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Drought identification in the Eastern Baltic region using NDVI

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Abstract. The droughts are the phenomena which affect large areas. Remote sensing data covering large territory can be used to assess the droughts' impact and theirs extent. Drought effect on vegetation was determined using Normalized Difference Vegetation Index (NDVI) in the east Baltic Sea region located between 53–60 N and 20–30 E. The effect of precipitation deficit on vegetation in arable land, broad–leaved and coniferous forest was analysed using the Standardized Precipitation Index (SPI) calculated for 1 to 9 month time scales. The vegetation has strong seasonality in the analysed area. The beginning and the end of vegetation season depends on the distance to the Baltic Sea which affects temperature and precipitation patterns. The vegetation season duration in the south-eastern part of the region is 5–6 weeks longer than in the north-western part. The early spring air temperature, snowmelt water storage in the soil and precipitation has the largest influence on NDVI values in the first half of the growing season. The precipitation deficit in the first part of the vegetation season has a significant impact only on the vegetation in the arable land. The vegetation in the forests is less sensitive to moisture deficit. The positive correlation between 3 and 6 month SPI and vegetation condition was observed in the arable land and both types of forests in the second half of the vegetation season. The precipitation deficit is only one of the vegetation condition drivers and NDVI cannot be used universally to identify droughts, but it may be applied to better assess the effect of droughts on vegetation in the eastern Baltic Sea region.

Keywords: Baltic Sea region, Standardized Precipitation Index, Normalized Difference Vegetation Index, Vegetation Condition Index, drought, land cover

1 Introduction

Vegetation indices derived from the remote sensing data are very important for the accurate assessment of the plant grow conditions, especially in case of extreme weather events, such as droughts. Ground based meteorological and agro–meteorological drought indices only allow to evaluate the risks for agricultural lands, while the satellite information makes possible identification of damaged vegetation in various land types and assess the magnitude of damage.

Remote sensing of the vegetation condition is based on the fact that healthy plants have more chlorophyll and therefore absorbs more visible and reflects more infrared radiation (Myeni et al., 1995). Often vegetation conditions are determined by

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calculation the Normalized Difference Vegetation Index (NDVI). Since 1981 this index is provided on a global scale using Advanced Very High Resolution Radiometer (AVHRR) on–board of NOAA satellites.

The long-term data set is a big advantage, but the problems may arise in interpreting the index changes. During more than 30 years of measurements the land use has been changed in many locations and it is difficult to determine the climatic signal in the NDVI changes. Accuracy of the growing conditions evaluation depends on the assessment of environmental and atmospheric conditions as well as peculiarities of the sensor response (Jackson and Huete, 1991). During the period without precipitation NDVI values can decrease not only due to the deterioration of the plant, but also due to the increase of dust in the air and on the surface of the plant, which is usually "washed out" along with the rain. For this reason, the vegetation index can have lower values than they should (Mirzaei et al., 2010).

It is necessary to emphasize the fact that the vegetation (and hence NDVI values) response to the climatic impacts depends on the geographical region and environmental factors such as vegetation type, soil type and land use (Usman et al., 2013). NDVI is a good indicator of vegetation–soil moisture conditions, but seasonality should be taken into account when using this index for drought monitoring (Ji and Peters, 2003). Therefore, in most cases NDVI values are analysed in complex with ground based meteorological and agro–meteorological drought indicators such as Standardized Precipitation Index (SPI) (Ji and Peters, 2003; Bhuiyan et al., 2006; Quiring and Ganesh, 2010; Gebrehiwot et al., 2011; Gaikwad and Bhosale, 2014; Stagge et al., 2015), Standardized Precipitation–Evapotranspiration Index (SPEI) (Stagge et al., 2015), standardized Water–Level Index (SWI) (Bhuiyan et al., 2006), Palmer Drought Severity Index (PDSI), Moisture Anomaly Index (z–index) (Quiring and Ganesh, 2010). The most commonly the spatial and temporal variability of the drought is associated with precipitation deficit, so SPI index is often used due to its simplicity (Gebrehiwot et al., 2011).

Previous studies have shown that NDVI and SPI values are correlated and this relation is the strongest in the middle of the growing season, and the weakest – at the beginning and at the end (Ji and Peters, 2003). However, not in all cases negative NDVI anomaly can be related with low SPI values (Bhuiyan et al., 2006). The strongest relationship between SPI and NDVI was found in the areas with low soil water–holding capacity (Ji and Peters, 2003). Also, the relationship between these two indices differ in various agricultural areas: a positive correlation between SPI and NDVI was determined in the rain–fed areas, while negative in the irrigated areas (Ozelkan et al., 2016). The SPI indicates moisture conditions and vegetation reacts to the lack of precipitations with some delay. For this reason the strongest link was established between the SPI values in spring and NDVI values in summer, which means that spring watering is critically important for growth of the most plants (Ozelkan et al., 2016).

Frequently NDVI index is analysed by calculating Vegetation Condition Index (VCI), which compares the current NDVI to the observed values of this index in previous years (Gebrehiwot et al., 2011; Ozelkan et al., 2016) and have a good correlation with the SPI values (Dutta et al., 2015). In different regions of the world the relationship between the three (Gebrehiwot et al., 2011), six or nine months SPI (Quiring and Ganesh, 2010) and VCI values were established. Some studies showed that the impact of the short–term precipitation fluctuations on VCI values is weak (Quiring and Ganesh, 2010).

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The NDVI has not been used for the drought analysis in the Baltic Sea region yet. In this region, especially in the southern part, the agriculture is strongly developed, and development of the new methods for evaluation of drought extension and intensity are very important.

The main objectives of this study are to determine the impact of the droughts on the plant growing conditions in the eastern part of the Baltic region, to identify other factors which may lead to negative NDVI anomalies during growing season, and to find links between SPI and NDVI values. Areas of arable land, broad-leaved and coniferous forests were analysed separately and differences of precipitation deficit impact on vegetation in different types of land use was determined.

2 Data and methods

The analysed area covers eastern part of the Baltic Sea region and is located between 53 to 60 N and 20 to 30 E (Fig. 1). The NDVI index was used to analyse the vegetation condition in this area.

The NDVI data set was obtained from NOAA STAR–NESDIS system which generates global and regional vegetation health data. The NDVI index is derived from the radiance observed by the Advanced Very High Resolution Radiometer (AVHRR) on–board of polar orbiting satellites: the NOAA–7, 9, 11, 14, 16, 18 and 19. NDVI is calculated as the difference between reflectance in near infrared (NIR) and visible red (VIS) by following Eq. (1):

$$NDVI = (NIR - VIS)/(NIR + VIS) \quad (1)$$

The NOAA STAR–NESDIS NDVI product has 16 km spatial and 7–day composite temporal resolution and covers period from 1981 to the present. NDVI data set is generated using maximum–value composite (MVC) method (Holben, 1986). This method reduces the influence on NDVI from clouds, spectral properties, resolution, and residual atmospheric effects that all act to reduce NDVI (Scheftic et al., 2014). NOAA STAR–NESDIS system produces no noise NDVI. The NDVI is filtered in order to eliminate the high frequency noise. It is also adjusted for a non–uniformity of the land surface due to the climate and ecosystem differences using multi–year NDVI and brightness temperature data. Final NDVI product is provided in the geographic grid with equal latitude and longitude interval (0,144°×0,144°) (NOAA NESDIS, 2013). The data set has a several gaps: from 50 week of 1984 to 8 week of 1985; from 37 week of 1994 to 3 week of 1995; from 2 to 4 week, from 11 to 24 week and 29 week of 2004.

The NDVI values range from -1 to +1. Negative index value can be recorded over water bodies while values are close to 0 over the land without vegetation. The index value equal to 1 indicates perfect growing conditions (Lillesand and Kiefer, 1994; Belal et al., 2014).

The total number of analysed cells is equal to 2184. 31 cells in the coastal areas or near the big lakes were unequally recognized as a land or sea cells by different satellites, and in some cases the information was missing. In such cases data derived from particular cells were excluded from further analysis. Also 99 cells near the sea coast and probably partly covered by the sea, had negative NDVI values during the growing season and thus were excluded from analysis. In total 6 % of initial data set was not used in the study.

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The NDVI values are influenced not only by the natural variation and health of vegetation. In long–term data sets, variability related to the satellite orbital drift, sensor degradation, and satellite change are also determined (Kogan, 1997). Initial trend observed in this research was mostly related with satellite change and this trend was removed by applying systematic correction for each satellite data separately.

Active plant vegetation in the eastern Baltic region starts when the mean average daily air temperature exceeds 10 °C. In majority of years it happens at the first half of May. End of growing season usually occurs at the second half of September. Since the drought makes the greatest impact on the plants during the growing season data from 18–39 weeks of the year (May–September) were analysed. Not only absolute NDVI values were evaluated, but also their deviations from the mean. For this reason Vegetation Condition Index (VCI) (Kogan, 1995) was calculated. VCI compares the current NDVI with measured historical NDVI values. It is defined as following Eq. (2):

$$VCI = \frac{NDVI - NDVI_{min}}{NDVI_{max} - NDVI_{min}} \times 100 \qquad (2)$$

where NDVI – measured monthly (weekly) value, $NDVI_{min}$ and $NDVI_{max}$ – historical minimum and maximum values of analysed month (week).

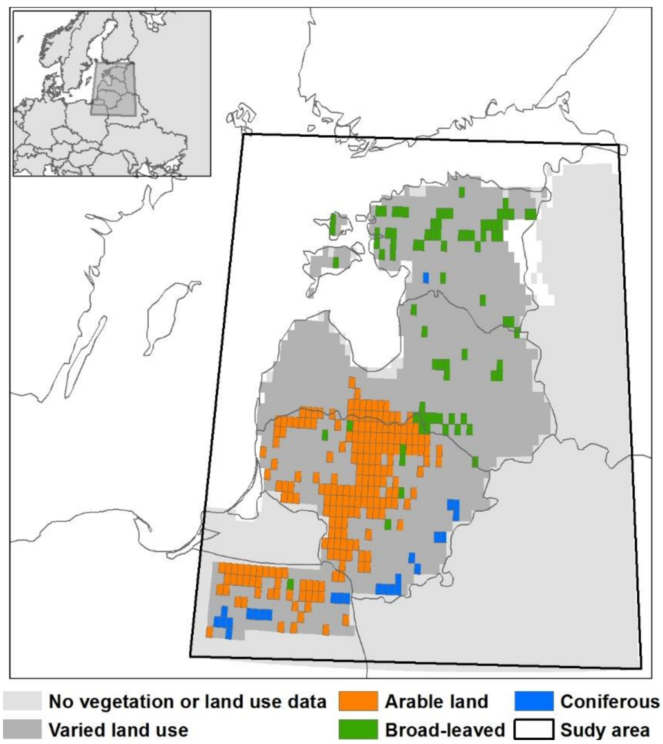

Figure 1: Analysed area in the eastern part of the Baltic Sea region and the dominant land use in cells.

According to Jain et al. (2010), the VCI is a better indicator of the moisture deficit than NDVI because it allows to separate short–term climate signal from the long–term ecological signal. VCI enables to compare simultaneously measured NDVI values not only under the different geographic conditions, but also in the different vegetation types. VCI vary from 0 to 100

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and according to Kogan (2002) low values bellow <40 can be described as mild drought, < 30 as moderate drought, <20 as severe drought and < 10 as extreme drought.

CORINE land cover data was used to identify the dominant land use type in the NDVI cells. Data sets with 100 m resolution were used. The CORINE data sets with reference years 1990 (CLC 1990) and 2012 (CLC 2000) were compared to identify land use changes during the study period. It was considered that land use in particular NDVI cell was stable if CORINE land use classes coincided at least in the 80 % of cell area. From the set of cells with the stable land use the cells with different dominant land use types were identified. The diverse land use is common in analysed region. To reduce the number of CORINE land use classes the mixed forests and transitional woodland–shrub areas were joined with broad–leaved forests and broad–leaved vegetation class was formed. It was considered that the land use class is dominant if it covers at least 50 % of the cell area. Only three types of land uses were identified as dominant in more than 5 cells: arable land (209 cells), broad–leaved (80) and coniferous forest (25 cells) (Fig. 1). These 3 land use types were used in this study to differentiate the effect of climatic conditions on vegetation.

Four cases with strong NDVI anomalies were investigated. Winter 1987 was one of the coldest during the entire study period in the whole eastern Baltic region. Also it was the only year when the average March–April temperature was negative (-1 °C), and it has led to a very late beginning of the vegetation season. In 1990, after one of the warmest winters, particularly high air temperature in March–April was recorded (5.9 °C), and this has led to a very early beginning of vegetation. Years 1992 and 2002 were analysed because the largest negative precipitation anomalies in May–September were recorded, respectively 37 and 43 % below long–term average. During these years the agro–meteorological droughts has been observed in the substantial part of analysed area (Valiukas, 2015).

In order to assess the impact of precipitation deficit on vegetation condition the Standardized Precipitation Index (SPI) was used in this study. The SPI calculation for any location is based on a monthly rainfall data series, first applying gamma distribution and then transforming it into a normal distribution (McKee et al., 1993; Edwards and McKee, 1997). Positive SPI values indicate greater than average precipitation amounts while negative values indicate lower amounts (Table 1).

Table 1: Interpretation of SPI values (McKee et al., 1993).

Value	*Interpretation*
≥2,0	Extremely wet
1,99– 1,5	Very wet
0,99 – -0,99	Near normal
-1 – -1,49	Moderately dry
-1,5 – -1,99	Severely dry
≤-2,0	Extremely dry

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High–resolution (0.5°×0.5° latitude/longitude) monthly precipitation data from CRU TS (*Climate Research Unit Time Series*) data set (Harris et al., 2014) has been used in this study for calculation of SPI vales. The initial analysis indicated that the vegetation conditions are not strongly affected by the moisture deficit calculated for time scales above 9 months. The effect of long term SPI might be weakened by the conditions of the cold season when water supply depends on precipitation type, snow melt and soil condition. The 1–, 3–, 6– and 9–month SPI values (SPI1, SPI3, SPI6) were used in this study to investigate the effect of short and medium term precipitation deficit.

3 Results

3.1 Spatial and temporal variation of NDVI

Vegetation has a very strong seasonality in the eastern Baltic region due to the variation of the day length, insolation and air temperature. During the cold season NDVI values in most of the cells are below 0.1 and begin to increase in the second half of March (week 12–13) (Fig. 2). The NDVI change from March till May follows clear spatial pattern. Firstly the NDVI increases in the southern part of the study area and near the Baltic Sea coast. With time vegetation index increases towards the northeast. At the end of April NDVI exceeds 0.2 in all study area. The maximum NDVI values are reached in June and July (peak of vegetation usually recorded on week 25). Large values (NDVI>0.50) are more common in the northern part of the domain (Fig. 2). NDVI begins to decline in the August. In September NDVI in majority of the study area drops below 0.40. Since the beginning of October (week 41–42) the NDVI values starts to decrease from the north-eastern part of the study area and in the beginning of November (week 44–45) NDVI values remain larger than 0.2 only in the several cells located in the south-western part of the domain (Fig. 2). The length of the period with NDVI higher than 0.2 in the southwestern part of the study area is 5–6 weeks longer than in the north-eastern part.

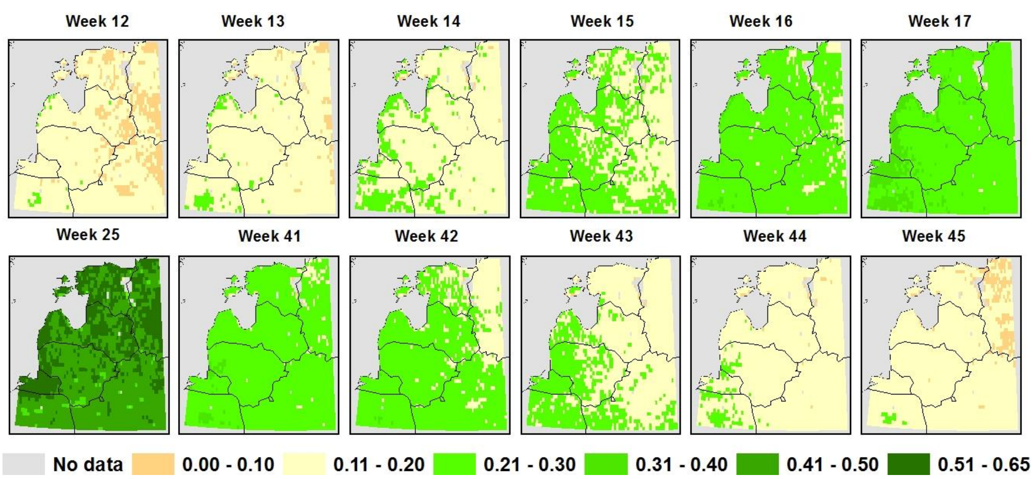

Figure 2: Median of 1982–2014 NDVI in spring (weeks 12–17), autumn (weeks 41–45) and during the vegetation peak (week 25) in the eastern part of the Baltic Sea region.

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There is a clear difference in the seasonal pattern of NDVI in the different land uses (Fig. 3). NDVI in the cells with dominant arable land cover and broad-leaved vegetation is below 0.20 till the middle of April. Later it gradually increases till the first half of June (week 23–24). From the second half of June the NDVI decreases in the cells with both arable land and broad-leaved vegetation. The rate of NDVI decreases in the cells with arable land is much sharper than the one in the cells with broad-leaved vegetation. The difference in the NDVI pattern may be attributed to the difference in vegetation type and land management practices. The annual plants are commonly seeded in the arable land and such type of vegetation has a faster vegetation cycle. On the other hand, the crops in the case study area are harvested in the August and September. NDVI has lower seasonality in the cells dominated by the coniferous vegetation. In this land cover type the NDVI values remain higher than in other vegetation classes during the cold season and are more stable during the warm season, but on average the highest NDVI values do not exceed 0.4 (Fig. 3).

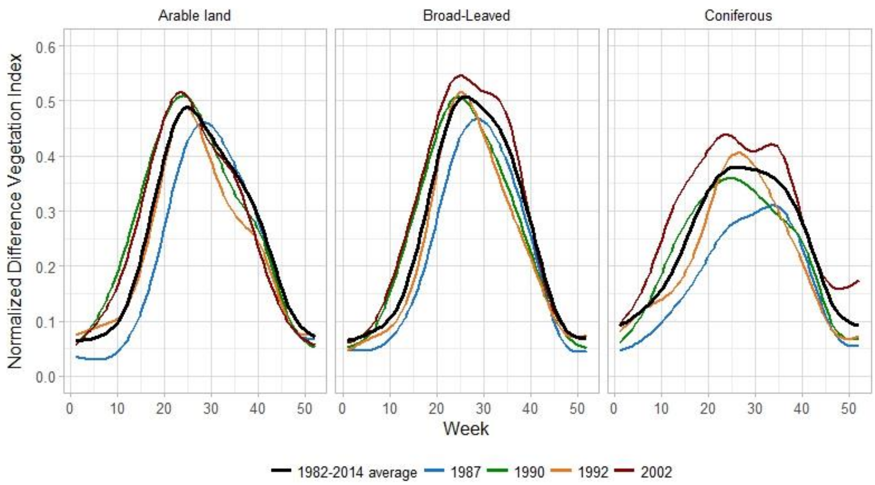

Figure 3: NDVI profile for different land uses of multi–annual average (1982–2014), years with cold (1987), warm (1990) winter and spring seasons, and during the years with precipitation deficit (1992, 2002).

During the particular year the seasonal NDVI pattern may considerably differ from the multi–annual average. In 1990 and 2002 spring was warmer than usual and it's likely led to the higher NDVI values in the first half of the growing season in the cells with all land uses (Fig. 3). The 2002 summer was among the driest during the analysed period, but despite of that the NDVI remained higher than average in the arable land till the August (week 30) and in the cells with broad-leaved and coniferous vegetation the NDVI remained above the average till the end of September (week 40). In 1987 winter and spring were colder than usual. It led to the 2–3 weeks later start of the vegetation season. In all land use classes the NDVI was considerably smaller than average. The late start of vegetation in 1987 also led to the late end (Fig. 3).

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3.2 Vegetation condition during the years with different hydrothermal regime

VCI index is more suitable to illustrate the deviation of vegetation condition from normal. If the VCI is lower than 50 the vegetation conditions are worse than normal. VCI values in May and June following the cold spring (1987) are smaller than 20 in the majority of the study area (Fig. 4). Within a few months the vegetation reaches normal condition again. Warm spring of 1990 led to the better vegetation condition in the May and June. In the large part of the area VCI values were higher than 80. Intensive vegetation in the first part of the year gradually turned into low VCI values on the second half of vegetation season (Fig. 4).

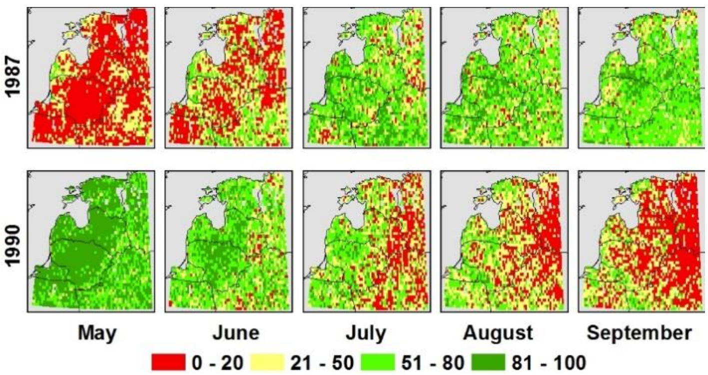

Figure 4: Vegetation condition index (VCI) during the year with cold winter and spring (1987) and warm winter and spring (1990).

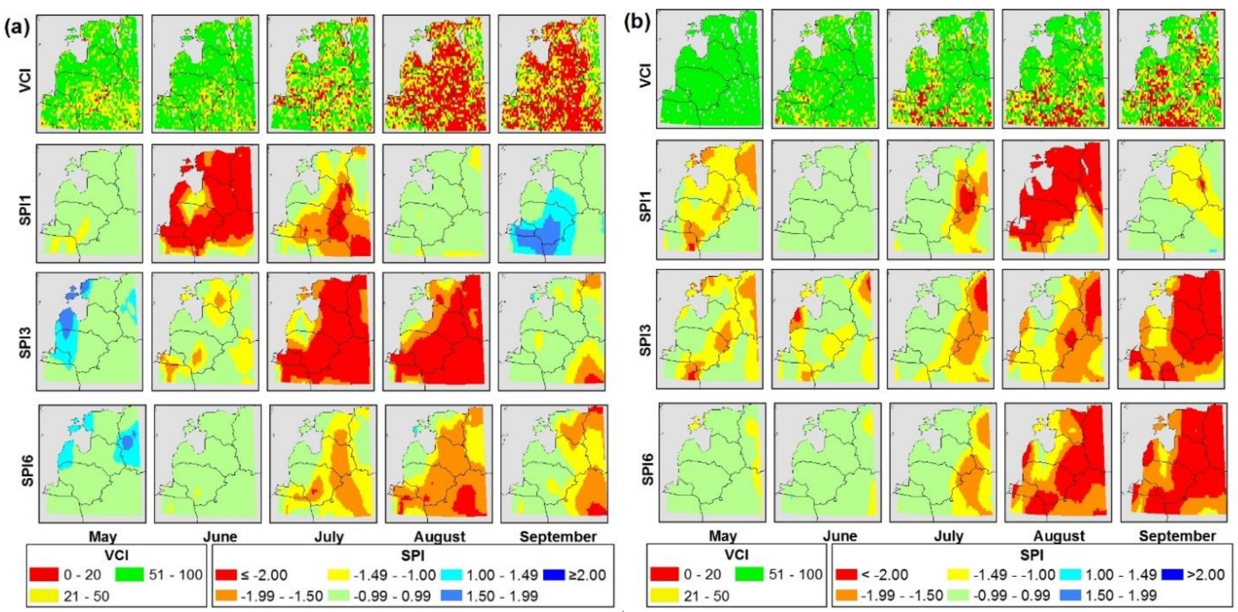

Figure 5: Vegetation condition index (VCI) and standardized precipitation index (SPI) during the dry years of 1992 (a) and 2002 (b).

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It seems that the precipitation deficit might not be the decisive factor determining the vegetation condition in the eastern part of the Baltic Sea region. Years 1992 and 2002 had a lower than normal precipitation amount during the vegetation season, but in 1992 the vegetation was affected much more than in 2002 (Fig. 5). June 1992 was particularly dry. SPI1 representing one month precipitation deviation from the norm was lower than -2.0 in the large part of the study area (Fig. 5a). July was dry only in the south-eastern part of the analysed region. Both SPI3 and SPI6 which represent the dryness for 3 and 6 months respectively were the lowest in July and August. Vegetation condition started to decline in some cells in July but in the majority of the study area the VCI felt below 20 in August and remained similar in September.

The vegetation season of 2002 was also exceptionally dry (Fig. 5b). In July the precipitation deficit was observed in the eastern part of the region, while in August extreme meteorological drought (SPI1≤-2.0) was determined almost in all area except the south-eastern part. The precipitation deficit at the beginning of vegetation season was small but it gradually accumulated with time and in August and September SPI3 and SPI6 indicated severely or extremely dry conditions in the large part of the region. However, vegetation was affected only in the southern part of the region (Fig. 5b).

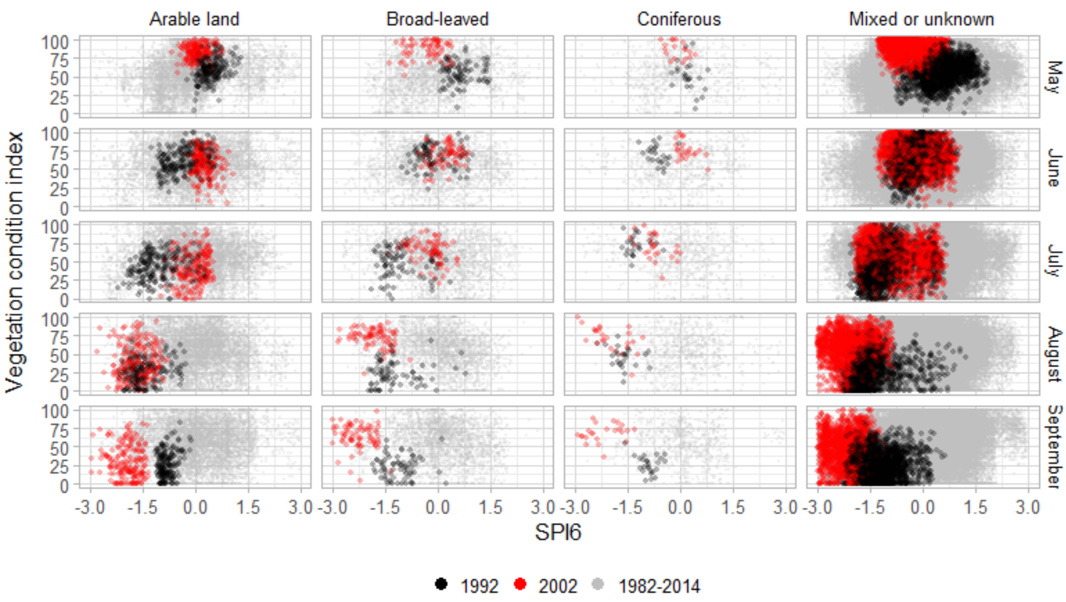

Figure 6: Relationship between SPI6 and VCI for different land use types during the normal (1982–2014) and dry (1992, 2002) years.

The most important distinction between dry 1992 and 2002 years was the reaction of vegetation in different land use classes to the precipitation deficit (Fig. 6). In both cases the vegetation in arable land was in good condition in May. Since June the VCI values in arable land decreased and in August–September there were a lot of cells with VCI<20. In land use classes with broad–leaved and coniferous vegetation the reaction to the precipitation deficit was different during 1992 and 2002, e.g. the

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VCI has decreased more significantly in 1992 than in 2002. On the other hand, one, three and six month SPI values calculated for August and September were lower in 2002 than in 1992.

Pearson correlation coefficient between monthly VCI and SPI was calculated to identify the effect of precipitation deficit on the vegetation in a particular cell. The correlation between VCI and the same month SPI1 is usually negative in the study area (Fig. 7a). The negative correlation coefficient shows that higher SPI or wetter conditions lead to lower VCI values. With longer SPI scale the correlation gradually shifts towards the positive coefficients (Fig. 7a). There is a weak spatial pattern of correlation coefficient distribution. The coefficients in the northern part of the study area tend to be negative while in the southern part correlation in the most cells is positive (Fig. 7a). The correlation is usually positive between the VCI and previous month SPI (Fig. 7b). There is a cluster of cells with statistically positive correlation between VCI in May and SPI in April in the western part of the study area. In August and September statistically significant positive correlation is common in the southern part of the region. The pattern of correlation between SPI and VCI implies the existence of spatial factor affecting the relationship. This pattern of VCI and drought indexes has been observed in other studies as well (Quiring and Ganesh, 2010).

When vegetation is affected by a certain factor its condition may remain distressed for some time. Only the months during which the VCI for the first time dropped below 20 were used to identify how the SPI values are distributed when VCI indicates poor vegetation condition (VCI<20) (Fig. 8). The distributions of SPI values one month before VCI drops below 20 have weak positive skew. Higher density of SPI values indicating severely or extremely dry conditions (SPI≤-1.5) could be expected if the decrease of vegetation condition would be caused mainly by the significant precipitation deficit. In majority of the months and all land use classes the SPI values indicated normal or moderately dry conditions (-1.49<SPI<1.0) before VCI dropped below 20. However according to SPI1 the vegetation condition in June can even worsen after wet May (Fig. 8).

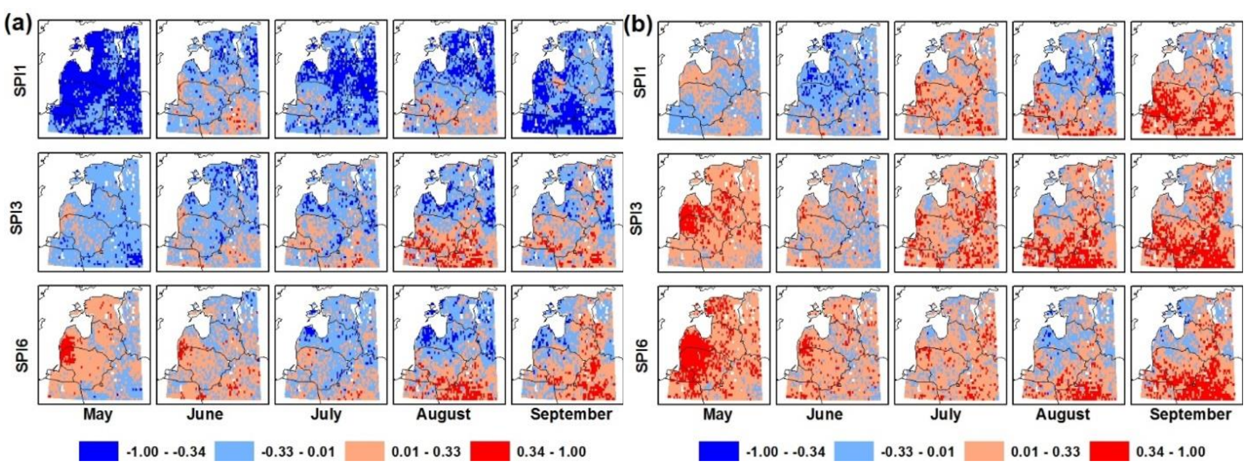

Figure 7: Pearson correlation coefficient between VCI and same month SPI values (a) and between VCI and SPI with one month lead (b). Coefficients large than 0.34 and smaller than -0.34 are statistically significant at 0.95%.

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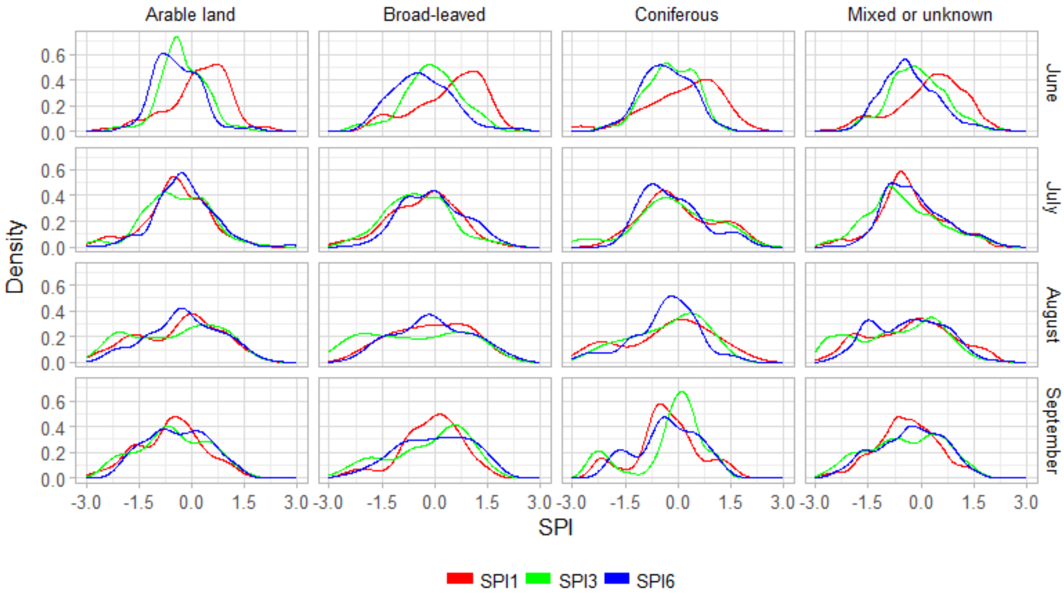

Figure 8: The distribution of SPI values for different land uses one month before VCI drops below 20.

4 Discussion and conclusions

NDVI values in the analysed area are determined by a number of climatic factors. On average growing season in the Baltic States lasts from the end of April till the beginning of October. The spatial pattern of the seasonal NDVI variation is closely related with the distance from the sea, because the Baltic Sea is a major factor, determining temperature and precipitation regime in the analysed area (Jaagus et al., 2010; Jaagus et al., 2014). The differences in NDVI values in spring and autumn in the west–east direction are larger than in the south–north. The south–north NDVI gradient would be more noticeable if the determining factors would be the day length and insolation.

The early spring air temperature, snowmelt water storage in the soil and precipitation has the largest influence on NDVI values in the first half of the growing season. Many studies shows, that beginning of the growing season is determined by the spring temperature prior the event (Jeong et al., 2011; Shen et al., 2014) in the temperate and high latitudes of the Northern hemisphere.

Negative correlation between SPI1 and VCI shows that the short–term precipitation deficit in the first half of the growing season leads to the higher VCI values. In spring the soil is saturated with melting snow water and excess moisture can worsen vegetation condition. Agricultural activity in the arable land usually starts when soil becomes rather dry. For this reason in the case of abnormally wet spring the negative NDVI anomalies can be recorded in May, which may be associated with the crop area and not to the crop conditions (Zhang et al., 2014). On the other hand, in June moisture deficit in the arable soil may lead to vegetation deterioration, while this effect in conifer and broad–leaved forests is almost invisible. Such differences can be explained by the fact that in the arable land mostly annual crops with relatively shallow roots are grown, so the lack of moisture may occur even during the short dry period. The boreal forests of the Northern hemisphere usually grow in the areas of excessive moisture, tree roots are deeper, so they react much slower to the precipitation deficit (such deficit may even lead to a higher VCI values). Also due to the high initial soil moisture the drought impact on forested areas can be minimal (Gao et al., 2016). Only during the prolonged extreme droughts (e.g., 1992), the VCI values in the forests of the study area decreased significantly.

Many studies indicate that VCI reacts with delay to the change of moisture conditions and this reaction is controlled by the previously accumulated soil water storage (Quiring and Ganesh, 2010). Therefore, the strongest connection between SPI and VCI was determined in the areas with low soil water–holding capacity (Ji and Peters, 2003). Other studies also show that forests respond to drought on the long-term scales, while arable land on the short-term scales (Li and Zhou, 2015).

In the second half of the growing season the positive correlation between SPI3, SPI6 and VCI has been determined in the large part of the territory. A positive and in many places statistically significant correlation was found in the first half of the season if SPI with one month lead was used. However, the moisture deficit has a significant impact on vegetation condition only in the second half of the growing season in the analysed part of the Baltic Sea region. Meanwhile, in the drier areas SPI6 and SPI9 has a strong positive correlation with VCI throughout the year (Quiring and Ganesh, 2010).

It should be mentioned that due to the early start of the growing season the peak of vegetation usually is reached earlier, and early vegetation start not always leads to an increase in aboveground production (Livensperger et al., 2016). Therefore the low VCI values in August and September are not always related to the precipitation deficit. However the time when the NDVI values fall close to the typical winter values (43–44 weeks) in arable soils and broad–leaved forests are very similar during the years with different hydrothermal regime (Fig. 3). This is related to the routine agricultural practices in the arable lands (when the land is plowed in autumn) while the fall of tree leaves is associated with the occurrence of the first intense frosts, which are usually in October. Meanwhile, in the coniferous forests the differences of NDVI values that form in the summer months remain until the end of the calendar year (Fig. 3).

In arid and semiarid areas the spatial and temporal patterns of vegetation are primarily related to precipitation (Wang et al., 2001). The analysed region has a surplus precipitation during the most of the years, thus the air temperature anomalies might be the limiting factor for vegetation condition, especially in transitional seasons (spring and autumn). The comparison of 1987 (cold spring) and 1990 (warm spring) also indicates that the interpretation of VCI values as an indicator of drought severity (Kogan, 2002) may not be universal in the eastern part of the Baltic Sea region. Dabrowska–Zielinska et al. (2002) also found that in the nearby Poland the VCI plays the minor role in defining of vegetation condition and crop yield.

It can be concluded that the NDVI can be used for the assessment of drought intensity and the crop damage, but the seasonal timing should be taken into consideration (Ji and Peters, 2003) and it should be used together with other indexes for drought identification.

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References

Belal, A. A., El–Ramady, H. R., Mohamed, E. S. and Saleh, A. M.: Drought risk assessment using remote sensing and GIS techniques, Arabian Journal of Geosciences, 7, 35–53, doi:10.1007/s12517-012-0707-2, 2014.

Bhuiyan, C., Singh, R. P. and Kogan, F. N.: Monitoring drought dynamics in the Aravalli region (India) using different indices based on ground and remote sensing data, Int. J. Appl. Earth Obs. Geoinf., 8, 289–302, doi:10.1016/j.jag.2006.03.002, 2006.

Dabrowska–Zielinska, K., Kogan, F. N., Ciolkosz, A., Gruszczynska, M. and Kowalik, W.: Modelling of crop growth conditions and crop yield in Poland using AVHRR–based indices, Int. J. Remote Sens., 23, 1109–1123, 2002.

Dutta, D., Kundu, A., Patel, N. R., Saha, S. K. and Siddiqui, A. R.: Assessment of agricultural drought in Rajasthan (India) using remote sensing derived Vegetation Condition Index (VCI) and Standardized Precipitation Index (SPI), The Egyptian Journal of Remote Sensing and Space Sciences, 18, 53–63, doi.org/10.1016/j.ejrs.2015.03.006, 2015.

Edwards, D. C. and McKee, T. B.: Characteristics of 20th century drought in the United States at multiple time scales, Atmospheric Science Paper No. 634, Colorado State University, Fort Collins, USA, 1997.

Gaikwad, Y. and Bhosale, R.: Survey On Predictive Analysis Of Drought In India Using AVHRR–NOAA Remote Sensing Data, International Journal of Advance Foundation and Research in Computer (IJAFRC), 1, ISSN 2348 – 4853, 2014.

Gao, Y., Markkanen, T., Thum, T., Aurela, M., Lohila, A., Mammarella, I., Kämäräinen, M., Hagemann, S. and Aalto, T.: Assessing various drought indicators in representing summer drought in boreal forests in Finland, Hydrol. Earth Syst. Sci., 20, 175–191, doi:10.5194/hess-20-175-2016, 2016.

Gebrehiwot, T., van der Veen, A. and Maathuis, B.: Spatial and temporal assessment of drought in the Northern highlands of Ethiopia. Int. J. Appl. Earth Obs. Geoinf., 13, 309–321, doi:10.1016/j.jag.2010.12.002, 2011.

Harris, I., Jones, P. D., Osborn, T. J. and Lister, D. H: Updated high–resolution grids of monthly climatic observations – the CRU TS3.10 Dataset, Int. J. Climatol, 34, 623–642, doi:10.1002/joc.3711, 2014.

Holben, B. N.: Characteristics of maximum–value composite images from temporal AVHRR data, Int. J. Remote. Sens., 7, 1417–1434, doi.org/10.1080/01431168608948945, 1986.

Jaagus, J., Briede, A., Rimkus, E. and Remm, K.: Precipitation pattern in the Baltic countries under the influence of large–scale atmospheric circulation and local landscape factors, Int. J. Climatol., 30, 705–720, doi:10.1002/joc.1929, 2010.

Jaagus, J., Briede, A., Rimkus, E. and Remm, K.: Variability and trends in daily minimum and maximum temperatures and in the diurnal temperature range in Lithuania, Latvia and Estonia in 1951–2010, Theor. Appl. Climatol., 118, 57–68, doi:10.1007/s00704-013-1041-7, 2014.

Jackson, R. D. and Huete, A. R.: Interpreting vegetation indices, Prev. Vet. Med., 11, 185–200, doi:0167-5877/91/$03.50, 1991.

Jain, S. K., Keshri, R. and Goswami, A.: Application of meteorological and vegetation indices for evaluation of drought impact: a case study for Rajasthan, India, Nat. Hazards, 54, 643–656, doi:10.1007/s11069-009-9493-x, 2010.

Earth Syst. Dynam. Discuss., doi:10.5194/esd-2017-5, 2017
Manuscript under review for journal Earth Syst. Dynam.
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Jeong, S.–J., Ho, C.–H., Gim, H.–J. and Brown, M. E.: Phenology shifts at start vs. end of growing season in temperate vegetation over the Northern Hemisphere for the period 1982–2008, Global Change Biol., 17, 2385–2399, doi:10.1111/j.13652486.2011.02397.x, 2011.

Ji, L. and Peters, A. J.: Assessing vegetation response to drought in the northern Great Plains using vegetation and drought indices, Remote Sens. Environ., 87, 85–98, doi:10.1016/S0034-4257(03)00174-3, 2003.

Kogan, F. N.: Application of vegetation index and brightness temperature for drought detection, Adv. Space. Res., 15, 91–100, doi:10.1016/0273-1177(95)00079-T, 1995.

Kogan, F. N.: Global drought watch from space, Bull Am. Meteor. Soc. 78, 621-636, 1997.

Kogan, F. N.: World Droughts in the New Millennium from AVHRR–based Vegetation Health Indices, Eos, Trans. Amer. Geophys. Union., 83, 562–563, 2002.

Li, Z. and Zhou, T.: Responses of vegetation growth to climate change in China, Int Arch Photogram Rem Sens Spatial Inform Sci, XL-7/W3, 225–229, doi:10.5194/isprsarchives-XL-7-W3-225-2015, 2015.

Lillesand, T. M. and Kiefer, R.W.: Remote Sensing and Image Interpretation, 3rd. Ed., John Wiley and Sons, Inc., Toronto, 1994.

Livensperger, C., Steltzer, H., Darrouzet–Nardi, A., Sullivan, P. F., Wallenstein, M. and Weintraub, M. N.: Earlier snowmelt and warming lead to earlier but not necessarily more plant growth, AoB PLANTS, 8, doi: 10.1093/aobpla/plw021, 2016.

McKee, T. B., Doesken, N. J. and Kleist, J.: The relationship of drought frequency and duration to time scales, in: Proceedings of the 8th Conference on Applied Climatology, Am. Meteor. Soc., 17–22 January, Anaheim, USA, 179–184, 1993.

Mirzaei, F. T., Tajamolian, M., Ardakani, A. S. and Azimzadeh H. R.: Study of the Vegetation Effect on Dust Reduction Using Satellite Images, Yazd city, 2010.

Myeni, R. B., Hall, F. G., Sellers, P.J. and Marshak A.L.: The interpretation of spectral vegetation indexes, IEEE Trans. Geosci. Remote Sens., 33, 481–486, 1995.

NOAA NESDIS: AVHRR Vegetation Health Product (AVHRR–VHP) User Guide, available at: http://star.nesdis.noaa.gov/, 2013.

Ozelkan, E., Chen, G. and Ustundag, B. B.: Multiscale object–based drought monitoring and comparison in rainfed and irrigated agriculture from Landsat 8 OLI imagery, Int. J. Appl. Earth Obs. Geoinf., 44, 159–170, doi.org/10.1016/j.jag.2015.08.003, 2016.

Quiring, S. M. and Ganesh, S.: Evaluating the utility of the Vegetation Condition Index (VCI) for monitoring meteorological drought in Texas, Agric. For. Meteorol., 150, 330–339, doi:10.1016/j.agrformet.2009.11.015, 2010.

Scheftic, W., Zeng, X., Broxton, P. and Brunke, M.: Intercomparison of seven NDVI products over the United States and Mexico, Remote Sens., 6, 1057–1084, doi.org/10.3390/rs6021057, 2014.

Shen, M., Tang, Y., Chen, J., Yang, X., Wang, C., Cui, X., Yang, Y., Han, L., Li, L., Du, J., Zhang , G. and Cong, N.: Earlier–Season Vegetation Has Greater Temperature Sensitivity of Spring Phenology in Northern Hemisphere, PLoS ONE 9, e88178, doi:10.1371/journal.pone.0088178, 2014.

© Author(s) 2017. CC-BY 3.0 License.

Stagge, J. H., Kohn, I., Tallaksen, L. M. and Stahl K.: Modeling drought impact occurrence based on meteorological drought indices in Europe, J. Hydrol., 530, 37–50, doi.org/10.1016/j.jhydrol.2015.09.039, 2015.

Usman, U., Yelwa, S. A., Gulumbe, S. U. and Danbaba A.: Modelling Relationship between NDVI and Climatic Variables Using Geographically Weighted Regression, Journal of Mathematical Sciences and Applications, 1, 24–28, doi:10.12691/jmsa-1-2-2, 2013.

Valiukas, D.: Analysis of droughts and dry periods in Lithuania, Summary of Doctoral Dissertation, Vilnius university, Vilnius, Lithuania, 1–49, 2015.

Wang, J., Price, K. P. and Rich, P. M.: Spatial patterns of NDVI in response to precipitation and temperature in the central Great Plains, Int. J. Remote Sens., 22, 3827–3844, 2001.

Zhang, M., Wu, B., Yu, M., Zou, W. and Zheng, Y.: Crop Condition Assessment with Adjusted NDVI Using the Uncropped Arable Land Ratio, Remote Sens., 6, 5774–5794, doi:10.3390/rs6065774, 2014.