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Some meteorological aspects of severe agricultural drought in the Northern Black Sea region in 2019-2020 †

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† Presented at the title, place, and date.

Abstract: An overview of the meteorological and synoptic conditions for the formation severe drought occurred in 2019-2020 in the southwest of Ukraine showed that the combination of several adverse factors influenced on evolution of drought for a long time. Analysis of two type of drought indices and anomalies of the tropospheric pressure fields showed that the formation of precipitation deficit began long before the occurrence of drought due to the high repeatability of the high pressure fields in the region, whereby the intensity of drought increased gradually.

Keywords: drought, drought index; blocking index; vegetation

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1. Introduction

The territory of Eastern Europe is a region, where droughts of different intensity and duration occur often. Southern regions in the warm period of the year are especially susceptible to drought, when anticyclonic processes prevail in the atmosphere and contribute to intensive heating and drying air and soil due to lack of precipitation. Meteorological and agricultural droughts are widespread and can significantly reduce the yield of grain crops, especially if they occur in spring and summer. Drought 2019-2020 in the Northern Black Sea region of Ukraine due to the long lack of precipitation and warm winter was the strongest since 1947 to reduce soil moisture available for crops and led to the damage of 80-100 % of crops in the Odessa region in the spring of 2020. This drought case had a catastrophic impact on the regional agricultural sector and led to an essential decrease in the export of grain crops.

The drought is a high impact hydrometeorological hazard, which requires the improvement of monitoring and forecasting methodologies due to the increasing frequency of drought episodes in changing climate in all regions of the Earth. The absence of a universal definition of drought and a variety of assessment methods are a problem, when choosing the most effective methodology for regional monitoring. This fact leads to adapt existing methods and developing new approaches that can take into account both the physical mechanism for the origin and evolution of drought and the influence of the geographical and climatic features of the study region.

Natural drought is defined as the deviation of meteorological, agricultural and hydrological parameters (for example, the amount of precipitation, soil moisture, river runoff, groundwater level etc.) from climatic conditions. Meteorological (or atmospheric) drought is formed under conditions of precipitation deficit, under the high temperatures and at low humidity, which are created due to the high level of insolation in the absence of clouds [1]. This a combination of meteorological parameters leads, on the one hand, to an increase in evaporation and transpiration, on the other hand to a decrease in runoff, infiltration and soil water supply. Meteorological droughts can quickly begin and suddenly end, if the abundant amount of precipitation occurred. However, if there are no precipitation for a long period, the reserves of soil moisture are gradually depleted. Agricultural drought is often determined by the lack of water in the soil to support the growth of crops than the absence of normal precipitation for a certain period.

The purpose of this study is a comprehensive analysis of drought indicators and atmospheric processes to identify the conditions for formation of sever agricultural drought in the Odessa region, which located at the southwest of Ukraine in the Northern Black Sea region.

2. Materials and Methods

The drought is characterized by severity, duration and distribution area. Drought monitoring is based on indicators and indices that evaluate changes in the hydrological cycle of the region. Indicators that are used to describe drought conditions are variables such as precipitation, temperature, runoff, groundwater levels, reservoir levels, soil moisture and snow cover. The indices, on the other hand, are the calculated numerical parameters that describe the intensity of drought using climatic and / or current hydrometeorological data. Indices are provided by quantitative measurements, e.g. precipitation and air temperature that correspond to intensity, duration, place and time of drought. They are necessary for tracking and predicting the impact of drought, and can also form a historic records to assess future droughts. Within the Drought Risk Reduction Framework and Practices [2], three basic drought monitoring methods are defined for evaluation and early warning:

- use of one indicator or index;
- use of several indicators or indexes;
- use of composite or hybrid indicators.

Historically, only one indicator or the index for tracking drought was used historically due to restrictions. Recently, hybrid or composite indicators combining various indicators or indexes, have become more reliable to detect drought. Composite indicators are more effective, because the degree of drought severity is estimated using various water-content data available in a particular region [3].

Composite drought indicators can combine the parameters obtained from data both ground observations and satellite remote sensing. These indicators, as a rule, become the basis of drought monitoring systems.

In this study, the severe drought in the Northern Black Sea region was estimated using two indices: a meteorological drought index SPI (the Standardized Precipitation Index; on 1 month time scale) based on ground observation of precipitations, and an index of anomalies of the satellite-derived index NDVI (Normalized Difference Vegetation Index). The first parameter characterizes the level of precipitation deficit relative to the norm, and the second index characterizes the degree of water stress on vegetation due to impact of the drought conditions.

Grid dataset of SPI index (0.5 degree) were obtained from the IRI Analyses SPI: Standardized Precipitation Index analyses of multiple global precipitation datasets (http://iridl.ldeo.columbia.edu/SOURCES/.IRI/.Analyses/.SPI/). For any region, meteorological drought is indicated as SPI decreases below –1.0. To determine the intensity of drought, the following criteria of SPI are used [4]: –1.0... –1.49 is moderately dry; –1.5... –1.99 is severely dry; ≤ –2.0 is extremely dry.

The time series of the SPI values were analyzed at the grid points closest to the 10 district centers of the Odessa region, which is the largest region of Ukraine (http://rada.com.ua/eng/regionspotential/odesa/), and which most suffered from drought. Since the area of Odessa region has a meridional orientation, the estimate was made for the northern and southern part of the region (Figure 1).

Area averaged monthly 0.05 degree NDVI for the southern and northern part was taken from the Giovanni database (https://giovanni.gsfc.nasa.gov/giovanni/). Calculation of the monthly index of NDVI anomalies was done using the formula according to [5]:

$$NDVIA = \frac{NDVI_i - \overline{NDVI}}{\sigma_{NDVI}}, \quad (1)$$

where, $NDVI_i$ is value at a particular moment in time; $\overline{NDVI}$ is long-term mean value; σ_{NDVI} is standard deviation. Commonly, the values of $NDVIA \leq -1$ indicates a drought.

To assess the atmospheric condition for the formation of precipitation deficit and the occurrence of drought, there was analyzed the pressure fields at the sea surface level (SLP) and in the middle troposphere (500 hPa level) over the Northern Black Sea region during the study period. Analysis and visualization of the results are based on the ERA5 reanalysis data using the web-tool of KNMI Climate Explorer (https://climexp.knmi.nl).

The blocking process in the region was estimated using the ECBI (European Continental Blocking Index), based on assessment of the state of zonal flow at level 300 hPa [6]. This index is calculated using data of NCEP-NCAR reanalysis for the restricted area (10-60 E and 40-60 N) by the formula:

$$ECBI = 1 - \frac{\bar{u}_{pt}}{\bar{u}_{cl}}, \quad (2)$$

where, $\bar{u}_{pt}$ is a current pentad value of the zonal component of wind at the level of 300 hPa averaged over the area; $\bar{u}_{cl}$ is a climatic value of zonal component of wind at same level averaged over the area (over the basic period of 1981-2010).

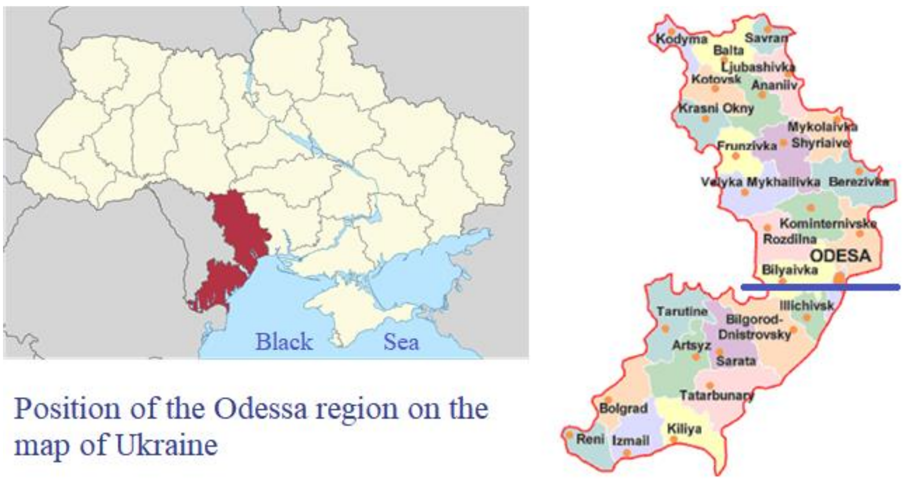

Figure 1. A schematic map of the Odessa region, on which the blue line divides it conditionally on the northern and southern parts.

3. Results and Discussion

3.1. Time course of the SPI

Analysis of the time course of the drought index SPI on 1 month time scale showed that after relatively favorable spring months at the different points of the Odessa region, the deficit of precipitation (SPI < 0) was observed almost at all months in 2019 (except October), and continued in the first months of 2020 (except February). The minimum of SPI values was observed in April 2020 (-1.88... - 1.66), which corresponds a severe drought.

Analysis of the spatiotemporal distribution of the anomalies of satellite-derived vegetation index NDVI in March-October showed that in 2019, the positive anomalies were observed only in the spring months, but since the beginning of summer and until the middle of the autumn, an increase in the negative anomalies of the NDVI index was observed. March 2020 was characterized by favorable conditions for the vegetation, however, in April, the anomalies of NDVI became negative and reached the minimum in May (-1.87), which indicates a drought state. In the summer and autumn months, the negative anomalies of NDVI continued throughout the study region, and the NDVI values did not exceed 0.47-0.53, which indicates the moderate stress of vegetation during warm season 2020.

According to the time course of the SPI index, in the southern part of the Odessa region, the periods of drought from weak to moderate intensity were observed in February-March 2019, as well as from November 2019 to January 2020 (Figure 2, a). From April to October 2019, the SPI values varied about 0, which indicates precipitation within the norm. The level of moisturizing above norm was in February 2020, but in March, the moderate drought was observed and in April drought reached the severe intensity (SPI values up to -1.88). The summer season of 2020 in the southern part of the Odessa region was characterized by the predominance of drought of different intensity, despite some improvement in the situation with precipitation in May 2020. In August, drought in all points reached the criterion of moderate intensity.

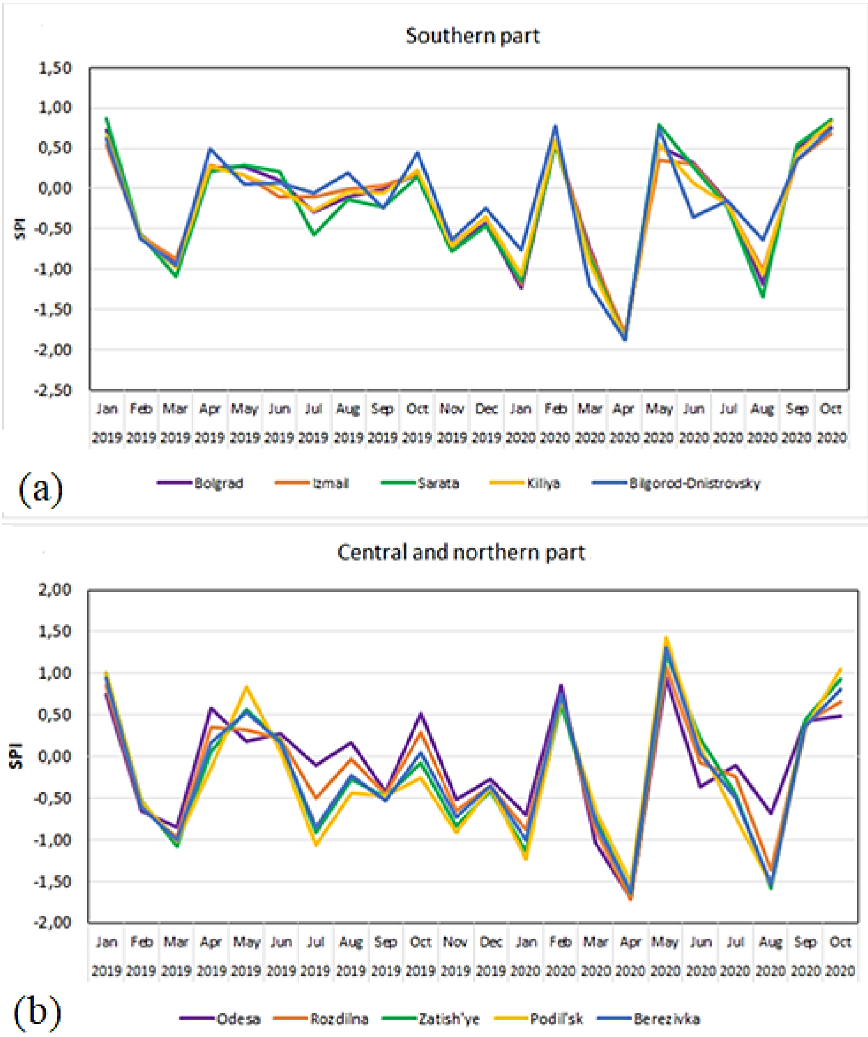

Figure 2. Time course of monthly drought index SPI in the southern part (a) and northern and central part (b) of the Odessa region in January 2019 – October 2020.

In the central and northern parts of the Odessa region (Figure 2, b), the time course of the SPI index in 2019 is similar to the southern part, but in summer the weak drought prevailed, with the exception of the Odessa, and April-May was characterized by more favorable moisturizing conditions. As in the southern part, the strongest drought was observed in April 2020 (SPI = -1.71 ... -1.62). In the summer, the intensity of drought was higher than in the southern part, and severe drought was observed in August.

The analysis showed that in the cold seasons 2019-2020 there was a continuous lack of precipitation, which was caused by absence of southern (or Mediterranean) cyclones, which are the main source of precipitation and accumulation of soil moisture in the south of Ukraine in winter [7]. In addition, winter 2019-2020 turned out to be one of the warmest over the past decade: the air temperature in the Odessa region was 3-5 °C above average long-term values, and in February by 5-6 °C above. A steady transition through 0 °C, that is, the beginning of spring, occurred at the end of January 2020 [8]. High winter temperatures and absence of snow cover led to an additional soil draining at the beginning of the growing season of 2020.

3.2. Time course of the NDVIA

The analysis of the time series of the anomalies of the satellite vegetation index NDVIA in March-October 2019 showed that positive anomalies were observed only in the spring months, and the state of vegetation was better in the northern part of the Odessa region (Figure 3). However, since the beginning of the summer and until the middle of the autumn, an increase in the negative anomalies was observed and in September-October, NDVIA values reached -1, which indicates a stress of vegetation, associated not only with the end of the growing season, but also dry conditions observed during the summer time. March 2020 was characterized by favorable vegetation conditions, but in April the NDVIA became negative and reached the minimum in May (-1.87) in the southern part of the Odessa region, which indicates a severe drought and strong stress of the plants. In the summer and autumn months, NDVIA negative values continued throughout the region, and the values of the vegetation index NDVI did not exceed 0.47-0.53, which indicates a moderate stress of vegetation the entire warm season of 2020.

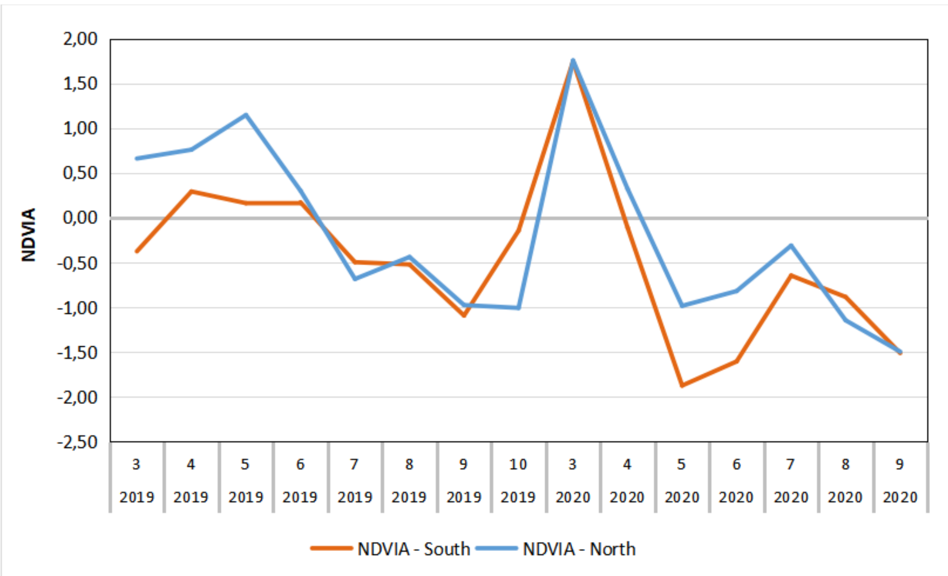

Figure 3. Time series of monthly NDVIA, averaged over the southern and northern parts of the Odessa region, in March - October 2019 and March-September 2020.

3.3. Dynamics of the regional atmocpheric processes

The formation of a long-term deficit of precipitation and deficit of soil moisture content is usually a consequence of the long-term exposure of the atmospheric processes, which are not favorable to the formation of precipitation. Therefore, there was analyzed the tropospheric pressure fields over the Northern Black Sea region not only for period of 2019-2020, but over the past ten years to see the dynamics of the development of atmospheric conditions that led to the severe drought.

The time course of the monthly anomalies of the SLP, averaged in the region of the study (Figure 4, a) showed that frequency of occurrence the positive and negative anomalies was about the same on the period from 2010 to 2020, but there were short periods (about two years) with a predominance one or another anomaly. Thus, the positive SLP anomalies in the region were typical for 2011-2012, 2015-2016, 2017, in which in Ukraine there were droughts of different intensity [9]. In the period from 2018 to 2020, the frequency of positive anomalies in general, exceeded negative one, which may indicate the prevalence of anticyclonic processes preceding to drought case study.

In the middle troposphere in the time course of the geopotential height H-500, there were three periods distinguished with the predominance of anomalies of various signs (Figure 4, b). In the period from 2010 to 2013, negative anomalies H-500 prevailed, from 2014 to 2017 there was not observed predominance of any sign of anomalies. Since 2018, the average monthly positive anomalies of geopotential heights prevailed, and in the second half of 2019 and in January 2020 positive anomalies reached maximum values. Thus, in the period preceding to drought, the atmospheric circulation conditions in the region were characterized by the predominance of high-pressure circulation systems in the middle troposphere, in which precipitation deficit is usually occurred.

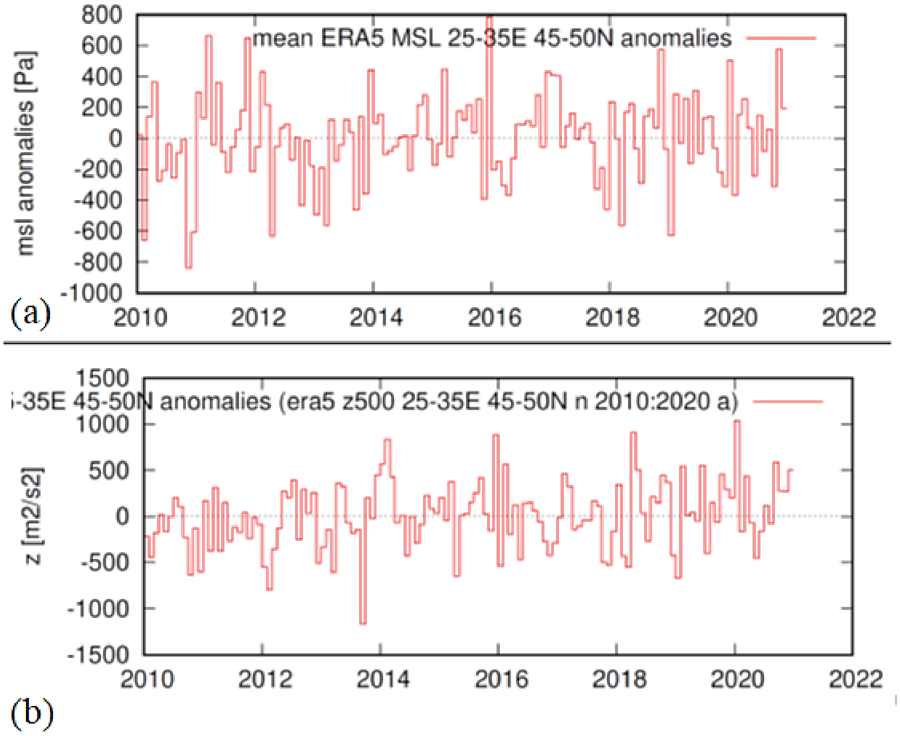

Figure 4. Time series of the monthly anomalies of the SLP (a) and anomalies of the geopotential height H-500 (b), averaged over the Odessa region during period 2020-2020.

Drought development occurs, as a rule, under the influence of stationary or blocking anticyclones, in the area with cloudless weather and intense radiative heating. Prolonged sequential periods with blocking situations lead to increased drought severity and expanding it in the area. It was shown that enough four consecutive pentad for a month to determine the stable spot of drought [10].

Analysis of the time course of the blocking index ECBI showed (Figure 5) that the most prolonged periods of blocking over the European continent were observed in March-April, August-September and November 2019 (from three to six pentad in sequence), as well as in December 2019-January 2020 (four consecutive pentads). At the end of winter and in the spring 2020, long-term blocking episodes were not observed.

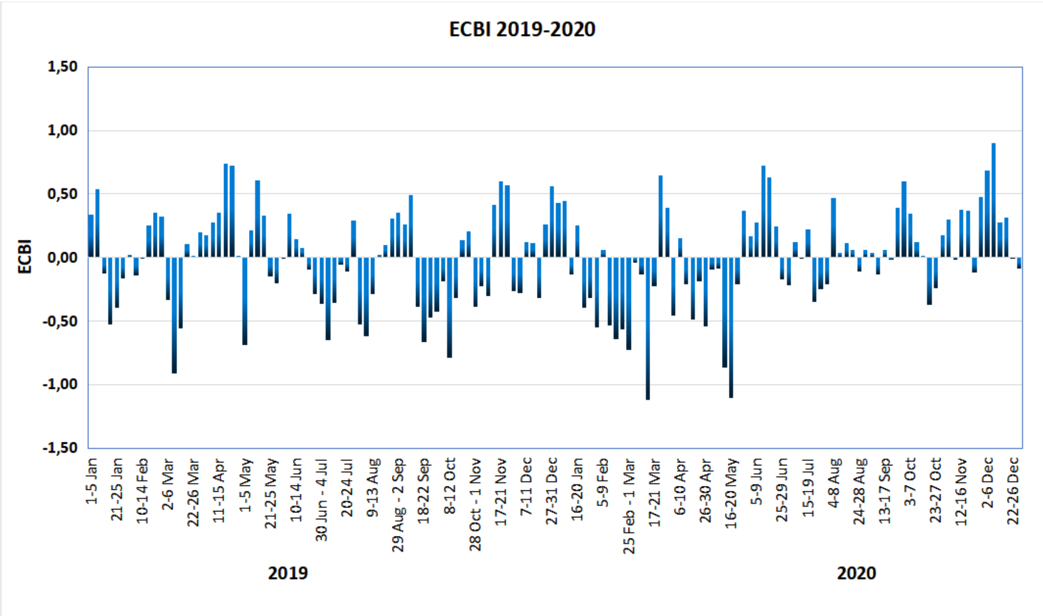

Figure 5. Time series of the pentad blocking index ECBI in January 2019 - December 2020.

4. Conclusions

A comprehensive analysis of the meteorological conditions for the formation of a severe agricultural drought in the Odessa region at the beginning of the growing season of 2020 has shown that this process developed for a long time, gradually gaining intensity. The long-term deficit of precipitation was caused by the high frequency of the high pressure field (compared to the norm) in the lower and middle troposphere, as well as the lack of conditions for the accumulation of soil moisture in the previous winter period due to the high air temperatures and the absence of cyclogenesis processes, which is a typical for cold season in the region.

Data Availability Statement:

1. IRI Analyses SPI: http://iridl.ldeo.columbia.edu/SOURCES/.IRI/.Analyses/.SPI/
2. Giovanni Online Data System: https://giovanni.gsfc.nasa.gov/giovanni/
3. ERA5 in KNMI Climate Explorer: https://climexp.knmi.nl
4. NCEP/NCAR Reanalysis 1: https://psl.noaa.gov/data/gridded/data.ncep.reanalysis.html

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