MONITORING OF WATER USE, DROUGHT AND YIELD IMPACTS OF WINTER WHEAT USING IMAGINERY FROM SATELLITES

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Abstract: Remote sensing can be very useful tool for drought monitoring, providing valuable information about yield-limiting moisture conditions and crop response under current climate conditions. In this study the Atmosphere-land Exchange Inverse (ALEXI) model was used. The ALEXI model uses the morning surface temperature (LST) rise and provides information on the surface moisture status. In this paper correlations between yields and satellite indicators of crop water use or evapotranspiration (ET) were studied for the period 2002–2014. Correlations were studied for winter wheat at district scale in Vysočina, Jihomoravský and Olomoucký regions since winter wheat is one of the traditional and most important crops grown in these regions. The Evaporative Stress Index (ESI) was used for these correlations as an ET-based index. Time series of Pearson correlation coefficient (r) computed between ESI and winter wheat yields at district scale were analysed. Strongest correlations are associated with districts within the Southern Moravian lowlands in Jihomoravský and Olomoucký region, where frequency of occurrence of severe drought was highest over the period of record. Severe drought resulted in significant yield impacts, particularly in years 2003 and 2012. Correlations tend to be lower over the highlands districts of Vysočina and surroundings. In these districts, yields are more temperature than moisture limited and were more stable over the period of record.

Key Words: Remote sensing, drought, yield, ALEXI, ESI

INTRODUCTION

Drought events in recent years have significantly impacted crop yields and water availability in the certain regions of the Czech Republic. One of the most vulnerable regions is the south-east part of the country – Southern Moravia (mostly the Jihomoravský region) which is important agriculture region, known also for its production of wine. Remote sensing can be very useful tool in the area of drought monitoring, providing valuable spatiotemporal information about yield-limiting moisture conditions and crop response under current climate conditions (Anderson et al. 2015).

Satellite data can provide excellent spatial detail, but no single satellite provides all the information required to adequately support all agricultural applications. Different wavebands provide information about different characteristics of crop development. Visible (shortwave) reflectance data can be used to estimate amount of vegetation. They are typically used at resolutions of 5 to 300 m. Thermal infrared radiation (TIR) can be used to map land-surface temperature (LST) which can be related to patterns in canopy stress and water use at resolutions of 60 m to 5 km. Microwaves enables mapping of soil moisture and surface temperature at coarser spatial scales that are smaller than 5 km. It is good to mention that thermal and shortwave retrievals are restricted to clear sky conditions, while collecting of coarser resolution microwave can be done under nearly all sky conditions (Gao et al. 2012).

There is clearly a benefit to integrate information from multiple satellites. This paper describes a strategy for uniting multi-satellite remotely sensed data at multiple wavelengths to support water use, drought monitoring and yield analysis. Examples of results at coarse resolution (5 km) are provided for districts in the Vysočina, Jihomoravský and Olomoucký regions. All together, there were 14 districts studied in these 3 regions. Studied districts can be divided into lowlands and highlands showing the different moisture and temperature distribution and drought vulnerability. One of the most vulnerable districts towards the drought events is the Znojmo district in the Jihomoravský region (Zahradníček et al. 2014). Generally, districts in the Vysočina region have good moisture distribution and therefore are not as vulnerable as districts in the Southern Moravia.

The long-term goal of this work is to identify remote sensing ET, drought and yield monitoring tools that can be used at multiple spatial scales not only in the certain regions of ČR but over the whole country and surroundings. Remote sensing outputs should complement the existing tools created by the InterDrought team.

MATERIAL AND METHODS

Due to the influence of evaporation on land surface temperature, thermal remotely sensed data can provide useful information about the surface moisture conditions. The Atmosphere-land Exchange Inverse (ALEXI) model was used to provide data related to the surface moisture status (Anderson et al. 2007). It uses time-differential signals of morning land-surface temperature (LST) rise, typically collected by geostationary satellites in order to map daily ET and other surface fluxes at 3 to 10 km resolution (Anderson et al. 2015). The ALEXI model is constrained to work under clear sky conditions when the surface is visible to the satellite sensor. An algorithm for estimating fluxes during cloudy days is used, defining moisture stress function which is obtained from the model on clear sky days. During the clear days, model estimates available water fraction in the soil surface layer and root zone (Anderson et al. 2007).

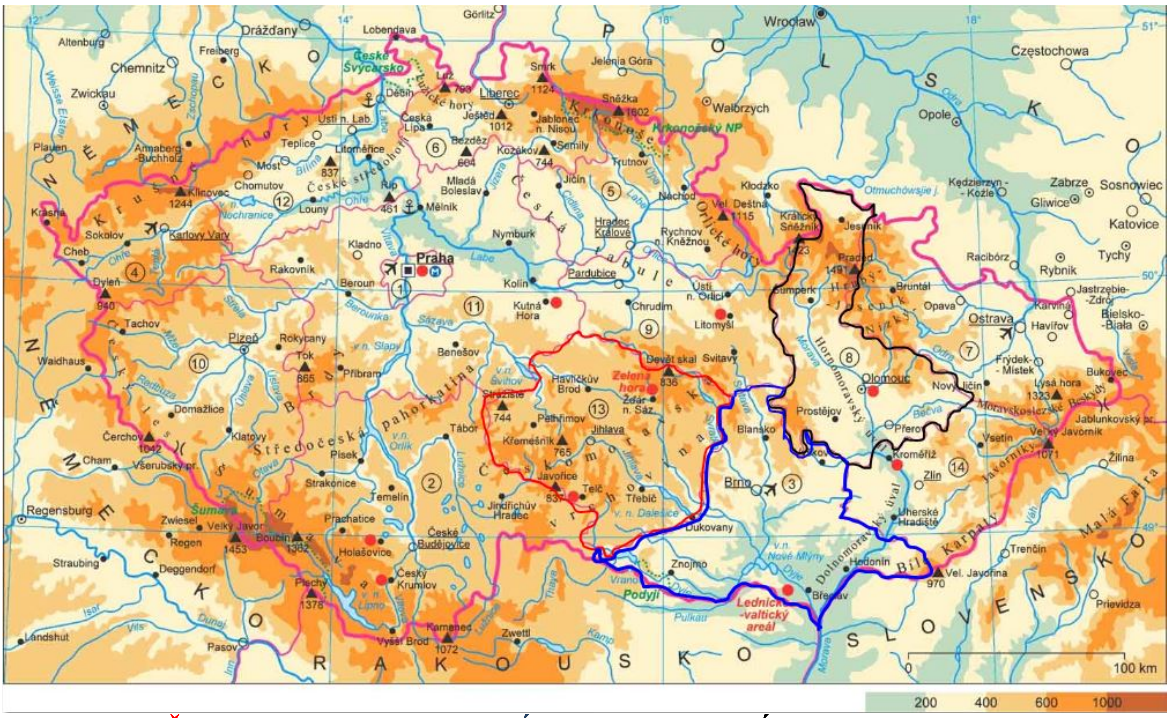
Table 1 Full names, abbreviations and region localisation of studied districts of the Czech Republic

Region of ČR	**District**	**Abbreviation**
Vysočina	Havlíčků Brod	HR
	Jihlava	JI
	Pelhřimov	PE
	Třebíč	TR
	Žďár nad Sázavou	ZR
Jihomoravský	Blansko	BK
	Brno-venkov	BI
	Břeclav	BV
	Hodonín	HO
	Vyškov	VY
	Znojmo	ZN
Olomoucký	Olomouc	OL
	Prostějov	PV
	Přerov	PR

In this paper correlations between yields and satellite indicators of crop water use or evapotranspiration (ET, as conveyed by the Evaporative Stress Index – ESI) were studied for the period 2002–2014. Correlations were studied for winter wheat at district scale in the Vysočina, Jihomoravský and Olomoucký regions. The Table 1 shows all studied districts, their abbreviations and region localisation. Figure 1 shows a map with 3 studied regions of the Czech Republic.

The ESI is formulated as standardized anomaly in ET normalized by a potential or reference ET (ET_{ref}) expected under non moisture-limiting conditions ($f_{RET} = ET/ET_{ref}$) (Anderson et al. 2007, 2011, 2013, 2015). Different indicators provide information on different aspects of environment. Precipitation-based drought indicators provide information on variability in moisture supply and soil moisture-based indicators on moisture storage. The ESI is one of ET-based drought indicators that over full vegetation cover sample primarily anomalies in plant water use. These anomalies are more tightly related to plant health and functioning. Response assessments during periods of rapid drought onset (so called "flash drought") suggest that TIR-based ESI responded more quickly to changing conditions than did precipitation or vegetation index-based drought indicators and may provide early warning of degrading health (Anderson et al. 2013, Otkin et al. 2013, 2014).

Figure 1 A map showing 3 studied regions of the Czech Republic



VYSOČINA JIHOMORAVSKÝ OLOMOUCKÝ

ALEXI model application over the Czech Republic

This study is a result of collaboration of teams from Mendel University in Brno, the Czech Globe InterDrought project (Intersucho in the Czech language), USDA – Agriculture Research Service and University of Maryland. Together, a preliminary investigation of the utility of ESI for drought monitoring and yield assessment within the Czech Republic has been conducted. In this prototype application, ESI time series computed from 3-month composites of ALEXI-derived f_{RET} were extracted at 7-day intervals from a global dataset. During this process, morning LST rise inferred from Moderate Resolution Imaging Spectroradiometer (MODIS) day/night temperature differences were used (Anderson et al. 2015).

Index-yield correlations were quantified by use of the Pearson correlation coefficient (r). Coefficient was computed from ny x ns samples, where ny represents number of years of yield data included in the study (2002–2014), ns is the number of districts included in regional evaluation. It is also important to mention that yields were reported as ratio of production (tons) per harvested area (ha). Yield dataset over the period 2002–2014 was provided mainly by Ministry of Agriculture of the Czech Republic and partly by the Czech Agrarian Chamber. Yield dataset was collected for 14 districts in the regions of Vysočina, Jihomoravský and Olomoucký which are located in the south-central Moravia (eastern part of the Czech Republic). Especially southern part of Jihomoravský region (the Znojmo district) is known for its sensitivity for severe drought events (Zahradníček et al. 2014).

RESULTS AND DISCUSSION

Results are shown in following figures. Figure 2 compares maps based on ESI in April and September of 2014 with drought maps of Drought Intensity (DI) from InterDrought website (intersucho.cz). Presentations of DI product reflect moisture conditions in the depth from 0 to 1 m of soil profile as estimated with the SoilClim water balance modelling system developed by the Czech Globe team. The SoilClim model is based on the climate conditions between 1961 and 2000 (Hlavinka et al. 2011). Maps of ESI show bigger area, whereas maps from InterDrought website show just the area of the Czech Republic. Even thought there are different drought intensity scales, impacted areas are still clearly visible.

Figure 2 Comparison of Drought Intensity (DI) and Evaporative Stress Index (ESI) maps for April and September of 2014.

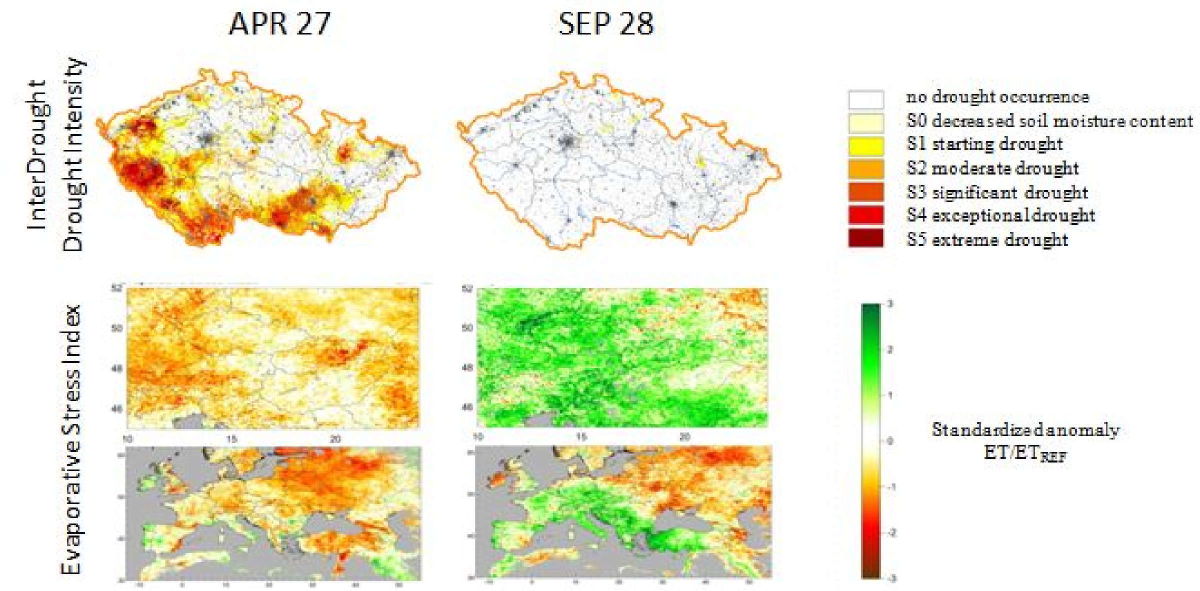


Figure 3 Correlations between Evaporative Stress Index (ESI) and district-level yields for 2002–2014 as a function of date (week of year) of averaging window end-date. Dotted line indicates nominal harvest date for winter wheat.

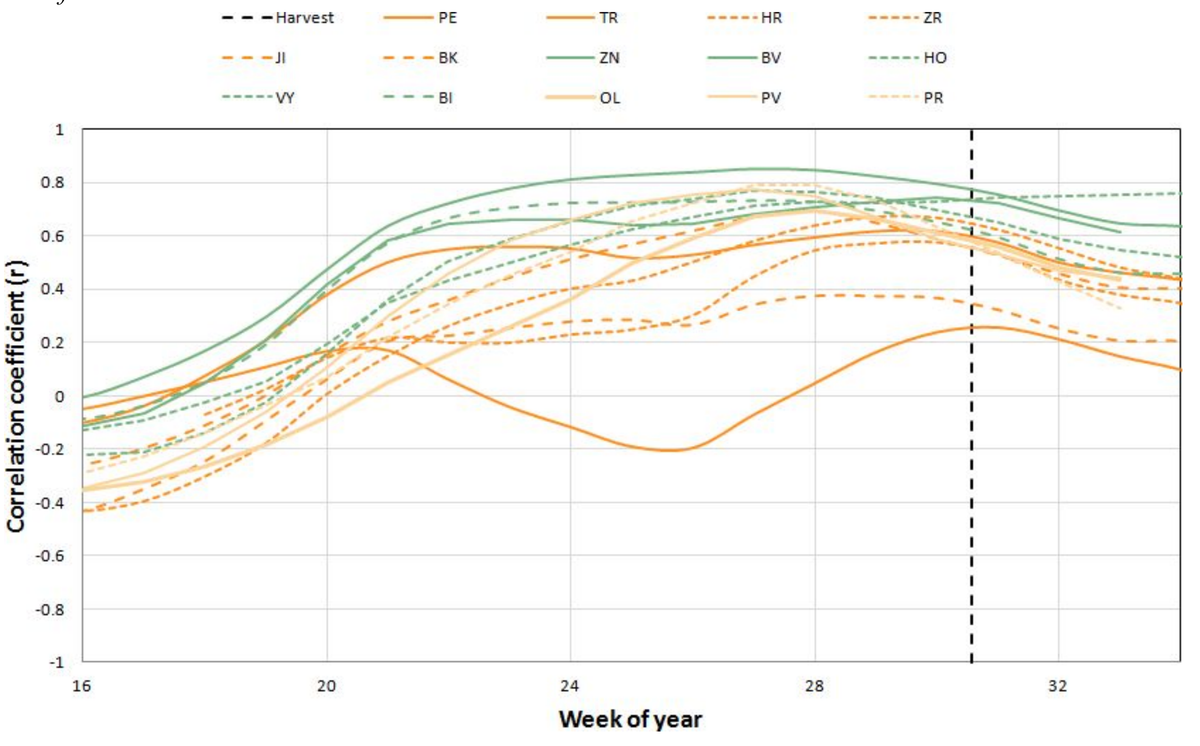


Figure 3 shows time series of Pearson correlation coefficient (r) computed between ESI (sampled at different times during the growing season) and winter wheat yields reported at district scale in the Vysočina, Jihomoravský and Olomoucký regions. Dotted line in the figure indicates nominal harvest date for winter wheat under the conditions of the Czech Republic.

Peak correlations are obtained within the weeks prior to the typical harvest window for winter wheat, indicating some utility for yield forecasting. Strongest correlations are connected with districts within the Southern Moravian lowlands found in Jihomoravský and Olomoucký region, where frequency of occurrence of severe drought was highest over the period of record. Correlations tend to be lower over the highlands districts of Vysočina and surroundings (especially Blansko district). In these districts, yields are more temperature than moisture limited and were more stable over the period of record.

CONCLUSION

Peak correlations behave differently in case of the Southern Moravian lowlands and the highlands districts mostly founded in Vysočina region and surroundings, showing different drought vulnerability. Despite of these results, the study is related only to one crop and 3 regions of the ČR. It is therefore necessary to expand these yield analyses to include additional districts, crops and drought/vegetation indicators. Previous study done by the USDA team in Brazil (Anderson et al. 2015) suggested that the optimal yield indicator, or combination of indicators, may vary with geographic location within the country and with crop type. The insight brought through this kind of spatial analysis can facilitate development of a multi-index yield analysis approach.

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