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Geospatial Statistical Hydro – Thermal Indicator for Drought Monitoring in the Changing Climate Conditions

Mikhail V. Nikolaev

Agrophysical Research Institute

Russia

Among the Drought indicators recommended by WMO (Handbook of Drought Indicators and Indices, WMO – No 1173, 2016) the focus is placed on the ‘Hydro – Thermal Coefficient’ (HTC) proposed by Russian agrometeorologist Georgij Selyaninov as:

$$HTC_{i} = \Sigma P_{i} / 0.1 * \Sigma T_{i}$$

Where: ***i*** *is a number of year*

ΣP – *precipitation totals (decadal, month, growing season)*

ΣT – *accumulated air temperatures (decadal, month, growing season)*

Materials:

The 70-yr monthly precipitation and mean monthly air temperature series (since 1945 to 2014) was based on the meteorological data obtained at the stations located within the territory under study. Further, they were transformed into the agroclimatic variables series, including those for the intensive growth season, i.e. May-June

Moreover, a set of years with HTC values less than 0.75 is revealed, i.e. the years with drought occurrence

For detailed gradation of drought severity during early stages of crop growth, the grade scale proposed by Russian agrometeorologist Evgenij Zoidze has been applied:

Drought Severity	Agroclimatic indicator of occurrence
Extreme	$HTC_{V\text{-}VI}$ =< 0.19
Severe	0.20 =< $HTC_{V\text{-}VI}$ =< 0.39
Moderate	0.40 =< $HTC_{V\text{-}VI}$ =< 0.60
Light	0.61 =< $HTC_{V\text{-}VI}$ =< 0.75

Spatiotemporal monitoring of crop areas vulnerable to drought effects in the changing climate conditions

Based on this grade scale, the spatiotemporal monitoring of crop areas with different percentage of years with different severity drought in the changing climate conditions has been performed, using 5-yr step shift within 30-yr observed period beginning from 1946

As an example, Fig.1 illustrates the dynamics of areas vulnerable to extreme drought (**HTC_{V-VI} =< 0.19)** by mapping

The optimal configuration of isolines contoured risk farming areas with different recurrence of extreme drought is achieved using the **GIS interpolation method,** such as **kriging**

. This monitoring enables visualization of temporal changes in the boundaries of vulnerable areas relative to those for the **baseline climate conditions (in the observed period 1961 – 1990)**

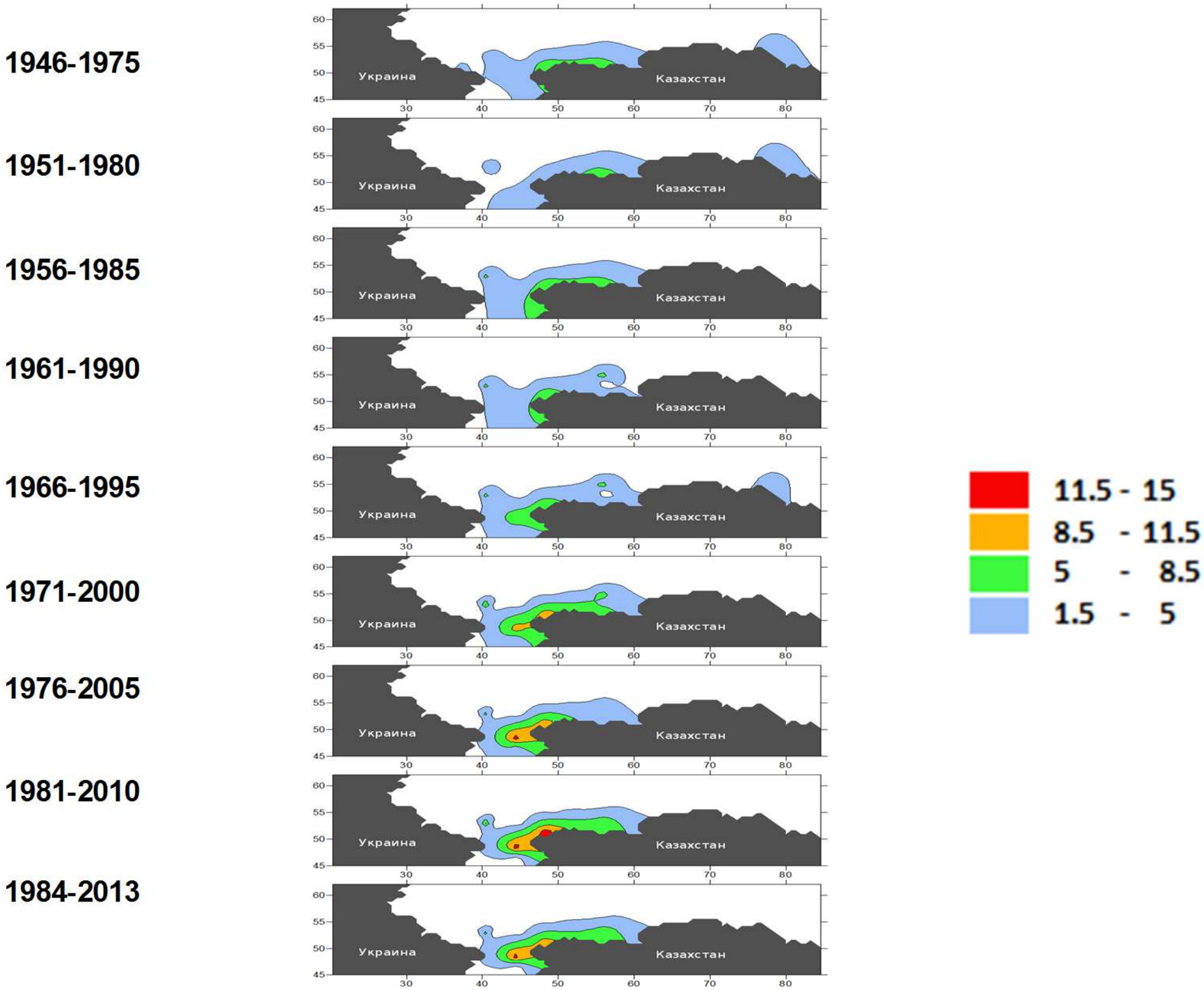

Fig.1 Change in boundaries of vulnerable areas with different recurrence of extreme drought within principal zone of wheat durum cultivation (Lower Volga and South Pre - Ural regions)

Legend: percentage of years

ASSESSING CHANGE IN CONTRIBUTION OF PRECIPITATION AND THERMAL CONDITIONS TO DROUGHT EFFECTS WITHIN RISK FARMING ZONE

(SEMIARID REGIONS OF RUSSIA)

To assess the changing contribution of precipitation and thermal conditions to drought severity and recurrence the **functional analysis** has been applied

The **HTC indicator** is considered as a **function** of two variables: the precipitation totals and the accumulated air temperatures (degree-days)

As an example, Fig. 2 shows the Three – dimension representation of the HTC indicator with the plotted HTC values <= 0.75 (as related to time intervals of 1945 – 1979 and 1980 – 2014) at Bezenchuk

(For comparative analysis of drought risk under climate change, it would be convenient to subdivide the period since 1945 to 2014 into two 35-yr intervals: 1945-1979 and 1980-2014, the upward trends in the mean annual air temperature series, which are noted for the Russian regions since the 1980s taking into consideration)

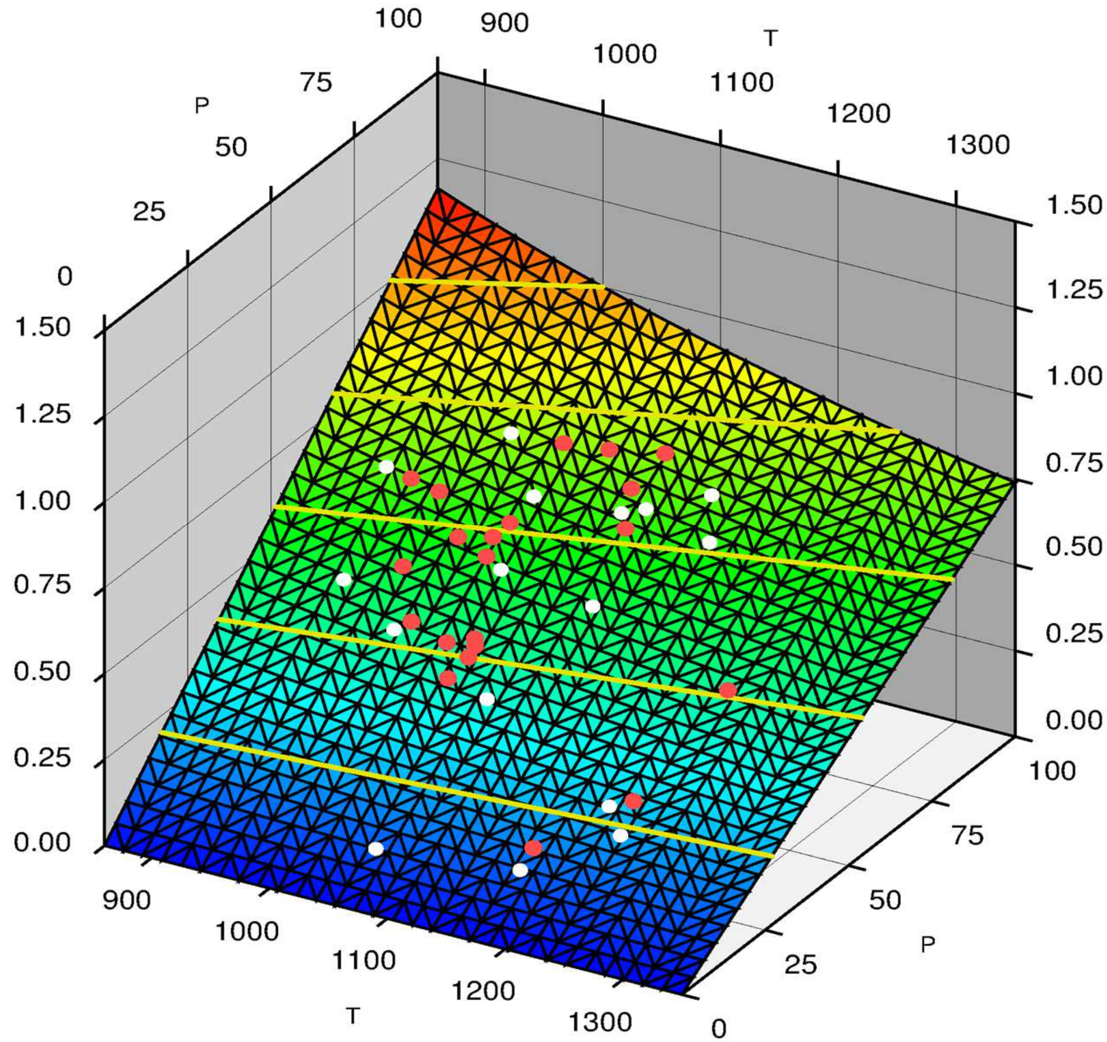

Fig.2 Three – dimensional representation of the HTC values <= 0.75 for May - June

Bezenchuk: 53.0º N; 48.4º E

(Lower Volga region. Common Chernozem soil)

Between isolines: events with extreme drought; severe drought; moderate drought; light drought

red dots: time interval of 1945 - 1979; white dots: time interval of 1980 - 2014

The assessment is made of the contribution of each factor to the low HTC values as well as their variation ratios to the low HTC values in indicated intervals by means of this surface projection on the plane for each of these factors

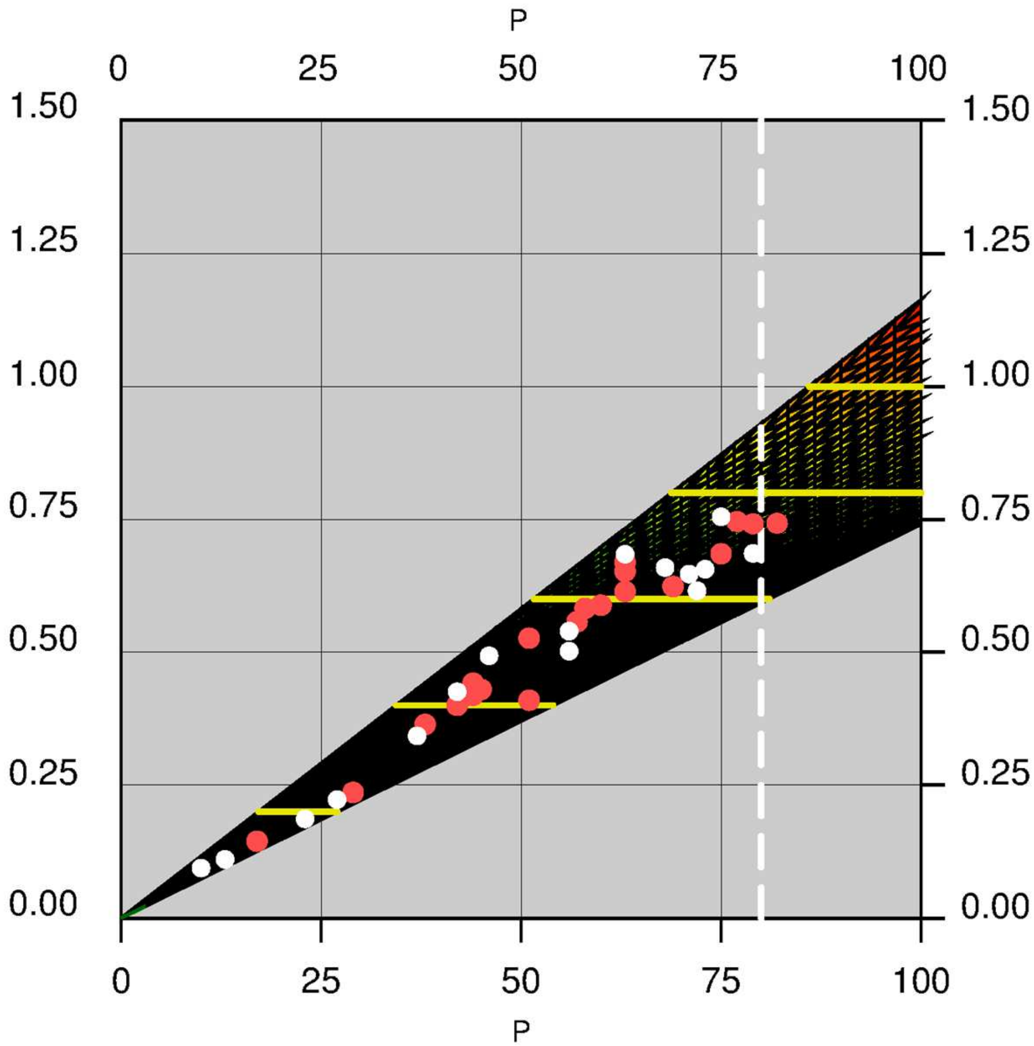

Fig.3 Change in contribution of low precipitation totals in May - June to low $HTC_{V–VI}$ values

Bezenchuk: 53.0º N; 48.4º E

Horizontal axis: precipitation sums for May - June (mm); vertical axis: the HTC Index values for May - June

Dotted line: 70-yr mean value of precipitation amounts for May - June equals of $\sum P_{V\text{-}VI}$ = 79 mm

red dots: time interval of 1945 - 1979; white dots: time interval of 1980 - 2014

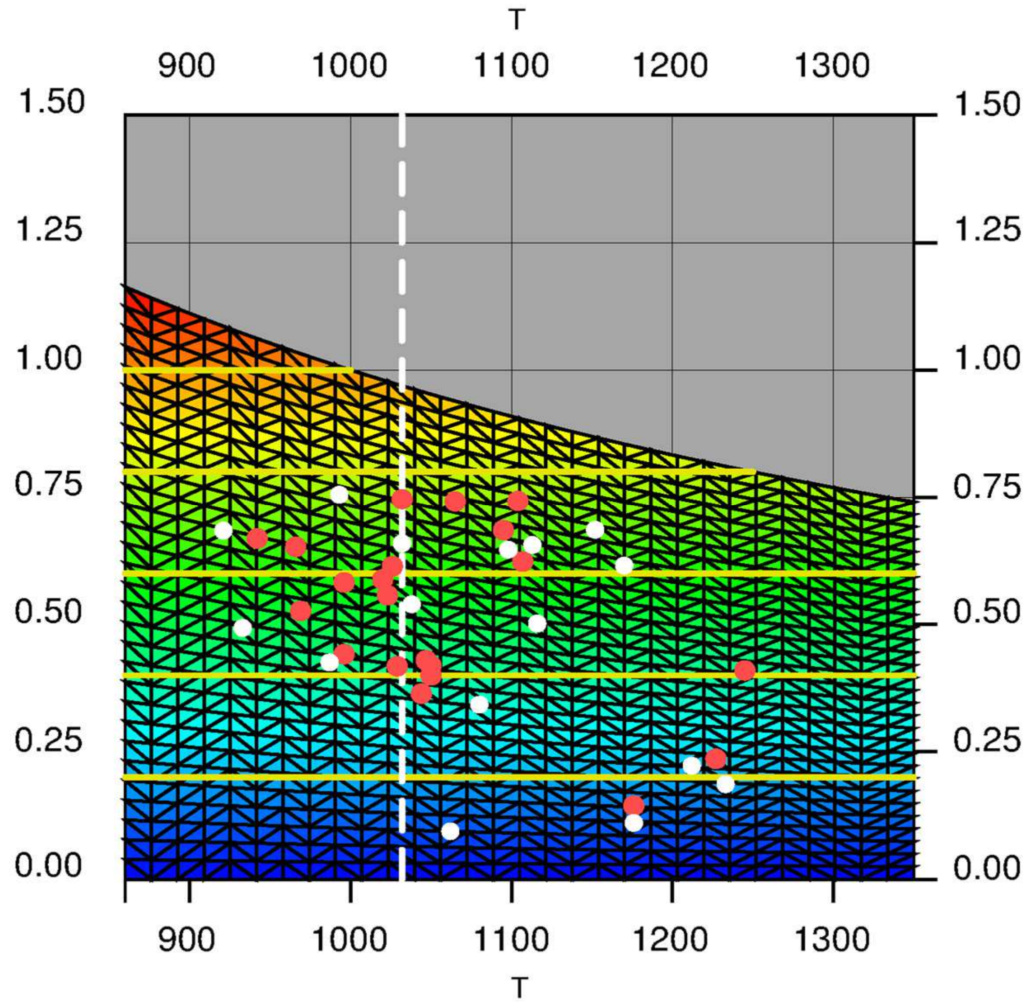

Fig. 4 Change in contribution of degree - days for May - June to low *HTC V-VI* values

Bezenchuk: 53.0º N; 48.4º E

Horizontal axis: degree -days for May-June (ºC); vertical axis: the HTC Index values for May-June

Dotted line: 70-yr mean value of degree - days for May-June equals of $\sum T_{V-VI}$ = 1034 ºC

red dots: time interval of 1945 - 1979; white dots: time interval of 1980 - 2014

Table 1 Recurrence of Droughts in the Semiarid Regions South of 54° N (Prairie and Dryland Natural Formations)

(red color: increase in recurrence)

Meteorological station coordinates Sub- Region	Drought Severity							
	Light (% of years) 0,61=< HTC v-vi =<0,75		Moderate (% of years) 0,40=< HTC v-vi =<0,60		Severe (% of years) 0,20=< HTC v-vi =<0.39		Extreme (% of years) HTC v-vi =<0,19	
	1945- -1979	1980 - 2014	1945- -1979	1980 - 2014	1945- -1979	1980 - 2014	1945- -1979	1980- 2014
Sterlitamak **53.6° N 56.0° E** (South Pre- Ural)	9%	9%	11%	11%	**3%**	**6%**	**3%**	**6%**
Orenburg **51.8° N 55.6° E** (South Pre- Ural)	14%	11%	23%	20%	**11%**	**26%**	6%	6%
Bezenchuk **53.0° N 46.4° E** (Lower Volga)	23%	20%	26%	6%	6%	6%	**3%**	**9%**
Ershov **51.4° N 48.3° E** (Lower Volga)	**11%**	**17%**	26%	17%	20%	9%	**6%**	**11%**

Table 2 Drought Events at the Air Temperature above (numerator) and below (denominator) 70- yr mean value

100% - always at the air temperature above 70-yr mean value

(Prairie and Dryland Natural Formations)

Meteorological station coordinates Sub- Region	Drought Severity							
	Light (% of years) 0,61=< HTC v-vi =<0,75		Moderate (% of years) 0,40=< HTC v-vi =<0,60		Severe (% of years) 0,20=< HTC v-vi =<39		Extreme (% of years) HTC v-vi =<0,19	
	1945- -1979	1980 - 2014	1945- -1979	1980 - 2014	1945- -1979	1980 - 2014	1945- -1979	1980- 2014
Sterlitamak **53.6° N 56.0° E** (South Pre- Ural)	1/2	1/2	**2/1**	**3/1**	**100%**	1/1	**100%**	**100%**
Orenburg **51.8° N 55.6° E** (South Pre- Ural)	**5/3**	**5/2**	3/6	0/2	**100%**	**100%**	**100%**	**100%**
Bezenchuk **53.0° N 46.4° E** (Lower Volga)	2/3	2/2	3/5	**5/2**	**3/1**	**6/3**	**100%**	**100%**
Ershov **51.4° N 48.3° E** (Lower Volga)	1/3	2/4	4/5	**4/2**	**5/2**	**100%**	**100%**	**3/1**

Table 3 Recurrence of Droughts in the Semiarid Regions North of 54° N

(Grassland and Prairie Natural Formations)

(red color: increase in recurrence)

Meteorological station coordinates Sub- Region	Drought Severity							
	Light (% of years) 0,61=< HTC v-vi =<0,75		Moderate (% of years) 0,40=< HTC v-vi =<0,60		Severe (% of years) 0,20=< HTC v-vi =<39		Extreme (% of years) HTC v-vi =<0,19	
	1945- -1979	1980 - 2014	1945- -1979	1980 - 2014	1945- -1979	1980 - 2014	1945- -1979	1980- 2014
Ufa 54.7° N 55.8 ° E (Middle Pre-Ural)	11%	14%	6%	11%	6%	6%	3%	3%
Tyumen' 57.1° N 65.4° E (Western Siberia)	9%	11%	3%	6%	3%	0%	0%	0%
Kurgan 55.5° N 65.4° E (Western Siberia)	11%	23%	11%	17%	14%	6%	0%	0%
Omsk 55.0° N 72.4° E (Western Siberia)	11%	14%	3%	9%	17%	9%	0%	0%
Barabinsk 55.2° N 78.2° E (Western Siberia)	11%	9%	14%	6%	3%	9%	3%	0%

Table 4 Drought Events at the Air Temperature above (numerator) and below (denominator) 70- yr mean value

(**100%** - always at the air temperature above 70-yr mean value)

(Grassland and Prairie Natural Formations)

Meteorological station coordinates Sub- Region	Drought Severity							
	Light (% of years) 0,61=< HTC v-vi =<0,75		Moderate (% of years) 0,40=< HTC v-vi =<0,60		Severe (% of years) 0,20=< HTC v-vi =<39		Extreme (% of years) HTC v-vi =<0,19	
	1945- -1979	1980 - 2014	1945- -1979	1980 - 2014	1945- -1979	1980 - 2014	1945- -1979	1980- 2014
Ufa 54.7° N 55.8 ° E (Middle Pre-Ural)	3/1	3/2	0/2	100%	100%	100%	100%	100%
Tyumen' 57.1° N 65.4° E (Western Siberia)	2/1	3/1	0/1	100%	100%	-	-	-
Kurgan 55.5° N 65.4° E (Western Siberia)	2/2	5/3	3/1	100%	4/1	1/1	-	-
Omsk 55.0° N 72.4° E (Western Siberia)	2/2	4/1	100%	100%	4/2	2/1	-	-
Barabinsk 55.2° N 78.2° E (Western Siberia)	2/2	2/1	4/1	1/1	100%	100%	100%	-

Based on the analysis conducted, the increasing contribution of extreme low precipitation totals to increasing recurrence of extreme drought in recent decades is revealed.

At the same time, the increasing recurrence of moderate and light droughts is also revealed due to increasing contribution of high air temperatures.

All this serves as evidence of increasing extreme character of climate in recent decades

Comparison of HTC indicator with other indicators (indices)

As drought indicator developed in Russia, the D_i index discovers on attention, proposed by Russian agrometeorologist Daniil Ped'

$$D_i = \Delta T_i / \sigma T - \Delta P_i / \sigma P - (\Delta W_i / \sigma W)$$

$D_i > 1.5$ – indicates drought occurrence

This index may supplemented by data on soil moisture content (W_i)

However, this index is not much applicable in terms of geographical distribution of droughts

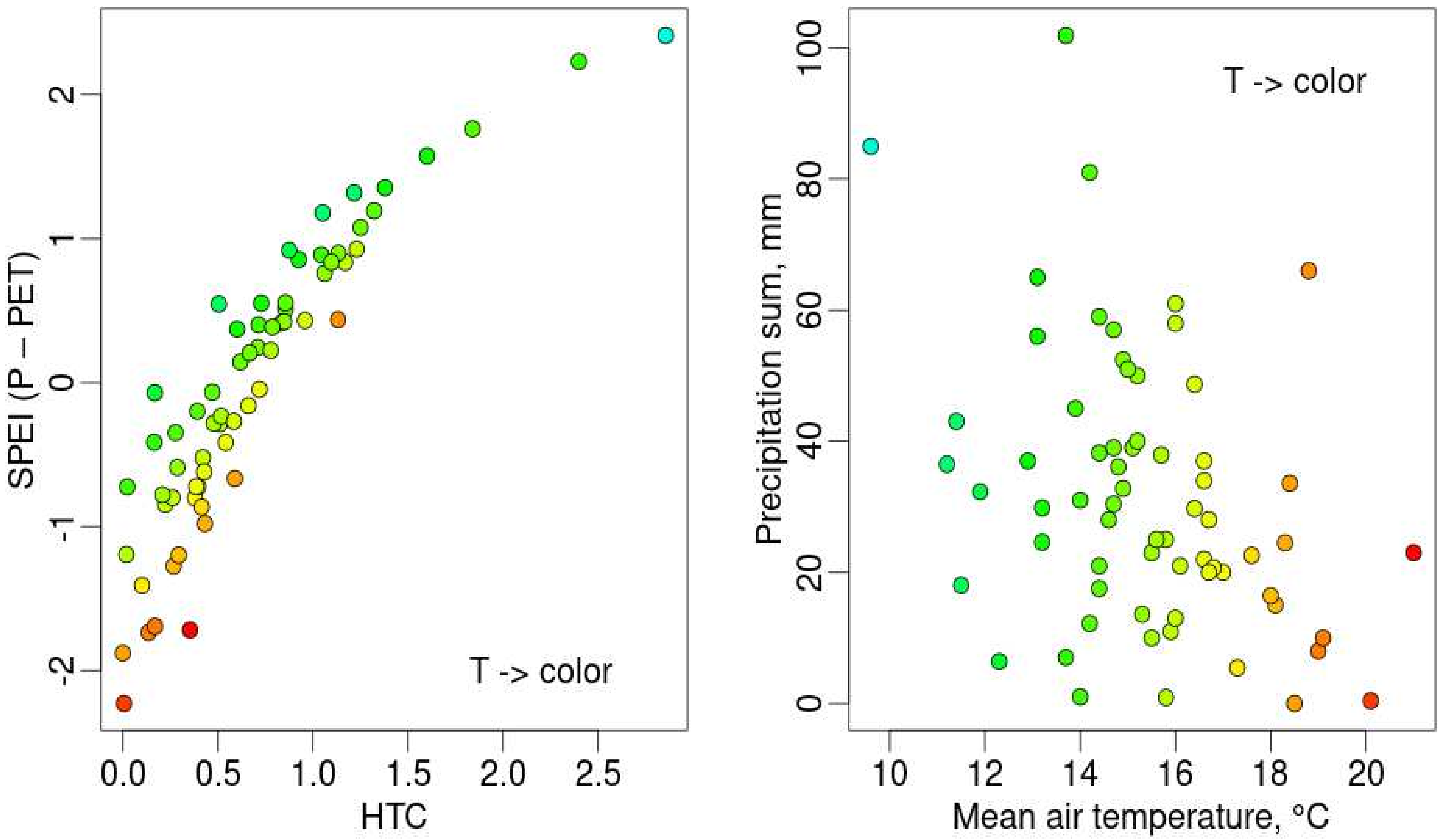

Fig.5 Relationship between HTC and SPEI for May (1982 – 2010)

Ershov: 51.4º N; 48.3º E (around 21 x 33 km)

(Dryland formation nearby the Kazakhstan boundary)

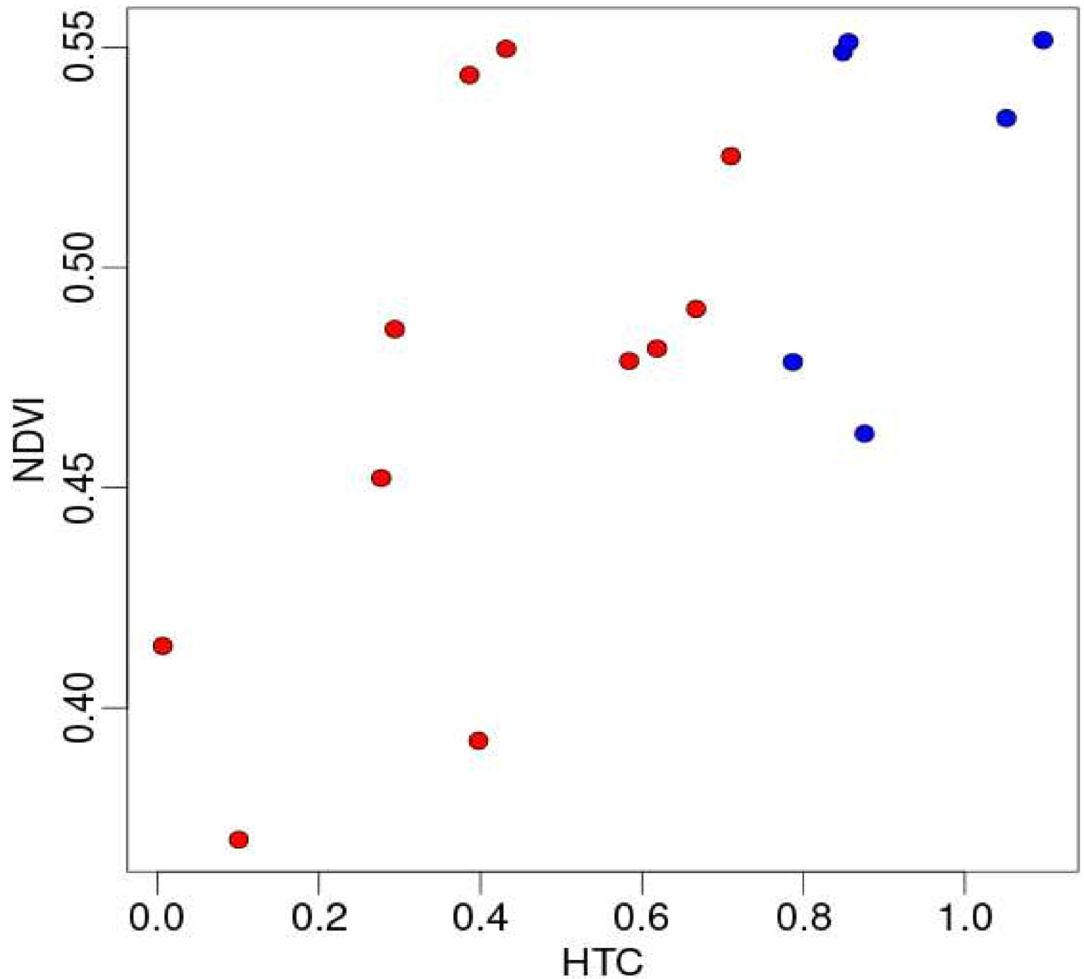

Fig.6 Relationship between HTC and NDVI for May (1982 – 2010)

Ershov: 51.4º N; 48.3º E (around 21 x 33 km)

(Dryland formation nearby the Kazakhstan boundary)

red dots: dry years; blue dots; wet years

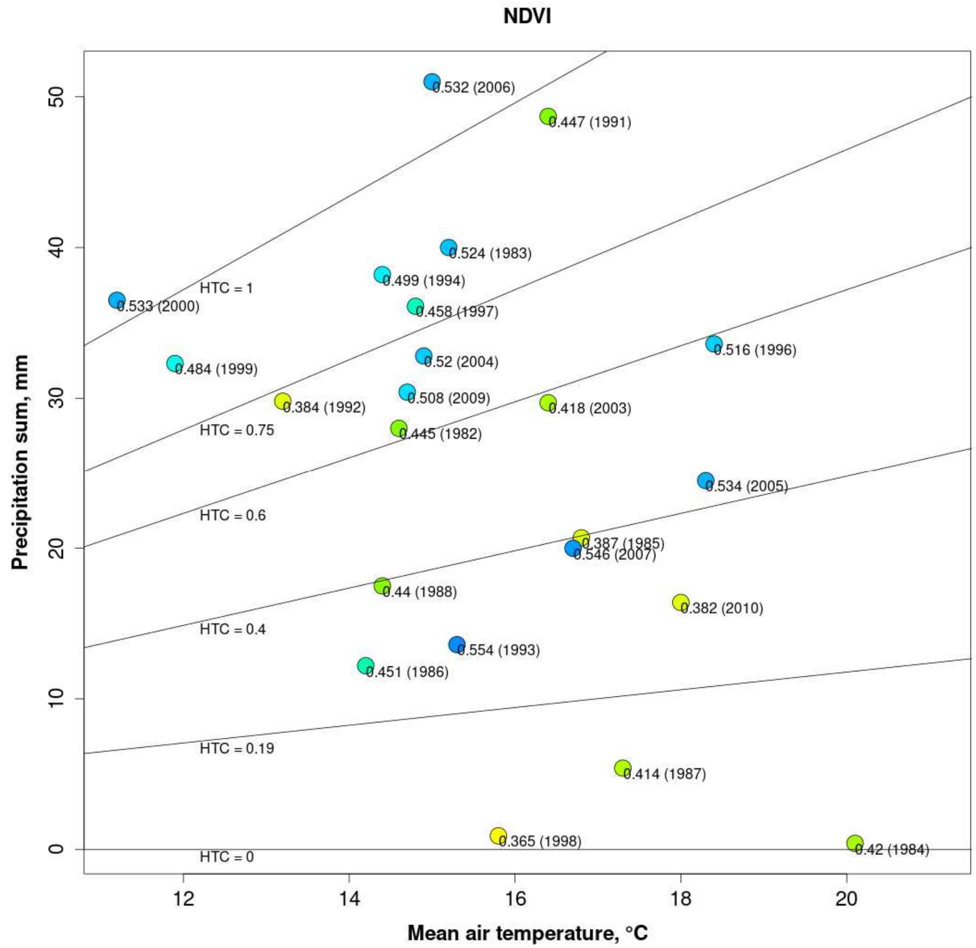

Fig.7 Comparison NDVI with HTC for May (1982 – 2010) at different air temperatures and precipitation amounts

(Families of HTC for May presented similar those for drought gradation for May – June proposed by Evgenij Zoidze)

Ershov: 51.4º N; 48.3º E (around 21 x 33 km)

(Dryland formation nearby the Kazakhstan boundary)

Comparison of daily NDVI values during May with HTC values for May (with indicating precipitation totals and mean air temperature)

phase ‘Sowing – Shooting’ for spring wheat

Ershov

(Dryland formation, deep chestnut soil)

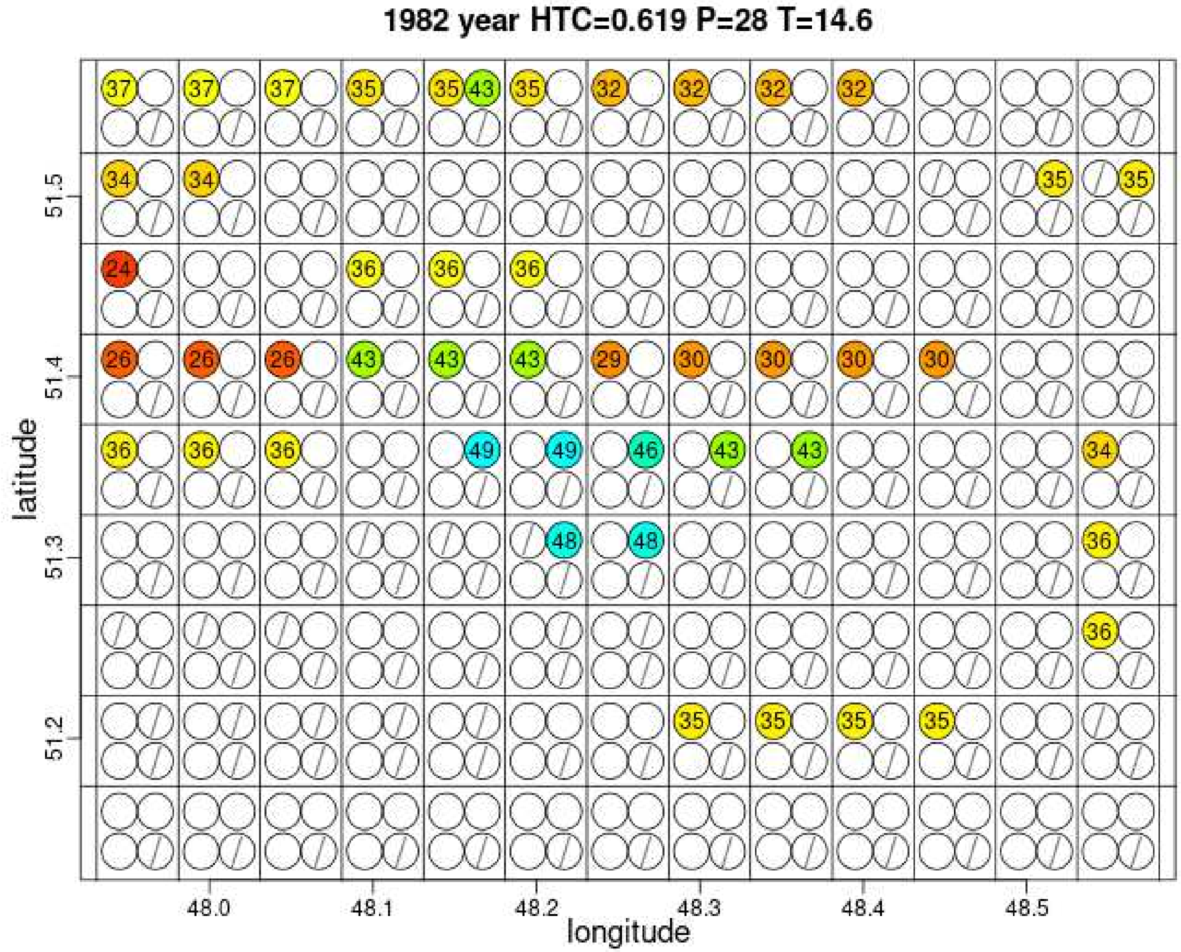

Fig.8 Daily NDVI values during May 1982
Ershov: 51.4º N; 48.3º E (around 21 x 33 km)
(Dryland formation nearby the Kazakhstan boundary)

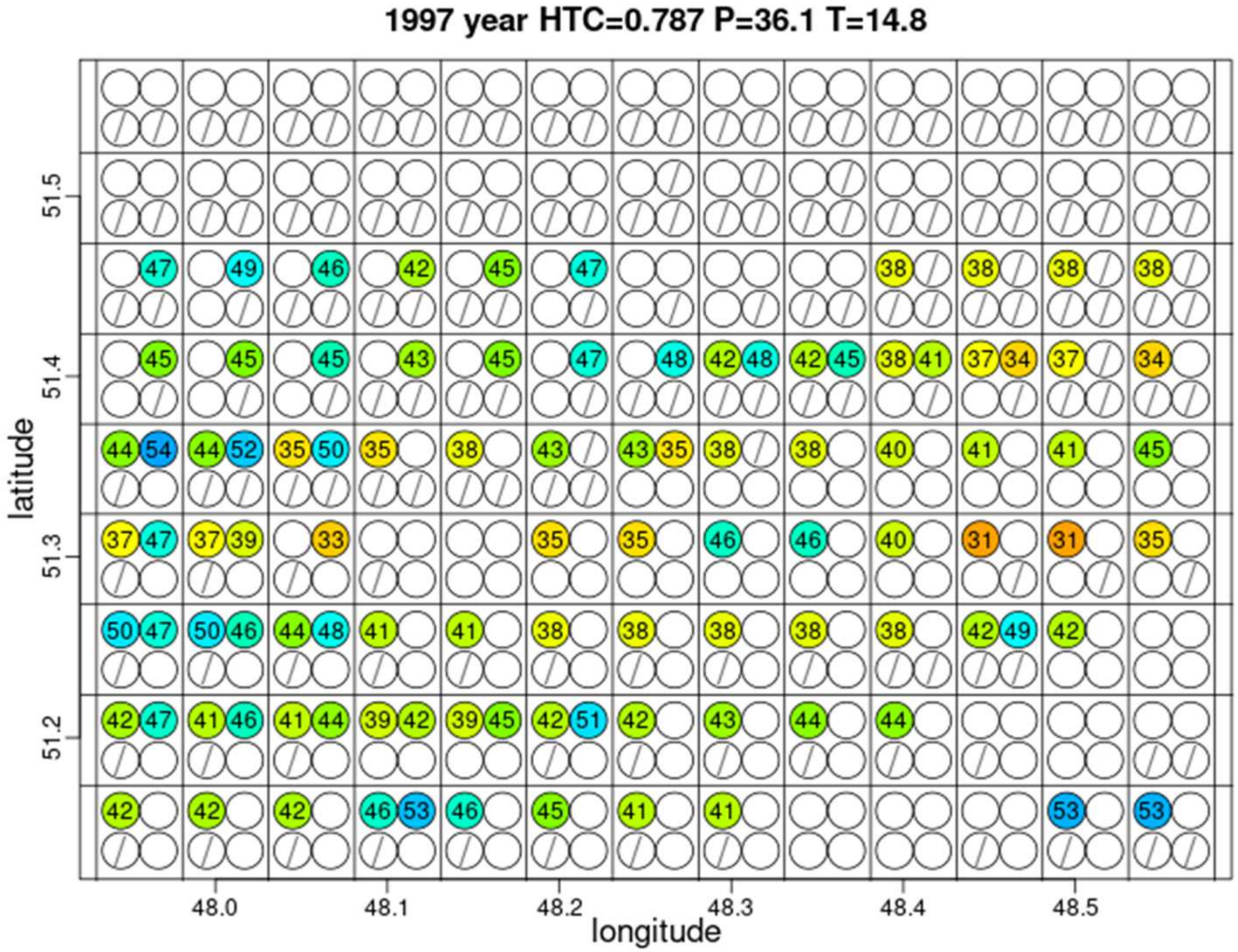

Fig.9 Daily NDVI values during May 1997

Ershov: 51.4º N; 48.3º E (around 21 x 33 km)

(Dryland formation nearby the Kazakhstan boundary)

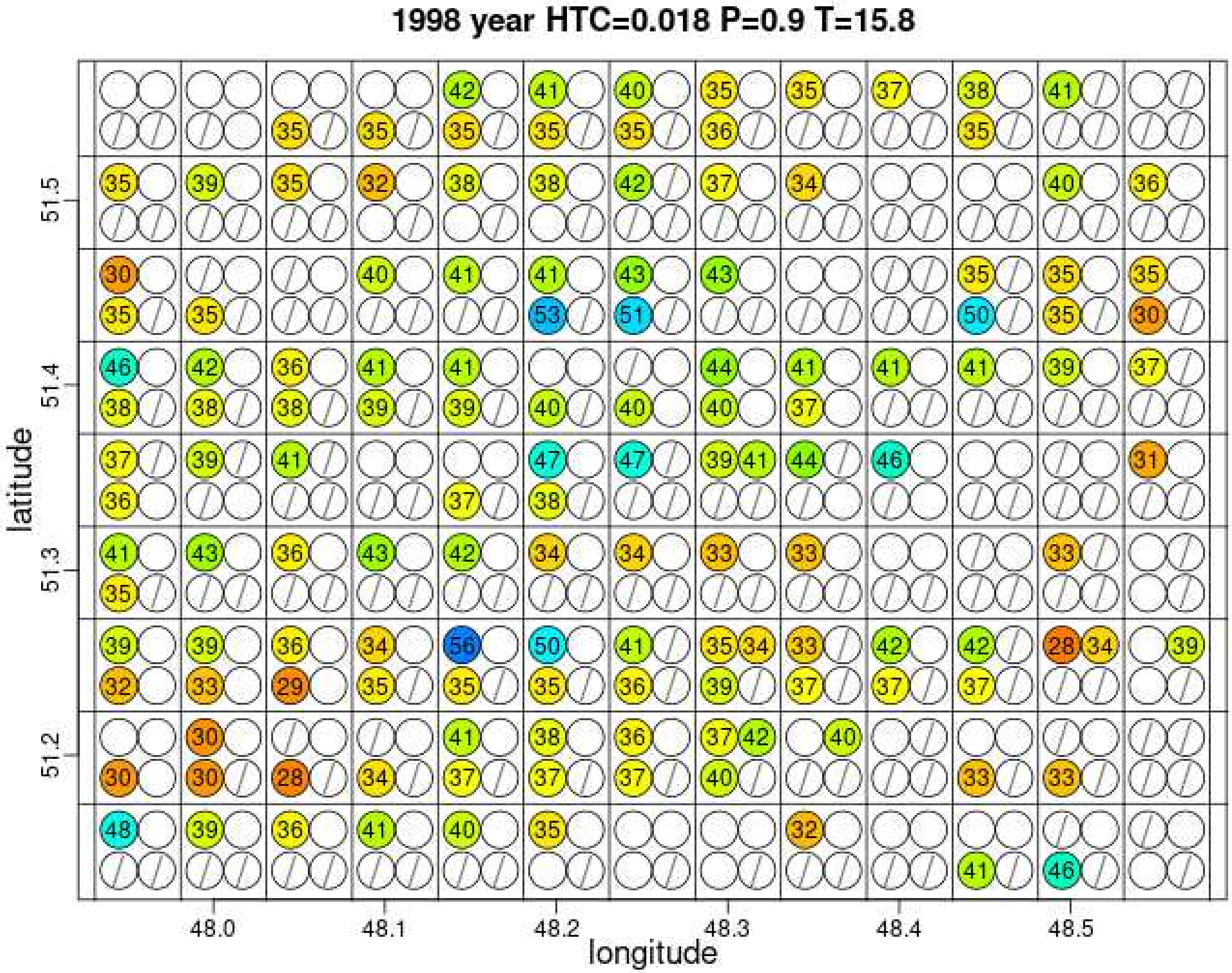

Fig.10 Daily NDVI values during May 1998
Ershov: 51.4º N; 48.3º E (around 21 x 33 km)
(Dryland formation nearby the Kazakhstan boundary)

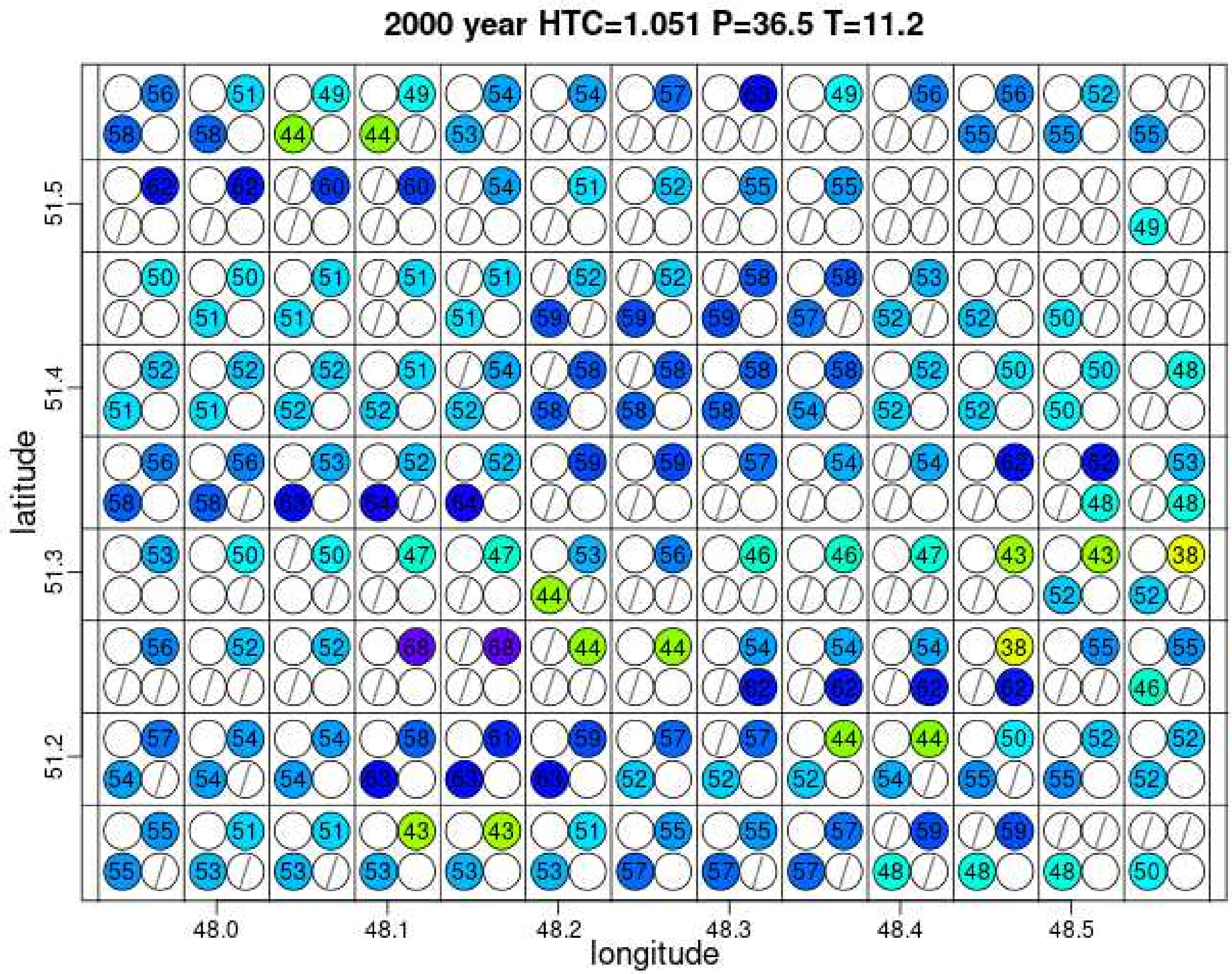

Fig.11 Daily NDVI values during May 2000

Ershov: 51.4º N; 48.3º E (around 21 x 33 km)

(Dryland formation nearby the Kazakhstan boundary)

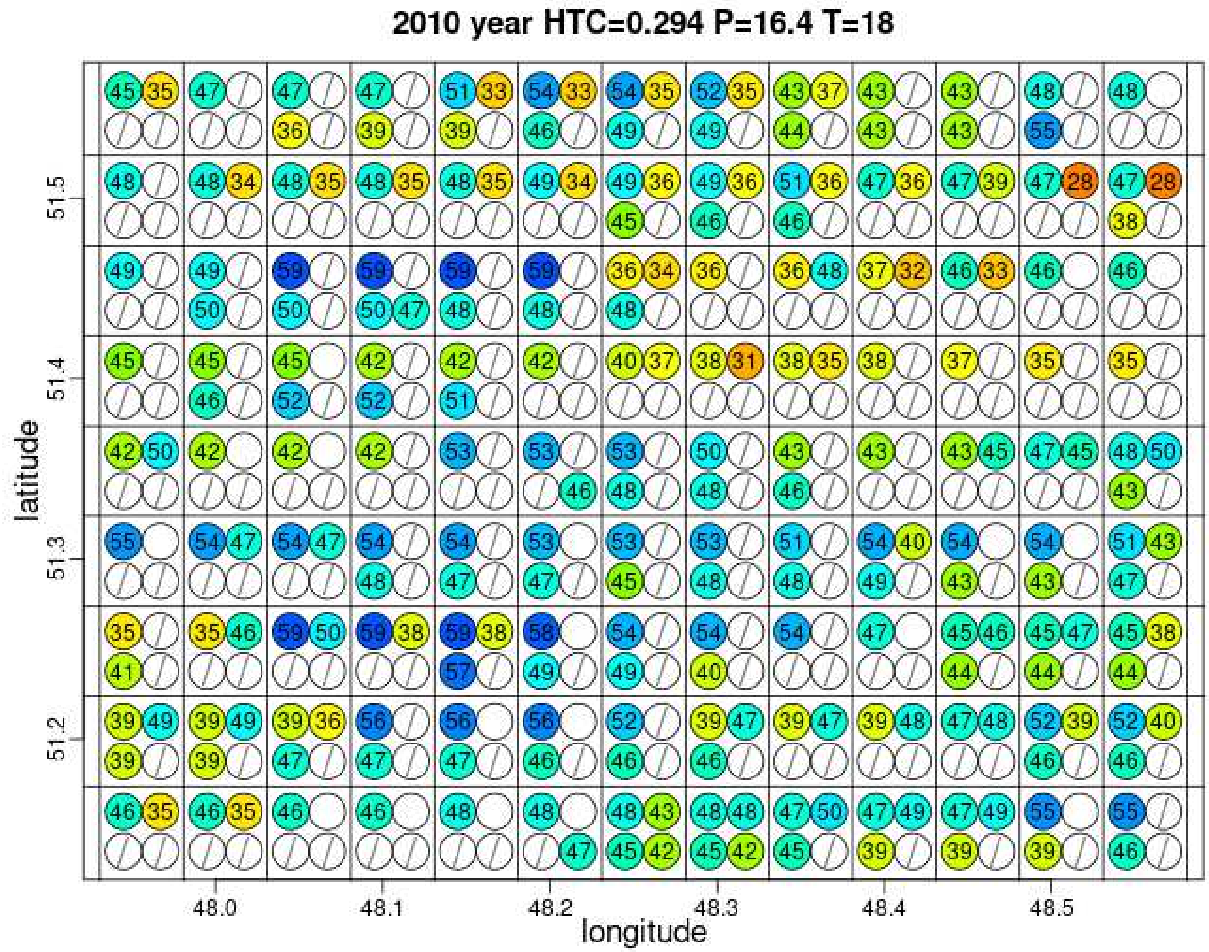

Fig.12 Daily NDVI values during May 2010
Ershov: 51.4º N; 48.3º E (around 21 x 33 km)
(Dryland formation nearby the Kazakhstan boundary)

Conclusions:

- the indicator proposed is simple for calculation. It includes the climatic variables, anomalous values of which are indentified of sporadic occurrence of drought phenomenon

- using this indicator we manage to define more distinctly the boundaries of areas vulnerable to different severity droughts and also to revealed the boundaries shift in the changing climate conditions

- variables contained in this indicator influence directly on the conditions of crop growth and development, as contrasted to variables determined from indices, which contain complex approximations and relationships

- the comparability of this indicator with the vegetation index is reached. However, the pattern of drought impact according to the satellite observations is not somehow distinct – due to inhomogenity of underline surface, local meteorological conditions, effects of agricultural practices and resistance ability of local crops and cultivars

- variables contained in this indicator good estimates from climate scenarios. Therefore the drought assessment for perspective may be performs on the probabilistic basis, using additional statistical tools


Thank you