Variability of vegetation index NDVI during periods of drought in the Tomsk Region

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Abstract. Current climate changes are characterized by an increase in the frequency of occurrence of extreme natural phenomena, which include droughts and over moistening periods of the territory. The main indicator of drought / over moistening periods is the state of vegetation. Estimation of the interannual and intraseasonal variability of drought can be carried out using vegetation indicators obtained from satellite image data. In article statistical characteristics of NDVI for seven basic types of land cover, identified at the territory of the Tomsk region were studied. NDVI is most stable during the summer in wetlands, changing on average during the study period from 0.58 in May to 0.71 in July, then decreasing to September to 0.64. The variability of NDVI in dark coniferous forests is slightly greater (0.64–0.81). The greatest variability of NDVI was obtained for floodplain meadows (0.46–0.81) and croplands (0.51–0.79). VCI is used to identify drought situations and determine the onset, especially in areas where drought episodes are localized and ill defined. According to the analysis of the VCI index, in May the greatest frequency of dry periods was observed in the Tomsk region. Analysis of changes in frequency of extreme events occurrence have shown that the number of droughts decreases, and number of excessive moisture periods increases since 2000 till 2017.

1. Introduction
The study of the current state of the environment and the forecast changes in the individual components of the landscape is not possible without a detailed analysis of the available information on the hydroclimatic characteristics of the region [1, 2]. The identifying the occurrence of extreme natural phenomena using various quantitative indicators is increasingly interested under the conditions of modern climate change. The most dangerous processes include extreme droughts and periods of excessive moistening. There are a number of hydrothermal indices by which the state of atmospheric, soil, or general drought / excessive moistening is estimated [3-6].

Following publication of the Intergovernmental Panel on Climate Change report on extreme events [1], the issue of quantifying loss and damage from extreme climate events such as droughts has become important for policy implementation, especially with regard to the United Nations Framework Convention on Climate Change agenda. In addition, due to the magnitude of associated disaster losses, improved drought monitoring and management will be fundamental to implementing the Sendai Framework for Disaster Risk Reduction 2015–2030 and the Sustainable Development Goals. Effective and accurate monitoring of hydrometeorological indicators is a key input to risk identification [3].
In the past, decision-makers and scientists employed one indicator or index because that was the only measurement available to them, or they had only limited time in which to acquire data and compute derivative indices or other deliverables. Over the past 20 years or so, there has been strong global interest and growth in the development of new indices based on various indicators that are suitable for different applications and scales, both spatial and temporal. These new tools have given decision-makers and policymakers more choices, but, until recently, they have still lacked a clear-cut method to synthesize results into a simple message that can be relayed to the public. The advent of geographic information systems and increasing computing and display capabilities has increased the capacity to overlay, map and compare various indicators or indices. For a more detailed discussion on mapping drought indices and indicators, see the Handbook of Drought Indicators and Indices [4].

2. Material and methods
Standardized Precipitation Index (SPI) was developed as the result of research in 1992 at Colorado State University, United States, by McKee et al [7]. The basis of the index is that it builds upon the relationships of drought to frequency, duration and timescales. In 2009, WMO recommended SPI as the main meteorological drought index that countries should use to monitor and follow drought conditions [8]. By identifying SPI as an index for broad use, WMO provided direction for countries trying to establish a level of drought early warning [9].

Hydro-thermal Coefficient of Selyaninov (HTC) developed by Selyaninov [10] in the Russian Federation and based on the Russian climate. Uses temperature and precipitation values and is sensitive to dry conditions specific to the climate regime being monitored. It is flexible enough to be used in both monthly and decadal applications. HTC is useful in the monitoring of agricultural drought conditions and has also been used in climate classifications.

Palmer Drought Severity Index (PDSI) was developed in the 1960s as one of the first attempts to identify droughts using more than just precipitation data [11]. Palmer was tasked with developing a method to incorporate temperature and precipitation data with water balance information to identify droughts in crop-producing regions of the United States. For many years, PDSI was the only operational drought index, and it is still very popular around the world. Developed mainly as a way to identify droughts affecting agriculture, it has also been used for identifying and monitoring droughts associated with other types of impacts. With the longevity of PDSI, there are numerous examples of its use over the years.

The modern warming is characterized by an increase in the frequency of extreme natural phenomena. Recent years are characterized by an increase in the frequency of drought and excessive moistening periods over South Siberia [5]. Analysis of Ped’s Aridity Index (PAI), which is a normalized indicator of the ratio of air temperature to precipitation have shown that the in Western Siberia, aridity increases in May and decreases in June, in the other months positive and negative trends are found. The greatest differences between the trends of the aridity index, air temperature, and precipitation are observed in July [4].

Comparison of HTC, PAI, SPI application for drought monitoring sown that distribution of the number of strong and extreme droughts according to SPI and SPEI indices is the same. PAI and HTC indices demonstrated the highest frequency of strong droughts in July and August [6].

Satellite-born indices use state of the ground vegetation as an indication of the drought condition. Normalized Difference Vegetation Index (NDVI) developed from work done by Tarpley et al. and Kogan with the National Oceanic and Atmospheric Administration (NOAA) in the United States. Uses the global vegetation index data, which are produced by mapping daily radiance using various satellites and sensors. Radiance values measured in both the visible and near-infrared channels are used to calculate NDVI. It measures greenness and vigour of vegetation over a seven-day period as a way of reducing cloud contamination and can identify drought-related stress to vegetation. NDVI is an innovative in the use of satellite data to monitor the health of vegetation in relation to drought episodes. It has very high resolution and great spatial coverage.
Estimation of the interannual and intraseasonal variability of drought state was done using vegetation indicators obtained from MODIS satellite image data. We used the normalized difference vegetation index (NDVI) as an indicator of vegetation cover state. The MODIS data (MCD12C1: MODIS / Terra and Aqua Combined Land Cover Type CMG Yearly Global) of the first type (Type 1) from 2000 to 2017 with a spatial resolution of $0.05 \times 0.05^\circ$ [12] were used. Based on an analysis of ground-based observations on a network of FLUXNET stations and satellite data from the MODIS sensor [13], it was shown that the normalized difference vegetation index (NDVI) gives the best results compared to other vegetation indices in estimating the total ecosystem metabolism for different types of vegetation.

3. Results
Estimation of NDVI variability in nature landscapes was carried out taking into account the land cover types, represented by 15 classes [12]. The land cover map is a MODIS product, verified by field observations and expert judgment. We have studied the statistical characteristics of NDVI for seven basic types of land cover, identified at the territory of the Tomsk region. Basic land cover types include Evergreen Needleleaf Forests (1), Deciduous Forest (4), Mixed Forest (5), Floodplain Meadows (9), Grasslands (10), Permanent Wetlands (11), Croplands (12). Figure 1 shows spatial distribution on NDVI in July averaged for 2000-2017. Wetlands and croplands have relatively low values of the index comparing to forest sites.

\[ VCI_i = 100(NDVI_i - NDVI_{min})/(NDVI_{max} - NDVI_{min}), \]

**Figure 1.** Map of July NDVI averaged for 2000-2017.

NDVI is most stable during the summer in wetlands, changing on average during the study period from 0.58 in May to 0.71 in July, then decreasing to September to 0.64. The variability of NDVI in dark coniferous forests is slightly greater (0.64–0.81). The greatest variability of NDVI was obtained for floodplain meadows (0.46–0.81) and croplands (0.51-0.79). In all landscapes, the maximum amplitude of interannual fluctuations is observed in May (from 0.06 in wetlands to 0.39 in deciduous forests).

Vegetation Condition Index (VCI) was developed from work done by Kogan with NOAA in the United States [14]. VCI is used to identify drought situations and determine the onset, especially in areas where drought episodes are localized and ill defined. It focuses on the impact of drought on vegetation and can provide information on the onset, duration and severity of drought by noting vegetation changes and comparing them with historical values.

VCI is determined by the monthly NDVI values. The monthly VCI for the i-th year is calculated as

\[ VCI_i = 100(NDVI_i - NDVI_{min})/(NDVI_{max} - NDVI_{min}), \]
where NDVI<sub>i</sub> is the current monthly value of the i-th year, and NDVI<sub>max</sub> and NDVI<sub>min</sub> are the maximum and minimum values for the study period.

![NDVI diagram](image)

**Figure 2.** Annual course of NDVI for basic land types: 1 – Evergreen Needleleaf Forests, 4 – Deciduous Forest, 5 – Mixed Forest, 9 – Floodplain Meadows, 10 – Grasslands, 11 – Permanent Wetlands, 12 – Croplands.

The maximum characterizes the highest limit of NDVI under favorable weather conditions, and the minimum - the lowest limit under adverse conditions. In this range, variations in monthly NDVI from year to year at a particular location were detected. It is assumed that the anthropogenic component of the NDVI variations is incomparably weaker than the weather inducted. VCI varies from 0 to 100%, reflecting changes in the weather conditions of vegetation from dry to wet, relative to the studied period. With increased moisture in the area with the VCI become above 70%. VCI changes in the range of 30–70% reflect near-normal humidification conditions. A drought-induced state of vegetation is characterized by the VCI lower than 30%. This value can be considered an indicator of agronomic drought, characterizing the effects of atmospheric, soil or general drought. The advantage of this indicator from the indicator of yield decline is that it tracks the dynamics of the state of crops and other vegetation in different phases of their development.

According to the analysis of the VCI index, in May the greatest frequency of dry periods was observed in the Tomsk region. 39 cases of droughts from 129 were registered in May. From 2000 to 2017 VCI <30% for most types of vegetation was recorded in May in 2000, 2006, 2009, 2010, 2012, 2013, in June - in 2001, 2014, in July - in 2012, in August - in 2000, 2012, in September - in 2002, 2003, 2011. Totally, 2000, 2003, 2010, 2012 and 2013 has more than 10 drought events (see table 1) at seven land types.

Excessive moisture periods (with VCI >70%) is typical for the end of the growing season (August, September). VCI >70% for most types of vegetation was recorded in May – in 2003, 2015, in June – in 2003, 2011, 2015, in July – in 2006, 2016, 2017, in August – in 2009, 2013, 2014, 2016, 2017, in September – in 2005-2007, 2013, 2014, 2016. The last third of the study period (2013 – 2017) and 2006, 2008 was extremely wet with high frequency of excessive moisture periods.

2003, 2010 and 2013 years has both droughts and extremely wet periods during the growing season. Analysis of changes in frequency of extreme events occurrence have shown that the number of droughts decreases, and number of excessive moisture periods increases since 2000 till 2017.
Figure 3. Variations of VCI form 2000 to 2017 in May (a), June (b), July (c), August (d) and September (e) for basic land types: 1 – Evergreen Needleleaf Forests, 4 – Deciduous Forest, 5 – Mixed Forest, 9 – Floodplain Meadows, 10 – Grasslands, 11 – Permanent Wetlands, 12 – Croplands.

4. Conclusions
The study of the current state of the environment and the forecast changes in the individual components of the landscape is not possible without a detailed analysis of the available information on the hydroclimatic characteristics of the region. Effective and accurate monitoring of hydrometeorological indicators is a key input to risk identification. There are a number of hydrothermal indices by which the state of atmospheric, soil, or general drought / excessive moistening is estimated (SPI, HTC, PDSI, VCI). We used NDVI from MODIS data as an indicator of vegetation cover state. NDVI gives the best results compared to other vegetation indices in estimating the total ecosystem metabolism for different types of vegetation. We have studied the statistical characteristics of NDVI for seven basic types of land cover, identified at the territory of the Tomsk
region. The greatest variability of NDVI was obtained for floodplain meadows (0.46-0.81) and croplands (0.51-0.79).

Table 1. Number (N) of droughts (VCI < 30%) and periods of excessive moisture (VCI > 70%) for seven basic land types.

|       | N (VCI < 30%) | N (VCI > 70%) |
|-------|---------------|---------------|
|       | V  | VI | VII | VIII | IX | Yr  | V  | VI | VII | VIII | IX | Yr  |
| 2000  | 5  | -  | 3   | 7    | -  | 15  | -  | 1  | -   | -    | -  | 1   |
| 2001  | -  | 5  | 4   | -    | -  | 9   | 3  | -  | -   | -    | 2  | 5   |
| 2002  | -  | -  | -   | 5    | 5  | 2   | 3  | 3  | 1   | -    | 9  |
| 2003  | -  | -  | 2   | 4    | 5  | 11  | 5  | 7  | -   | -    | -  | 12  |
| 2004  | -  | -  | 2   | -    | -  | 2   | 1  | -  | 2   | 2    | -  | 5   |
| 2005  | -  | 1  | -   | -    | -  | 1   | -  | 1  | 3   | 3    | 7  | 14  |
| 2006  | 6  | 3  | -   | -    | -  | 9   | -  | 2  | 5   | 3    | 5  | 15  |
| 2007  | 1  | -  | -   | 2    | -  | 3   | -  | -  | 4   | 3    | 5  | 12  |
| 2008  | -  | -  | -   | -    | -  | 0   | 3  | 5  | 4   | 4    | 1  | 17  |
| 2009  | 5  | 1  | 1   | -    | -  | 7   | -  | 1  | 2   | 5    | 1  | 9   |
| 2010  | 7  | 3  | 3   | -    | -  | 13  | -  | 1  | 3   | 4    | 5  | 13  |
| 2011  | -  | -  | 1   | 1    | 6  | 8   | 4  | 6  | 1   | 1    | -  | 12  |
| 2012  | 5  | 2  | 6   | 5    | 3  | 21  | -  | -  | -   | -    | -  | 0   |
| 2013  | 7  | 3  | 2   | -    | -  | 12  | -  | 1  | 2   | 7    | 7  | 17  |
| 2014  | 2  | 6  | 2   | -    | -  | 1   | -  | -  | 3   | 6    | 6  | 15  |
| 2015  | -  | -  | -   | 2    | -  | 2   | 6  | 6  | 2   | 2    | 4  | 20  |
| 2016  | 1  | -  | -   | -    | -  | 1   | -  | 3  | 7   | 6    | 5  | 21  |
| 2017  | -  | -  | -   | -    | -  | 0   | -  | 1  | 6   | 5    | 4  | 16  |
| **Sum** | **39** | **24** | **26** | **21** | **19** | **129** | **24** | **38** | **47** | **52** | **52** | **213** |

VCI is used to identify drought situations and determine the onset, especially in areas where drought episodes are localized and ill defined. According to the analysis of the VCI index, in May the greatest frequency of dry periods was observed in the Tomsk region. Analysis of changes in frequency of extreme events occurrence have shown that the number of droughts decreases, and number of excessive moisture periods increases since 2000 till 2017. It was found that floodplain meadows and croplands are most sensitive to changing hydrothermal conditions from year to year, which affected the greater interannual VCI variability in these landscapes in all months.

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