UTILISATION OF REMOTE SENSING DATA IN AGRICULTURE DROUGHT MONITORING

DANIELA SEMERÁDOVÁ[1,2], MIROSLAV TRNKA[1,2], PETR HLAVINKA[1,2], JAN BALEK[1,2], TSEGAYE TADESSE[3], MICHAEL HAYES[3], BRIAN WARDLOW[4], VOJTÉCH LUKAS[1,2], ZDENĚK ŽALUD[1,2]

[1]Global Change Research Centre AS CR, v. v. i. Bělidla 986/4a, 603 00 Brno, Czech Republic
[2]Department of Agrosystems and Bioclimatology, Faculty of Agronomy, Mendel University in Brno, Zemědělská 1, 613 00 Brno, Czech Republic
[3]National Drought Mitigation Center, SNR, University of Nebraska-Lincoln, 3310 Holdrege Street, Lincoln, NE 68583, USA
[4]Center for Advanced Land Management Information Technologies, SNR, University of Nebraska-Lincoln, 3310 Holdrege Street, Lincoln, NE 68583, USA

Drought preparedness must be an important part of national environmental policies. The monitoring system for covering agricultural drought across the Czech Republic was launched in 2012. It is based on daily step calculations of soil parameters divided into regular grids with the spatial resolution of 500 m. Using freely available data from the MODIS (Moderate Resolution Imaging Spectroradiometer instrument onboard the Terra satellite), the vegetation condition is taken into account as a support tool for vegetation drought impact assessment. Based on the surface reflectance bands the Normalized Difference Vegetation Index (NDVI) is calculated. Consequently, weekly NDVI anomalies are expressed as Percent of Average Actual Greenness (PAAG) in relation to the average for the period of 2000-2014. The system contains filter algorithms that eliminate the noise in the satellite data mainly due to the cloud effects. The following operation allows for changing crop patterns between seasons and aggregates filtered values to the 5 x 5 km resolution with regard to the main land use categories. The results of this study show relationships between the satellite-based vegetation condition and the soil moisture calculation in order to better detect the impacts of drought on vegetation.

Keywords: drought, remote sensing, vegetation indices

INTRODUCTION

As major hydrometeorological extremes, the occurrence of meteorological and agricultural droughts have significant impacts on ecosystem services, especially on those involving plant production, horticulture or forestry (Wilhite et al., 2005). It must be emphasized that drought is a common feature of any climate. However, in the European context, central Europe is not currently thought of as being a particularly drought-prone region, with more of the attention concentrating on the Mediterranean region. In general, both the vegetation and the agricultural systems in central Europe have an advantage by profiting from evenly-distributed precipitation (e.g. Tolazs et al., 2007). Yet, severe droughts can occur in central Europe and cause significant agricultural losses, most recently in 2012 and 2014. With the development of remote sensing technology, there are many studies exploring the capability to assess drought by using remote sensing data and associated vegetation indices. The integrated drought monitoring system for the Czech Republic was launched in 2012. Individual parts of the integrated drought monitoring system have been validated in previous scientific papers. The databases of historical drought occurrences over Czech Republic needed for actual drought intensity assessment were analysed by Trnka et al. (2009a and 2009b) and Brázdil et al. (2008), the soil moisture depicted by the SoilClim model is based on work published by Hlavinka et al. (2011) and satellite measurements related to vegetation were primarily tested by Semerádová et al. (2013). The drought monitoring system is based on daily time step calculations of soil moisture for the entire Czech Republic region divided into regular grids with a spatial resolution of 500 m. The results are published on the weekly operated webpage (www.intersucho.cz). Using freely available data from the MODIS (Moderate Resolution Imaging Spectroradiometer) instrument aboard the Terra satellite, the vegetation status conditions are taken into account as a support tool for vegetation drought impact assessment. The aim of this contribution is to compare drought intensity (based on the drought monitoring system depicted through the soil water content estimates) and vegetation stress appearance within the Czech Republic based on remotely-sensed NDVI (Normalized Difference Vegetation Index) values derived by the MODIS onboard the Terra satellite, which is a multi-national NASA scientific research satellite in a sun-synchronous orbit around the Earth launched in 1999.

MATERIALS AND METHODS

The drought intensity based on soil moisture estimates is available in weekly time steps for the Czech Republic. For this purpose, the SoilClim model (Hlavinka et al., 2011) as a modification of Allen´s et al. (1998) approach is used in daily time steps within 500 x 500 m grids for the whole country (see Fig 1 or www.intersucho.cz). The SoilClim model is introduced as a tool for estimates of reference and actual evapotranspiration, the presence of snow cover, soil temperatures at 0.5 m depths and soil moisture within two defined layers. It enables one to determine the soil moisture and temperature regimes according to USDA (United States Department of Agriculture) soil taxonomy. As a next step, the state of the arable land vegetation based on weekly NDVI anomalies is assessed. The utilization of vegetation indices, such as NDVI, is based on the contrasting characteristics of surface reflectance in the infrared and red spectral bands. Healthy vegetation has a higher absorption than stressed vegetation in the visible (0.4-0.7 microns) range and higher reflectance in the near infrared (0.7-1.1 microns) range of the electromagnetic spectrum. In some cases it is hard to differentiate vegetation anomalies due to drought events from changes caused by other stress factors, such as flooding events or pest and disease outbreaks, or due to later onset of spring start of season without additional information. But drought impacts compared to the lack of nutrients or biotic damages are spatial ones. The NDVI anomaly is expressed as the Percent of Average Actual Greenness (PAAG) in relation to the average for the period from 2000 to 2014 for each 5 x 5 km grid and week.

Originally all values were derived from daily NDVI from MODIS with a resolution of 250 m. Due to the high appearance of noise (e.g. clouds reduction), a newly developed filter was used. Consequently weekly averages for 5 x 5 km grids were integrated for the selected landuse.

RESULTS

Reported drought intensity for the Czech Republic is published in weekly time steps (www.intersucho.cz) with a 500 x 500 m resolution for the entire country (Fig 1) and all 77 Czech districts and approximately 13,000 catasters. The resolution is based on soil moisture estimates within two soil layers, 0-40 cm and 40-100 cm, and the deviation from average results (data from 1961 to 2010 were used) for each grid and date. The current version of the model estimates the value of soil moisture content (Fig 3) for 11 different vegetation types. For this purpose, the dynamic growth and phenological model and the algorithm for snow cover accumulation and melting (Trnka et al., 2010) are also included within SoilClim.

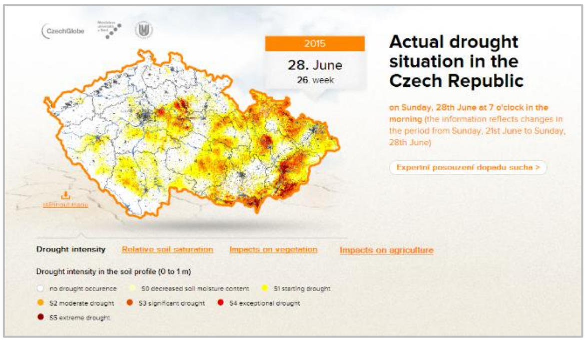

Fig 1: Example of reported drought intensity (June 28, 2015; www. Intersucho.cz)

Reported PAAG values for the arable land vegetation and permanent grasslands are determined in weekly time steps with a resolution of 5 x 5 km. The PAAG is shown for the Czech Republic (Fig 2) for the same time period as the reported drought intensity in Fig 1.

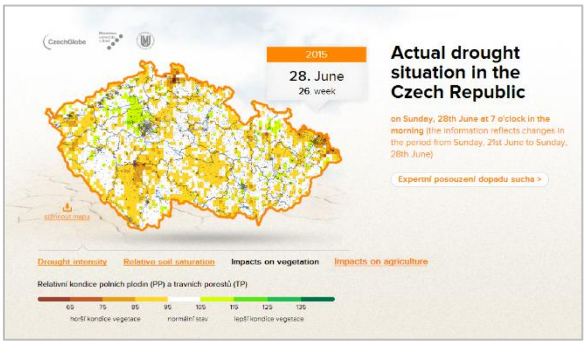

Fig 2: Example of reported Percent of Average Actual Greenness (PAAG) based on NDVI anomaly for vegetation within arable lands and permanent grasslands (June 28, 2015; www. Intersucho.cz)

Often, the main results are expressed in time-lines comparing drought intensity and vegetation conditons (PAAG) for individual weeks in selected years. As shown in Fig 4 for 2012, drought intensity and PAAG dynamics are depicted from Week 1 through Week 52. The more intense conditions are depicted in shades of yellow to red in Fig 4 and the percents of Average Actual Greenness below normal are also depicted in shades of yellow to red in Fig 5. There are clear relationships between both correlated values. This is especially true with the early spring drought experienced mainly in the eastern part of the country (Fig 4a, third line), which had serious impacts on spring crops (e.g. spring barley, maize) as shown in Fig 5a (third line).

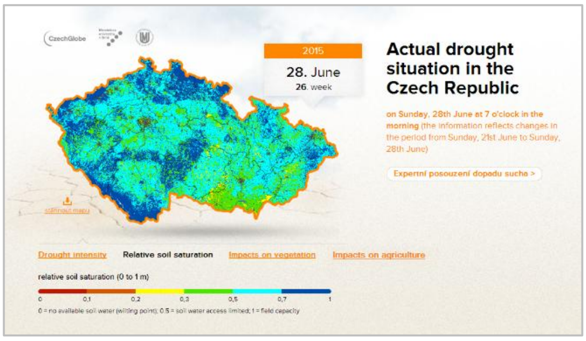

Fig 3: Example of reported available water relative capacity (AWR) based on soil moisture model SoilClim (June 28, 2014; www. Intersucho.cz)

It can also be seen that in some cases, drought episodes depicted in Fig 4 caused the deterioration of the vegetation depicted in Fig 5, while in other cases the drought episodes depicted in Fig 4 did not cause vegetation deterioration. The reasons of these opposite reactions can be explained by phenological shift (especially earlier start of season due to higher temperatures), the onset of maturity and harvest time, when the canopy is removed or precipitation occurence during drought episode and MODIS signal is accordingly changed. This knowledge is supported by relative soil moisture (%) expressed by available water relative capacity (AWR) as shown in Fig 6. E.g. increasing soil moisture between 23-25 weeks improved vegetation condition between 25-26 weeks.

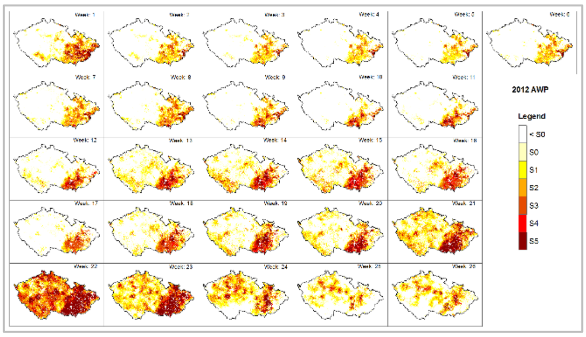

Fig 4a: Drought intensity in 2012, week 1 - 26

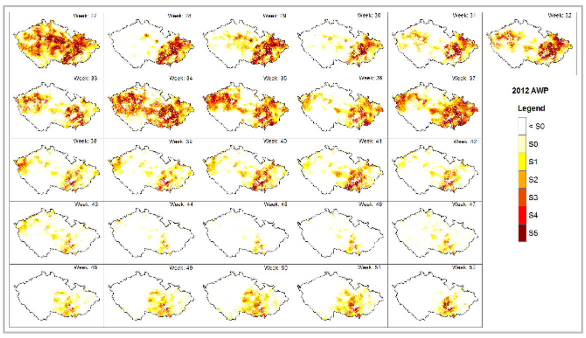

Fig 4b: Drought intensity in 2012, week 27 - 52

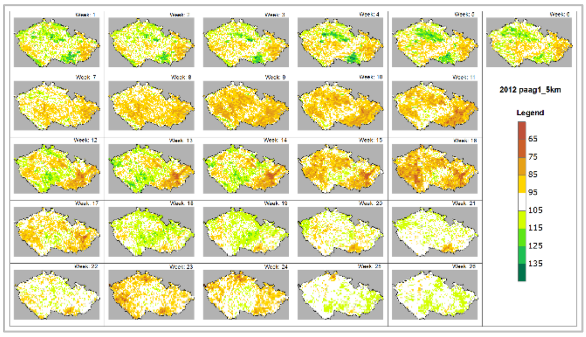

Fig 5a: Percent of Average Actual Greenness (PAAG) in 2012, week 1-26

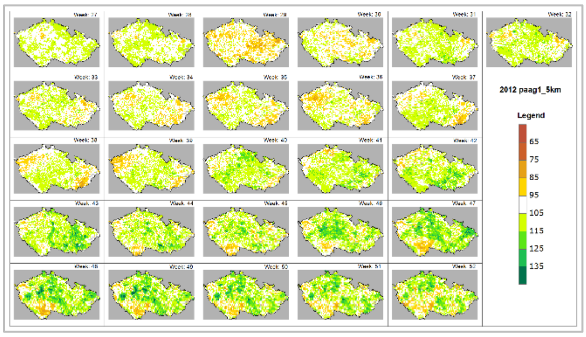

Fig 5b: Percent of Average Actual Greenness (PAAG) in 2012, week 27-52

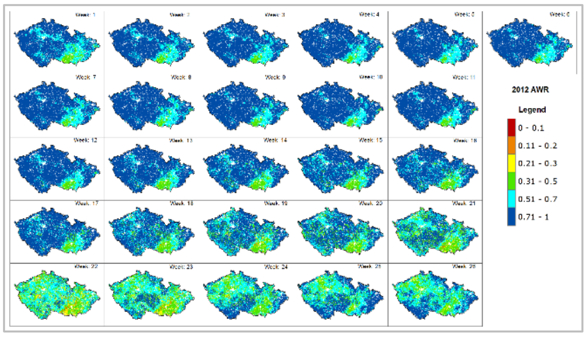

Fig 6a: Percent of Available water relative capacity (AWR) in 2012, week 1-26

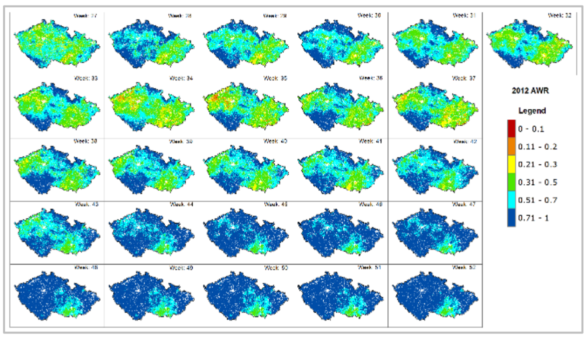

Fig 6b: Percent of Available water relative capacity (AWR) in 2012, week 27-52

CONCLUSION

The weekly operated integrated drought monitoring system offers an assessment of drought intensity for the Czech Republic with a detailed 500 x 500 m resolution for two layers at 0 – 40 cm and 40 – 100 cm depths. However, for agricultural drought impact assessment, in addition to the soil water amount (actual soil moisture), it is also necessary to take into account the complex biomass evaluation including the condition of vegetation. This can be accomplished through remotely-sensed vegetation assessments in form of PAAG (Percent of Average Actual Greenness). The PAAG has proven to be a useful supporting tool for drought impact analysis. The drought response of the vegetation within arable land and permanent grasslands (assessed by remotely-sensed NDVI) is dependent on the time of year and location. Next steps for improving the efficiency of this drought monitoring system will be to incorporate analyses using more advanced statistical approaches (e.g. datamining).

Acknowledgement

This contribution was supported by the COST CZ program of the Ministry of Education, Youth and Sports of the Czech Republic "The possibilities of using remote sensing to determine actual evapotranspiration of selected field crops" project No. LD14121 and the Operational Program of Education for Competitiveness of Ministry of Education, Youth and Sports of the Czech Republic project "Establishment of International Scientific Team Focused on Drought Research" (No. OP VK CZ.1.07/2.3.00/20.0248). This work was supported by the Ministry of Education, Youth and Sports of CR within the National Sustainability Program I (NPU I), grant number LO1415.

LITERATURE

Allen, R.G. Pereira, L.S. Raes, D, Smith M., 1998, Crop evapotranspiration. Guidelines for computingcrop water requirements. FAO Irrigation and Drainage Paper 56

Brázdil, R, Trnka, M, Dobrovolný, P, Chromá, K, Hlavinka, P, Žalud, Z, 2008, Variability of droughts in the Czech Republic, 1881–2006. Theoretical and Applied Climatology 97, 297–315

Hlavinka, P., Trnka, M., Balek, J., Semerádová D., Hayes, M., Svoboda, M., Eitzinger, J., Možný, M., Fischer, M., Hunt, E., Žalud, Z. 2011, Development and evaluation of the SoilClim model for water balance and soil climate estimates. Agriculture and Water Management 98: 1249–1261

Semerádová, D., Trnka, M., Hlavinka, P., Balek, J., Bohovic, R., Tadesse, T., Hayes, M., Wardlow, B., Žalud, Z., 2014, Detection of drought events using combination of satellite data and soil moisture modelling. In Mendel and bioclimatology. Brno: Masaryk University, s. 403-412

Tolasz, R., (ed). 2007, Atlas podnebí Česka: Climate atlas of Czechia. 1. vyd. Praha: Český hydrometeorologický ústav, s. 255

Trnka, M., Dubrovský, M., Svoboda, M., Semerádová, D., Hayes, M., Žalud, Z., Wilhite, D., 2009b, Developing a regional drought climatology for the Czech Republic. Int. J. Climatol. 29, 863–883

Trnka, M., Kocmánková, E., Balek, J., Eitzinger, J., Ruget, F., Formayer, H., Hlavinka, P., Schaumberger, A., Horáková, V., Možný, M., Žalud, Z., 2010, Simple snow cover model for agrometeorological applications. Agricultural and Forest Meteorology 150, 1115–1127

Trnka, M., Kyselý, J., Možný, M., Dubrovský, M., 2009a, Changes in Central–European soil–moisture availability and circulation patterns in 1881–2005. Int. J. Climatol. 29, 655–672

Wilhite, D.A, 2005, Drought and water crisis: Science, technology and management issues. Boca Raton: CRC Press, FL, 431