1). Pearson´s coefficient of determination expressed the strength of those relationships.

Table 1. *Biometeorological factors*

Spring biometeorological factors:	
Average air temperature February to April	$AAT_{II–IV}$
Average air temperature March to April	$AAT_{III–IV}$
Average air temperature in February	AAT_{II}
Average air temperature in April	AAT_{IV}
Number of chilling days ($T_{min} < 0$)	n_{CD}
Number of frozen days ($T_{max} < 0$)	n_{FD}
Autumn biometeorological factors:	
Climatic Water Balance April to September	$CWB\text{-}I_{IV–IX}$ [1)]
	$CWB\text{-}T_{IV–IX}$ [2)]
Climatic Water Balance July to September	$CWB\text{-}I_{VII–IX}$ [1)]
	$CWB\text{-}T_{VII–IX}$ [2)]
Actual evapotranspiration April to September	$E_{a,IV–IX}$
Actual evapotranspiration July to September	$E_{a,VII–IX}$
Average air temperature August to September	$AAT_{VIII–IX}$
Average air temperature in September	AAT_{IX}

[1)]potential evapotranspiration calculated according to Ivanov (1954), [2)]potential evapotranspiration calculated according to Tornthweit and Mather (1955)

Results and discussion

Onset of the spring phenological phases depends significantly on the temperature of the month when the phenophase started and on the temperature of previous 2–3 months (Menzel et al. 2006, Piao et al. 2006, Schieber et al. 2009). Phenological sensitivity to temperature strongly differs between species. Beech exhibits low sensitivity to January to May average air temperature –2 days/+1°C (Vitasse et al. 2009). In our study, the satellite-derived and visually observed beginning of leaf unfolding of beech stands depended most significantly on the average temperature of the period from February to April and average temperature of the period from March to April. The average air temperature of these periods increased by 1 °C, resulted in an advance in leaf unfolding of approximately –2,5 days (Tab. 2, Tab. 3). Strong correlation was found also between the February and April average air temperatures and *LU_10*. The increase of average air temperature by 1 °C in February advanced the *LU_10* of approximately –1,5 days, and the same increase in April advanced the *LU_10* of approximately –2 days. The shift to the later beginning of leaf unfolding could be caused by increasing number of frozen and chilling days (Tab. 2, Tab. 3).

Table 2. *Correlation analyses between visually observed beginning of leaf unfolding and biometeorological factors.*

dependent variable	independent variables	n	r^2_{yx}	p	b_1
LU_10_VIZ	$AAT_{II–IV}$	101	**0,69**	**0,00**	**–2,53**
	$AAT_{III–IV}$		**0,61**	**0,00**	**–2,36**
	AAT_{II}		**0,45**	**0,00**	**–1,52**
	AAT_{IV}		**0,54**	**0,00**	**–2,01**
	n_{FD}		**0,46**	**0,00**	**0,16**
	n_{CD}		**0,40**	**0,00**	**0,22**

Table 3. *Correlation analyses between satellite-derived beginning of leaf unfolding and biometeorological factors.*

dependent variable	independent variables	n	r^2_{yx}	p	b_1
LU_10_SAT	$AAT_{II–IV}$	101	**0,69**	**0,00**	**–2,52**
	$AAT_{III–IV}$		**0,64**	**0,00**	**–2,38**
	AAT_{II}		**0,40**	**0,00**	**–1,45**
	AAT_{IV}		**0,59**	**0,00**	**–2,05**
	n_{FD}		**0,56**	**0,00**	**0,17**
	n_{CD}		**0,36**	**0,00**	**0,20**

Table 4. *Correlation analyses between visually observed beginning of leaf coloring and biometeorological factors.*

dependent variable	independent variables	n	r^2_{yx}	p	b_1
LC_10_VIZ	$CWB\text{-}I_{IV–IX}$	111	**0,05**	**0,02**	**–0,01**
	$CWB\text{-}T_{IV–IX}$		**0,08**	**0,00**	**–0,02**
	$E_{a,\ IV–IX}$		0,00	0,98	0,00
	$CWB\text{-}I_{VII–IX}$		**0,09**	**0,00**	**–0,02**
	$CWB\text{-}T_{VII–IX}$		**0,11**	**0,00**	**–0,03**
	$E_{a,\ VII–IX}$		**0,04**	**0,03**	**–0,03**
	$AAT_{VIII–IX}$		**0,22**	**0,00**	**2,37**
	AAT_{IX}		**0,24**	**0,00**	**2,12**

Timing of the onset of autumn phenophases is affected by temperature. Estrela & Menzel (2006) reported a statistically significant correlation (r = 0,56) between the air temperature in September and leaf coloring, with later coloring at higher September temperatures. In our study, the average air temperature of September increased by 1 °C, resulted in delay in leaf coloring of approximately 2 days. The increase of average air temperature in August to September by 1 °C delayed the *LC_10* of approximately 2,5 days (Tab. 4). Similarly Vitasse et al. (2009) considered the average temperature in August to November as the main factor affecting the general yellowing of beech leaves in France. An appropriate indicator of the amount of available water in the soil is climatic water balance (CWB) (Eimern & Hacks ex Škvarenina et al. 2002). We found out statistically significant, but only weak correlation between *CWB* in April to September and *CWB* in July to September and visually monitored *LC_10* (Tab. 4). *LC_10* significantly correlated also with actual evapotranspiration in July to September, in terms of the higher *CWB* or E_a, the earlier beginning of leaf coloring.

Conclusions

Knowledge about the response of European beech, as a valuable tree species in forest management, to the meteorological factors could help in considering the possible effects of global climate change. We found out the sensitivity of European beech onset of phenophases to the temperature and amount of available water. The change in these meteorological variables may affect the competitive abilities and therefore the distribution range of European beech. Analyzing the temporal trend in biometeorological factors and onset of phenophases will be the next step of the work.

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