Czech University of Life Sciences Prague, Czech Republic

30th September – 13th October
Universitat Rovira I Virgili
Tarragona, Spain

Drought climatology

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ERASMUS PROGRAMME
STA - TEACHING ASSIGNMENT

Lifelong
Learning
Programme

Vera Potop, Czech University of Life Sciences Prague, Czech Republic

30th September – 13th October
Universitat Rovira I Virgili
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Objectives of the mobility:

- **To familiarize students of the host university with research focussed on the impact of drought on crop yields**

Added value expected from the mobility (both for the host institution and for the teacher):

- **Exchange of experience with current methodologies and introduction of new approaches in the teaching**

Content of the teaching programme:

- **Drought events and their impact on agriculture crops in Central Europe and South-Eastern Europe.**

Expected results:

- **Presentations, seminars and extended knowledge of students**

ERASMUS PROGRAMME
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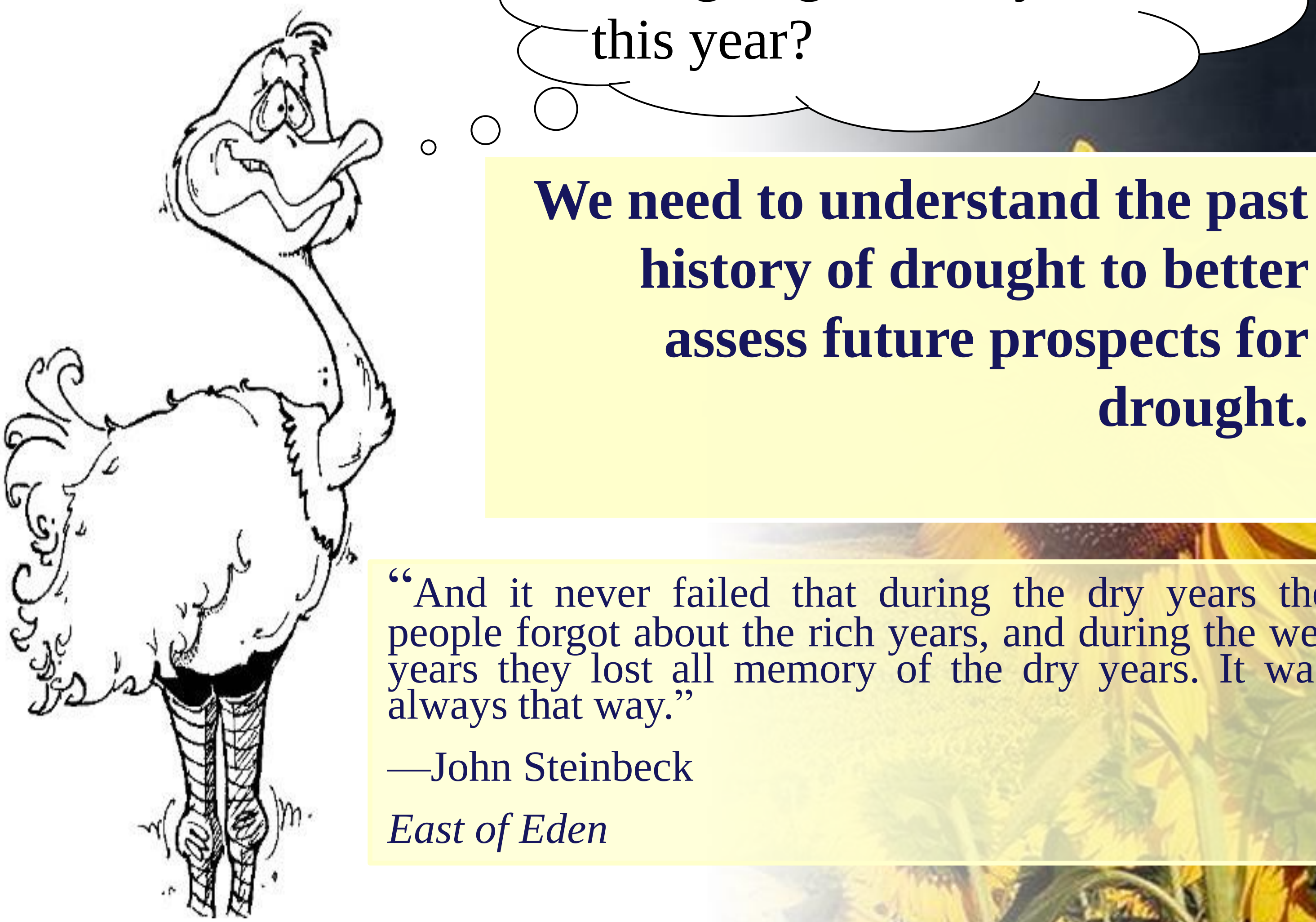
Outline

Vera Potop, Czech University of Life Sciences Prague, Czech Republic



We need to understand the past history of drought to better assess future prospects for drought.

"And it never failed that during the dry years the people forgot about the rich years, and during the wet years they lost all memory of the dry years. It was always that way."

—John Steinbeck

East of Eden

I. Introduction

- Drought is one of the most complex natural hazards, with impacts on agriculture, water resources, natural ecosystems and society.

- Drought should be understand as a natural part of a climate system under all climatic regimes since it occurs both in humid and arid areas and has a wide range of impacts and consequences.

- Four category of drought studies:
  - deals with the causes of drought and the search for an improved understanding of atmospheric circulation associated with drought occurrences;
  - the assessment of the probability of drought occurrence for various degrees of severity and spatial distribution;
  - the assessment and understanding of drought impacts;
  - deals with societal responses to drought threats, appropriate mitigation and adaptation strategies to drought impacts.

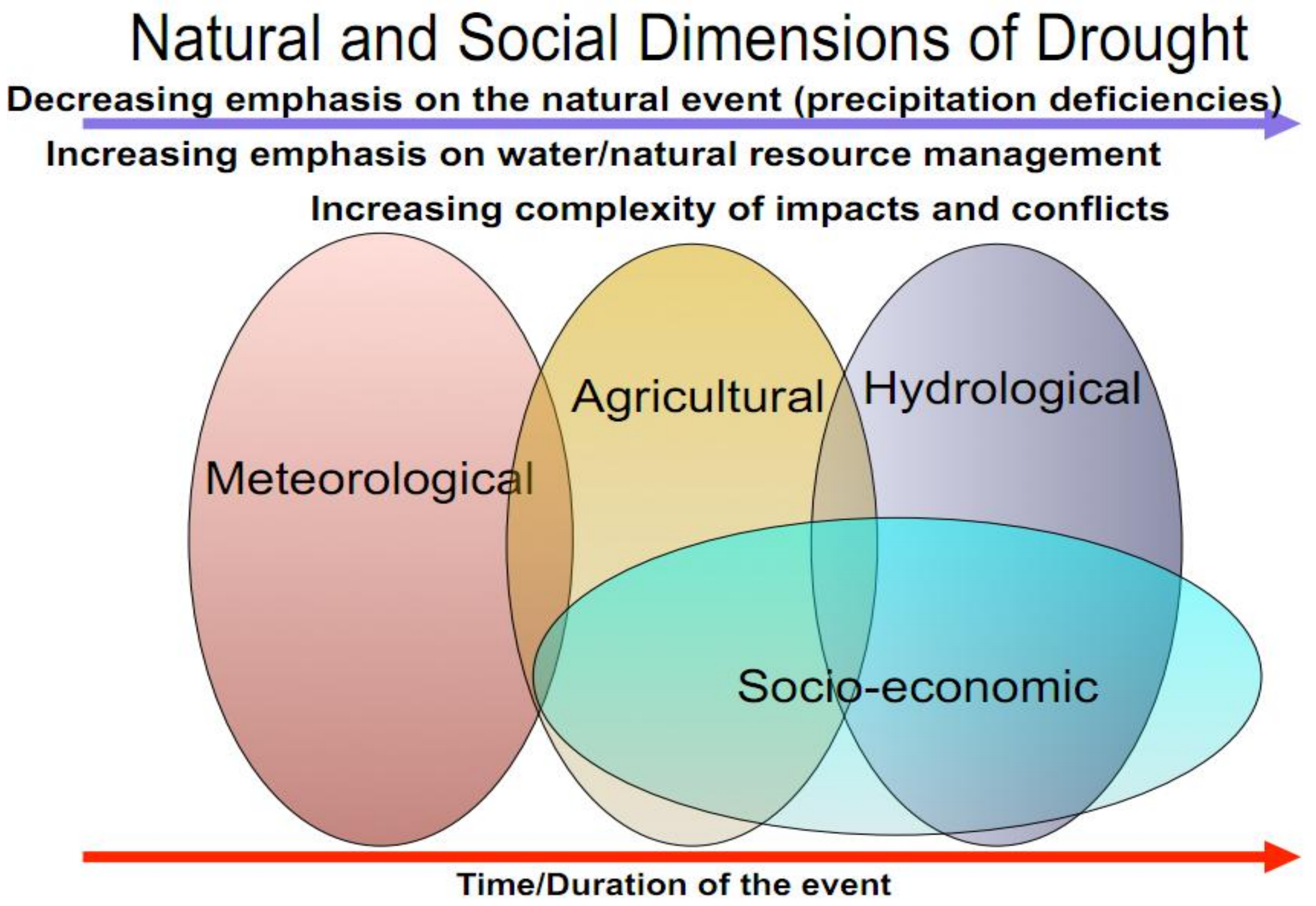
- It is difficult to precisely define drought because meteorological drought results from precipitation deficits, agricultural drought is identified based on total soil moisture deficits, and hydrological drought is related to a shortage of streamflow (*Keyantash and Dracup, 2002*).

II. What is drought?

Drought: a significant deficiency of precipitation from "normal" over an extended period of time, resulting in a water shortage for some activity, group, or environmental sector (Wilhite, 2011).

- Drought differs from other natural hazards in several ways:
  - I. drought is a slow-onset natural hazard, its effects accumulate slowly over a substantial period of time (the onset and end of drought are difficult to determine);
  - II. the absence of a universally accepted definition of drought adds to the confusion about whether a drought exists and, if it does, its degree of severity;
  - III. drought impacts are nonstructural and spread over a larger geographical area than are damages that result from other natural hazards such as floods.
- Drought is a temporary aberration, unlike aridity, which is a permanent feature of the climate.
- Seasonal aridity (i.e., a well-defined dry season) also must be distinguished from drought.

III. Types of drought



III. Types of drought

It is largely accepted the drought classification into 4 types:

***(1) Meteorological*:** **absence or reduction of precipitation (P)– can develop quickly and end abruptly** (accompanied with **above-normal temperatures (T)**, and precedes and causes other types of droughts);

(2) Agricultural: **dryness in the surface layers, which occurs during the growing season and thereby reduces crop yields** (*a period with dry soils that results from below-average* ***P****, intense but less frequent rain events, or above-normal* ***evaporation****, all of which lead to reduced crop production and plant growth*)

⇒ But: No direct relationship exists between P and infiltration of P into the soil. Infiltration rates vary according to antecedent moisture conditions, slope, soil type, and the intensity of the precipitation event. Soils also vary in their characteristics, with some soils having a high water-holding capacity and others a low water-holding capacity. Soils with a low water-holding capacity are more drought prone;

***(3) Hydrological*:** **occurs when river streamflow and water storages in aquifers, lakes, or reservoirs fall below long-term mean levels**. *Hydrological drought develops more slowly because it involves stored water that is depleted but not replenished*.

***(4) Socio-economic*:** *result of the 3 above drought* ⇒ occurs when human activities are affected by reduced precipitation and related water availability.

All three types are related to a prolonged period of insufficient precipitation;
However, evapotranspiration deficits can be critical for agricultural and hydrological droughts, and they can even be more relevant than precipitation deficits in certain cases

IV. Characterizing Drought and Its Severity

- Droughts differ from one another in three essential characteristics: intensity, duration, and spatial coverage.
- ***intensity*** - the degree of the precipitation shortfall and/or the severity of impacts associated with the shortfall. It is generally measured by the departure of some climatic parameter (e.g., precipitation), indicator (e.g., reservoir levels), or index (e.g., Standardized Precipitation Index) from normal and is closely linked to duration in the determination of impact.
- ***duration*** – droughts usually require a minimum of 2 to 3 months to become established but then can continue for months or years.
- ***magnitude*** - closely related to the timing of the onset of the precipitation shortage, its intensity, and the duration of the event.

- Droughts also differ in terms of their spatial characteristics.
  - the spatial extent of individual events;
  - the variability within the affected areas;
  - the dynamics of the spatial extent;
  - recurrent patterns in space.

V. Drought indicator

Time scales

- Another important feature of droughts is their characteristic **time scales**, which can vary substantially.
- A single month of deficient rainfall can adversely affect rainfed crops while having virtually no impact on a large reservoir system.
- As drought is generally viewed as a slow onset event, it may be that the most relevant time scale for drought predictions is seasonal (or longer).
- However, particularly in the agriculture sector, shorter-time scale meteorological information is also highly relevant.
- Drought impact involves the multi-scalar nature of drought because the responses of hydrological and/or agricultural systems to accumulating precipitation deficits have different response times.
- This explains why severe drought conditions can be recorded in one system (e.g., low river flows), while another system (high crop yields) in the same region displays normal conditions (*e.g., Guttman, 1999*).
- For this reason, a drought index must be associated with specific time scales to be useful for monitoring drought.

V. Drought indicator

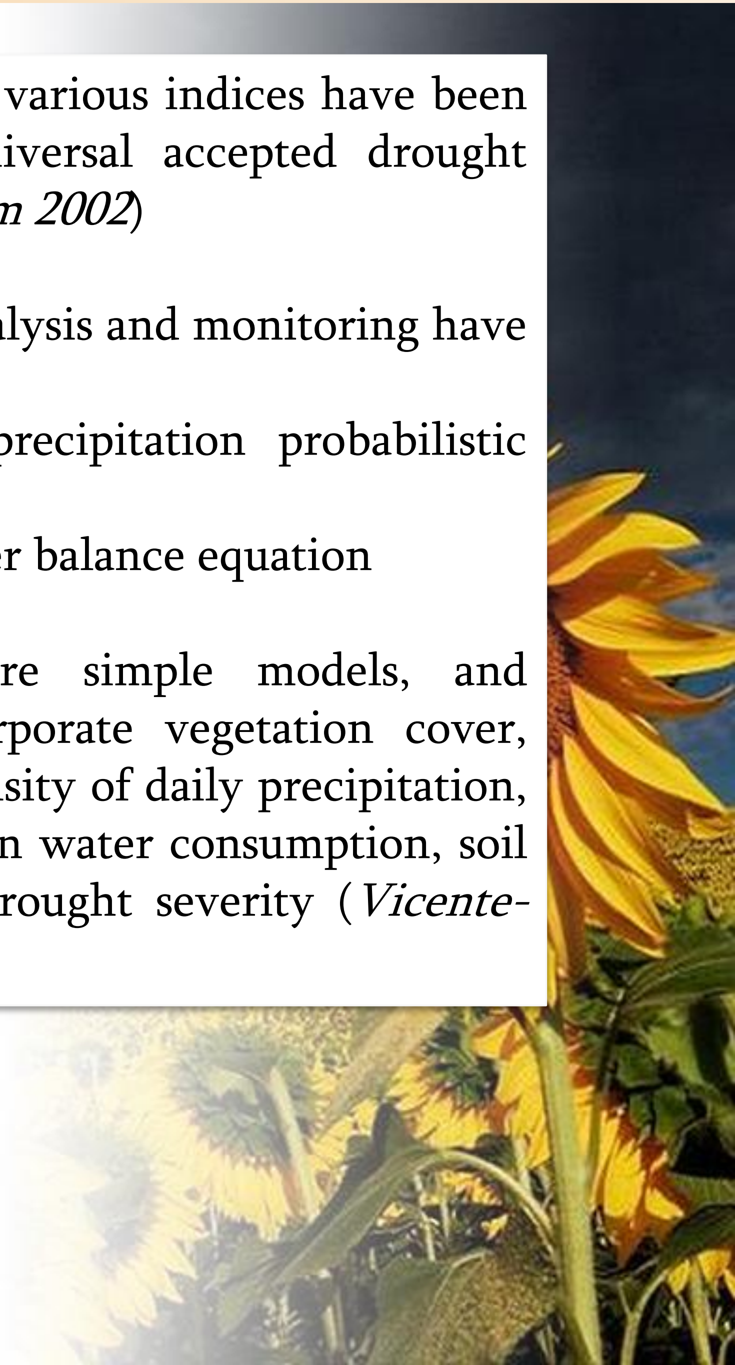
- To monitor and quantify drought, various indices have been developed but a unique and universal accepted drought indicator does not exist so far (*Heim 2002*)

- Most studies related to drought analysis and monitoring have been conducted using either

  1) the SPI, based on a precipitation probabilistic approach or

  2) PDSI, based on a soil water balance equation

- Overall, all drought indices are simple models, and consequently, they do not incorporate vegetation cover, height and albedo and/or the intensity of daily precipitation, all of which have direct impacts on water consumption, soil moisture, crop failures and the drought severity (*Vicente-Serrano et al., 2011*).



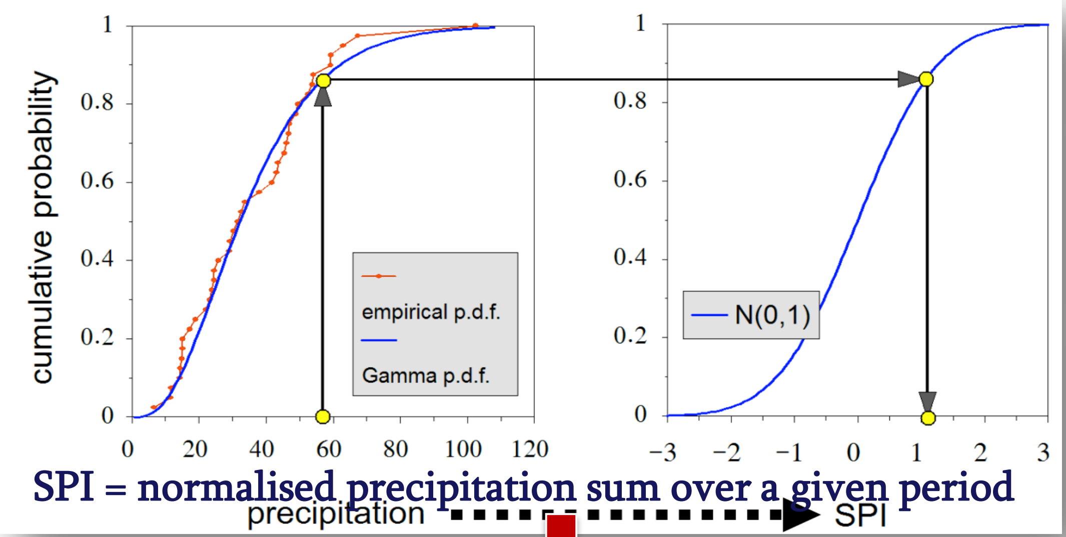
index	Description and Use	Strengths	Weaknesses
Standardized Precipitation Index (SPI) **McKee et al. (1993)**	• Based on the probability of precipitation for any time scale • Used by many drought planners • Gamma distribution is commonly used to approximate (other distribution functions may be used, alternatively [Pearson III distribution]) • High correlation with PDSI at time scales at 6 to 12 months (Redmonth, 2002)	• SPI can be calculated in all climatic regions and for any time period of interest. • It is commonly calculated using 1-month, 3-month, 6-month, 9-month, 12-month, and 24-month intervals. • These time-scales are appropriate for monitoring different types of drought and correspond to different drought impacts • SPI can readily be compared across time and space	• **Input**: only precipitation • It does not include water demand by means of evapotranspiration and the possible impact of temperature variability and change • May be less useful during short-term, low rainfall periods • **it is important to note that arid regions**, those that experience many months with zero precipitation • May be problematic for the SPI depending on which PDF is used to normalize precipitation (Wu et al. 2007)

index	Description and Use	Strengths	Weaknesses
Standardized Precipitation Evapotranspiration Index (SPEI) **Vicente-Serrano et al. (2010)**	• Based on monthly precipitation totals and temperature means and follows a simple approach to calculate the PET based on a normalization of the simple water balance $D_i = P_i – PET_i$ • PET is calculated using the Thornthwaite (1948) method It is necessary to use a 3-parameter model to fit the frequency distribution of the P-PET differences since, unlike when only precipitation is considered, negative values are possible • Loglogistic distribution was most appropriate for the SPEI	• The SPEI has all of the desirable characteristics of the SPI and that now includes a water balance approach that accounts for evaporative demand. • Combines the sensitivity of the PDSI to changes in evaporative demand with the multi-temporal nature of the SPI • Vicente-Serrano et al. (2011) claim that the SPEI is superior to the sc-PDSI because it can be calculated for any time period of interest • Lorenzo-Lacruz et al. (in press) conclude that the SPEI is slightly superior to the SPI for characterizing hydrological droughts and reservoir storage • Detecting, monitoring, and exploring the consequences of global warming on drought conditions	• One of the weaknesses of the SPEI is that it requires more data than the SPI • May also be more difficult to interpret than the SPI since both temperature and precipitation influence the index values • Like the SPI, the SPEI has trouble dealing with arid climates where precipitation is near zero (Vicente-Serrano et al., 2012).

index	Description and Use	Strengths	Weaknesses
Palmer Drought Severity Index (PDSI) **Palmer (1965)** **Alley (1984)**	• Soil moisture algorithm calibrated for relatively homogenous regions • Most prominnent drought index, widely used in sci. literature • Input: P and T (monthly, weekly); available water content (1 parametr) + latitude	• **The first comprehensive drought index, used widely** • **Very effective for agricultural drought since it includes soil moisture** • **It includes supply and demand** • **Includes the role of temperature variability and change.**	• Complexity of calculation • Several variables needed (Precipitation, Temperature, Soil water holding capacity) • Strong influence of calibration period • Limited utility in areas other than that used for calibration • Problems in spatial comparability • Fixed time-scale (between 9 and 12 months) • Lacks the multi-scalar character essential for both assessing drought in relation to different hydrological systems, and differentiating among different drought types

Standardized Precipitation Index (SPI)

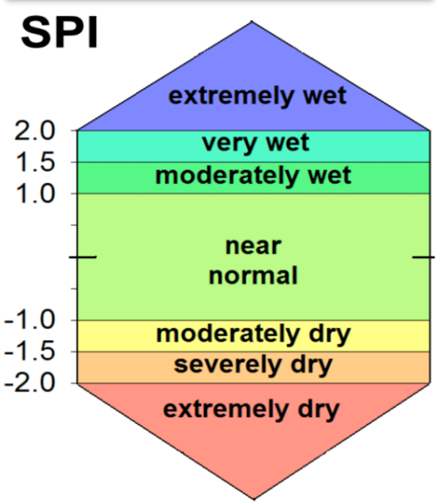
- Drought scientists are aware of the superiority of multi-scalar drought indices such as SPI. Moreover, the SPI has been accepted by the WMO as the reference drought index to characterise droughts, and it can be used by national hydrometeorological services worldwide.

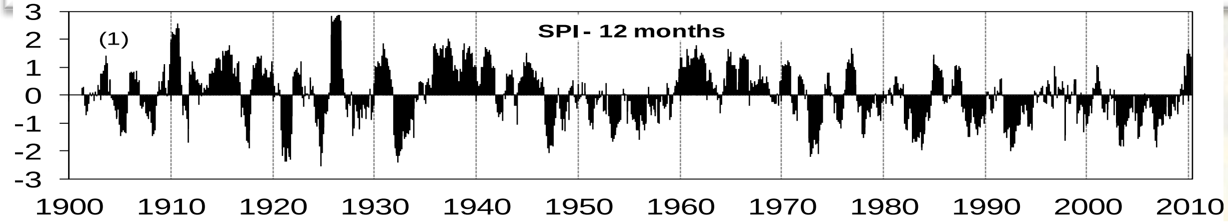


SPI = normalised precipitation sum over a given period

summarizes the calculation procedure, where the cumulative distribution frequency of a precipitation series (biased because the events of high intensity show a low frequency) is transformed into a normal standard distribution where mean = 0 and standard deviation = 1.

7 moisture category





Temporal evolution for data series of SPI at time scales of 12 months for the period 1901-2010 (at Doksany observatory, the Czech Republic).

V. Drought indicator

Standardized Precipitation Index (SPI) *calculation*

- The total precipitation in a given month *j* and year *i* depends on the time scale chosen, *k*.
- Pearson III distribution as suitable probability density function for calculation SPI in semi-arid region:

$$f(x) = \frac{1}{\alpha\Gamma(\beta)}\left(\frac{x-\gamma}{\alpha}\right)^{\beta-1} e^{-\left(\frac{x-\gamma}{\alpha}\right)}$$

where **α, β** and **γ** are the shape, scale and origin parameters, respectively, for precipitation values *x* > 0; and **Ѓ(β)** is the Gamma function of **β**.

The parameters of the Pearson III distribution, when L-moment ratios have been calculated, can be obtained following Hosking (1990):
If $\boldsymbol{\tau_3} = \mathbf{1/3}$, then $\tau_m = 1 - \tau_3$ and **β** can be obtained using the formula:

$$\beta = \frac{(0.36067\tau_m - 0.5967\tau^2{}_m + 0.25361\tau^3{}_m)}{(1 - 2.78861\tau_m + 2.56096\tau^2{}_m - 0.77045\tau^3{}_m)}$$

If $\boldsymbol{\tau_3 < 1/3}$, then $\boldsymbol{\tau_m = 3\pi\tau^2{}_3}$ and $\boldsymbol{\beta}$ can be obtained using the following expression:

$$\beta = \frac{(1 + 0.2906\tau_m)}{(\tau_m + 0.1882\tau^2{}_m + 0.0442\tau^3{}_m)}$$

$$\alpha = \sqrt{\pi}\lambda_2 \frac{\Gamma(\beta)}{\Gamma(\beta + 1/2)}$$

$$\gamma = \lambda_1 - \alpha\beta$$

The probability distribution function of *x* is given by:

$$F(x) = \frac{1}{\alpha\Gamma(\beta)}\int_{\gamma}^{x}\left(\frac{x-\gamma}{\alpha}\right)^{\beta-1} e^{-\left(\frac{x-\gamma}{\alpha}\right)}$$

V. Drought indicator

SPI calculation

Pearson III distribution is not defined for $x = 0$, which is a drawback as precipitation series may include months in which there is no precipitation. With this in mind, an adapted statistic $H(x)$ can be calculated using the following formula:

$$H(x) = q + (1 - q)F(x)$$

where ***q*** is the probability of zero precipitation. Edwards (2001) suggested that ***q*** can be calculated simply as ***m/n***, where ***n*** is the total number of months and ***m*** is the number of months with no precipitation.

After calculating ***H(x)***, the mean is standardised as **0** and standard deviation as **1**.

To transform ***H(x)*** and obtain SPI, the approach formulated by Abramowitz and Stegun (1965) is used:

$$SPI = W - \frac{C_0 + C_1 W + C_2 W^2}{1 - d_1 W + d_2 W^2 + d_3 W^3}$$

$$W = \sqrt{-2\ln(P)}$$

for $P \leq 0.5$

P is the probability of exceeding a determined precipitation value, ***P=1-H(u).*** If ***P>0.5, P*** is replaced by **1-P** and the sign of the resultant SPI is switched.

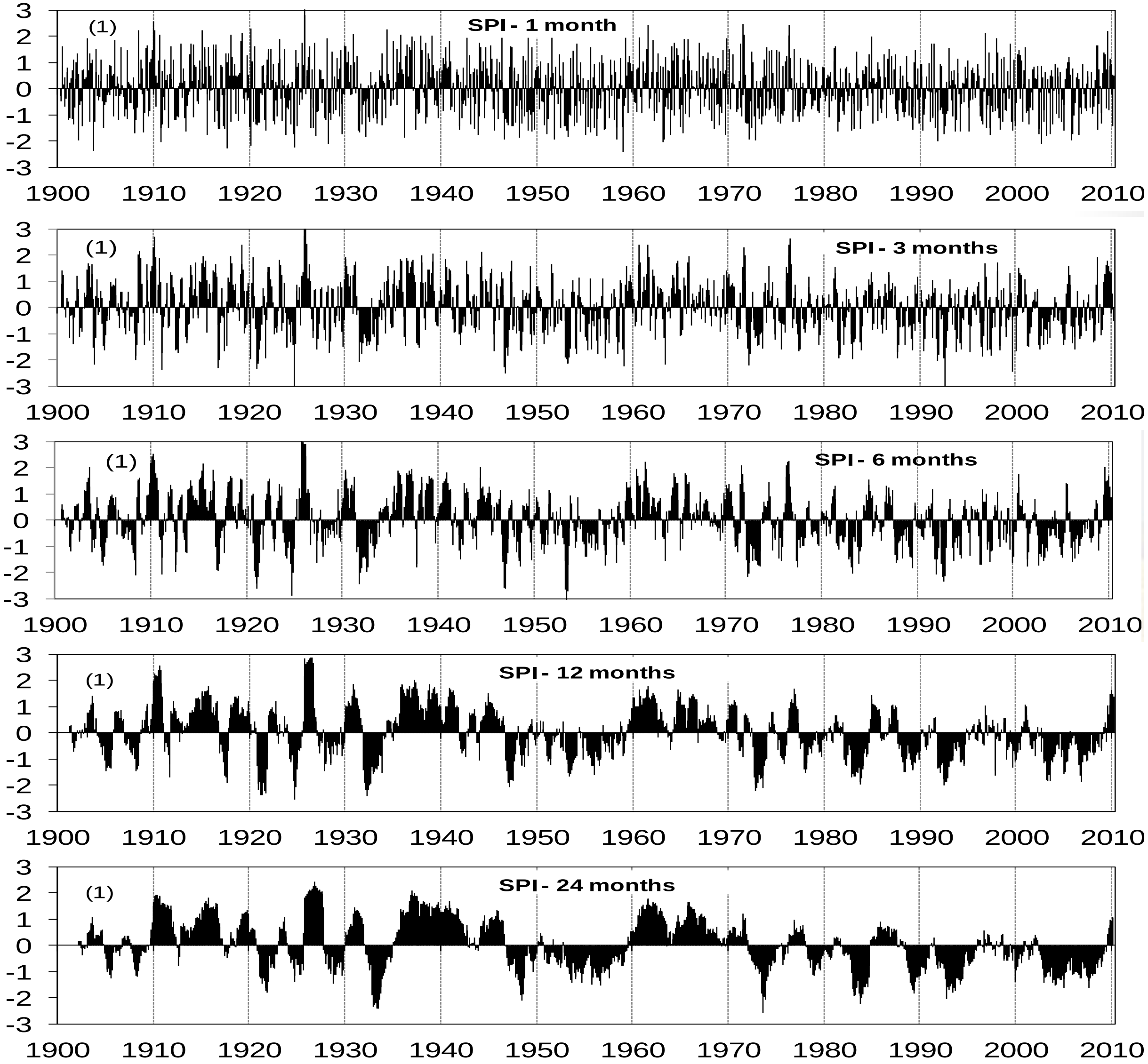
The constants are:

$C_0 = 2.515517$, $C_1 = 0.802853$, $C_2 = 0.010328$, $d_1 = 1.432788$, $d_2 = 0.189269$, $d_3 = 0.001308$

V. Drought indicator

Standardized Precipitation Index (SPI)

- Temporal evolution for data series of SPI at time scales of at time scales of 1, 3, 6, 12 and 24 months for the period 1901-2010 (at Doksany observatory, the Czech Republic)



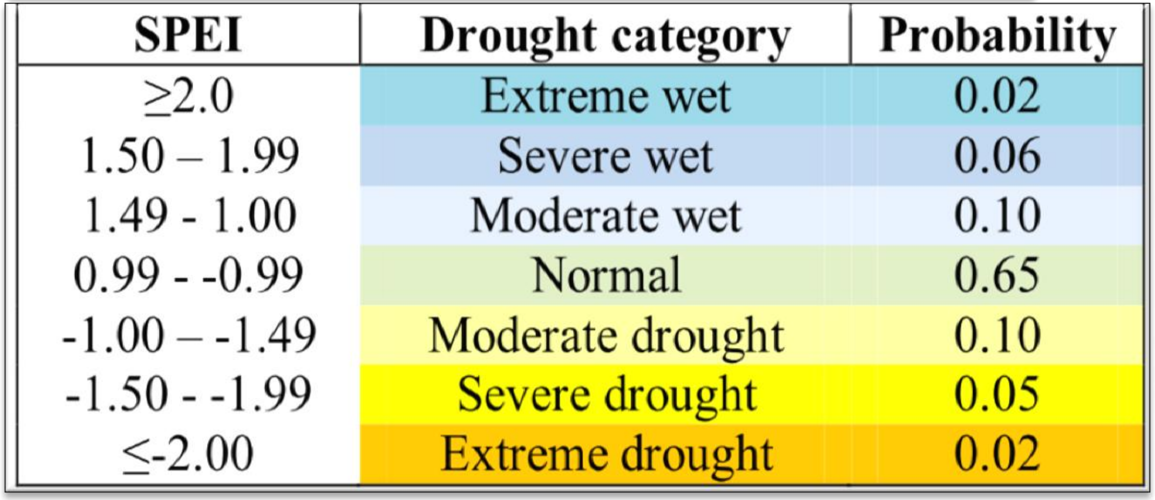
- Drought appears first on the short time scale and continues to the longer time scales if dry conditions persist
- The plots showed that the period in which dry (wet) conditions were identified tended to increase by some months as the time scale became longer
- This resulted from the procedure for calculation of the multi-scalar drought index, because longer time scales generated smoother fluctuations and thus a larger sequence of anomalies with the same sign
- These graphs also reflect the transition of meteorological drought (SPI-1) to agricultural drought (SPI-3 and SPI-6) and hydrological drought (SPI-12 and SPI-24)

V. Drought indicator

Standardized Precipitation Evapotranspiration Index (SPEI)

- **New variation of the SPI index by Vicente-Serrano et al. (2010) includes a temperature component.**
- The required input data to run the program on are monthly precipitation totals, mean temperature, and the latitude of weather station.
- **More information can be explored through obtaining the SPEI at http://sac.csic.es/spei/index.html.**

The 7 classes of SPEI category according to its value



SPEI	Drought category	Probability
≥2.0	Extreme wet	0.02
1.50 – 1.99	Severe wet	0.06
1.49 - 1.00	Moderate wet	0.10
0.99 - -0.99	Normal	0.65
-1.00 – -1.49	Moderate drought	0.10
-1.50 - -1.99	Severe drought	0.05
≤-2.00	Extreme drought	0.02

- A drought episode was defined as a period longer or equal to 1 month during the growing season (April to September) when the SPEI value was ≤ -1.
- The monthly SPEI values > -0.99 or < 0.99 were considered as normal conditions.

Source: Potop, V., Boroneanţ, C., Možný, M., Štěpánek, P., Skalák, P. Observed characteristics of drought over the Czech Republic and its link with the large scale circulation. Theor Appl Climatol (submitted). 2012

V. Drought indicator

Standardized Precipitation Evapotranspiration Index (SPEI)

- The probability distribution of cumulative $D_i = P_i - PET_i$ series is aggregated at different time scales, following the same procedure as that for the SPI:

$$D_n^k = \sum_{i=0}^{k-1} P_{n-i} - PET_{n-i}$$

where k (months) is the timescale of the aggregation and n is the calculation month.

- A three parameter distribution is needed to calculate the SPEI, since in **two parameter distributions the variable (x)** has a lower boundary of zero ($0 > x < \infty$), whereas **in three parameter distributions x can take values in the range** ($\gamma > x < \infty$, where is the parameter of origin of the distribution); consequently, x can have negative values, which are common in D series.
- The probability density function of a three parameter Log-logistic distributed variable is expressed as:
- $$-\left(—\right)\quad\left(\quad\left(—\right)\right)$$
  - *where a, β and γ are scale, shape and origin parameters, respectively, for D values in the range ($\gamma > D < \infty$).*

Source: More information can be explored through obtaining the SPEI at http://sac.csic.es/spei/index.html

V. Drought indicator

Standardized Precipitation Evapotranspiration Index (SPEI) Vicente-Serrano et al. (2010)

- Parameters of the Log-logistic distribution can be obtained following different procedures. Among them, the L-moment procedure is the most robust and easy approach (Ahmad et al., 1988).
- When L-moments are calculated, the parameters of the Pearson III distribution can be obtained following Singh et al. (1993):

$$\beta = \frac{2w_1 - w_0}{6w_1 - w_0 - 6w_2} \qquad \alpha = \frac{(w_0 - 2w_1)\beta}{\Gamma(1+1/\beta)\Gamma(1-1/\beta)} \qquad \gamma = w_0 - \alpha\Gamma(1+1/\beta)\Gamma(1-1/\beta)$$

where Γ(β) is the gamma function of β.

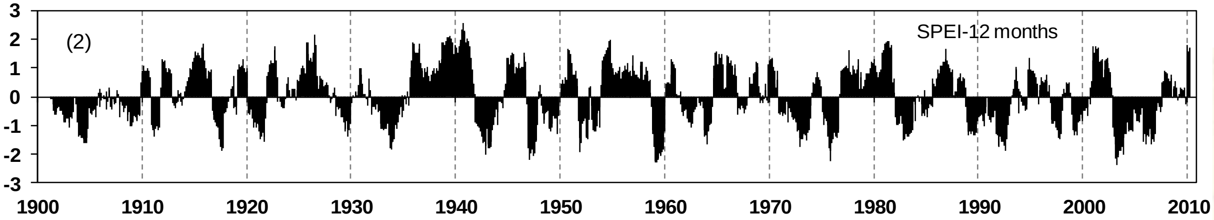
- The Log-logistic distribution adopted for standardizing the *D* series for all time scales is given by:

$$F(x) = \left[1 + \left(\frac{\alpha}{x - \gamma}\right)^{\beta}\right]^{-1}$$

- value the SPEI is then transformed to a normal variable With F(x) the SPEI can easily be obtained as the standardized values of F(x) by means of the following approximation (Abramowitz and Stegun, 1965):

$$SPI = W - \frac{C_0 + C_1W + C_2W^2}{1 - d_1W + d_2W^2 + d_3W^3} \qquad W = \sqrt{-2\ln(P)}$$

for $P \leq 0.5$ (the probability of exceeding a determined D value)



Temporal evolution for data series of SPEI at time scales of 12 months for the period 1901-2010 (at Doksany observatory, the Czech Republic).

V. Drought indicator

Standardized Precipitation Evapotranspiration Index (SPEI)

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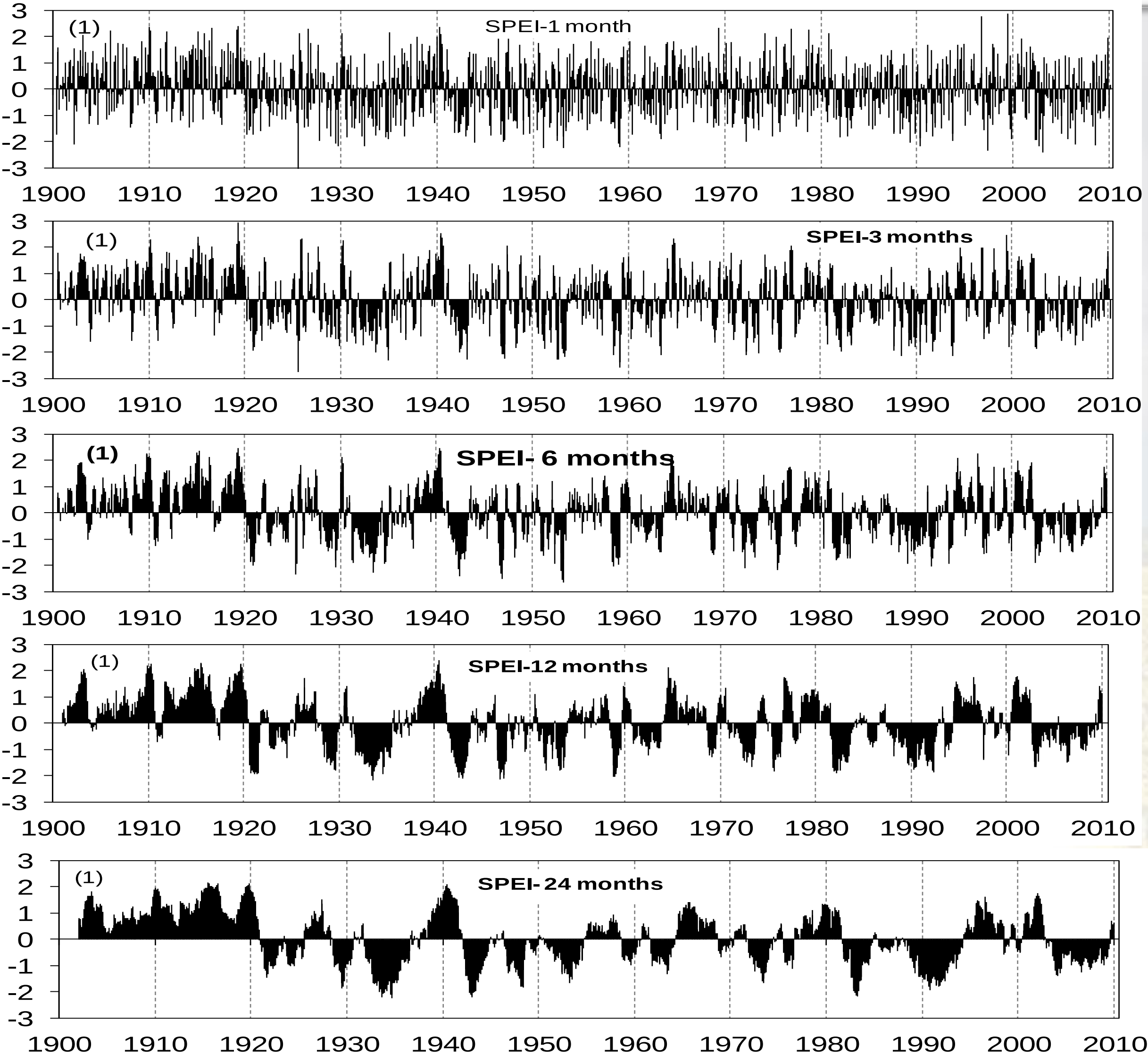
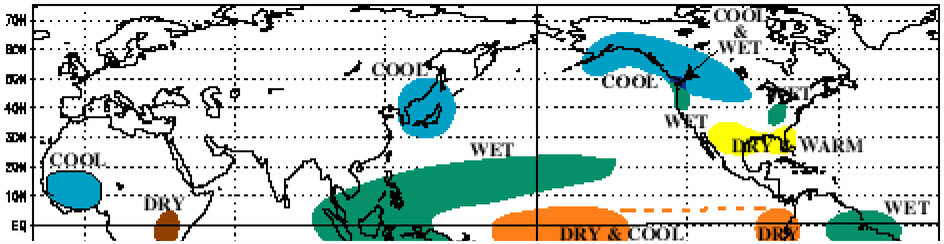


VI. Causes of drought

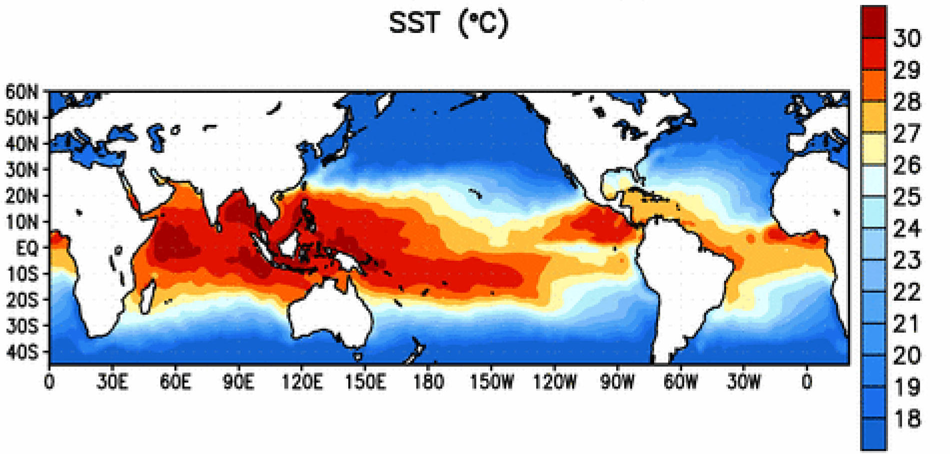
El Niño Southern Oscillation (ENSO)

- one of the main sources of variability in the Earth's climate
- a warm water current that periodically flows along the coast of Ecuador and Peru (every 2 to 7 years)
- the extremes of this atmosphere-ocean coupled mode are known as the El Niño and La Niña phases
- **El Niño** – pressure differences across the tropical Pacific Ocean are reduced, ⇒SST anomalies are "+" in the central and eastern tropical Pacific Ocean
- **La Niña** – cold SST, enhanced SLP gradient from W to E across the tropical Pacific Ocean.
- precipitation/soil moisture at the global scale is greater during **La Niña** events than during **El Niño** events
- **El Niño** - tended to generate more droughts globally than **La Niña** events
  - at the longest time scales the percentage of the global surface area affected by drought during **El Niño** years was more than 4 times that for **La Niña** years (Vicente-Serrano et al., 2011)

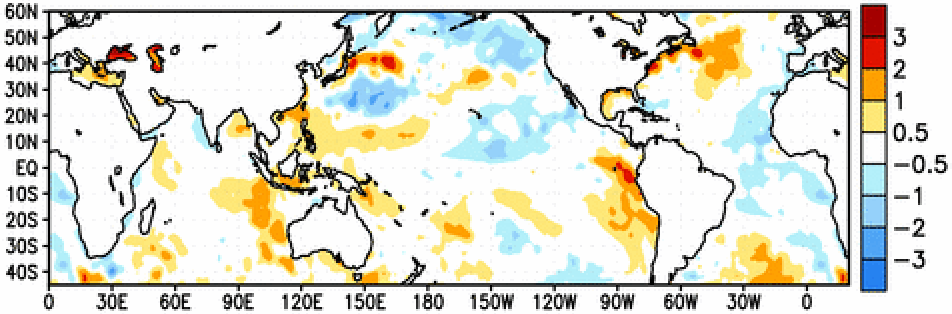
COLD EPISODE RELATIONSHIPS DECEMBER - FEBRUARY



Week centered on 02 MAY 2012
SST (°C)



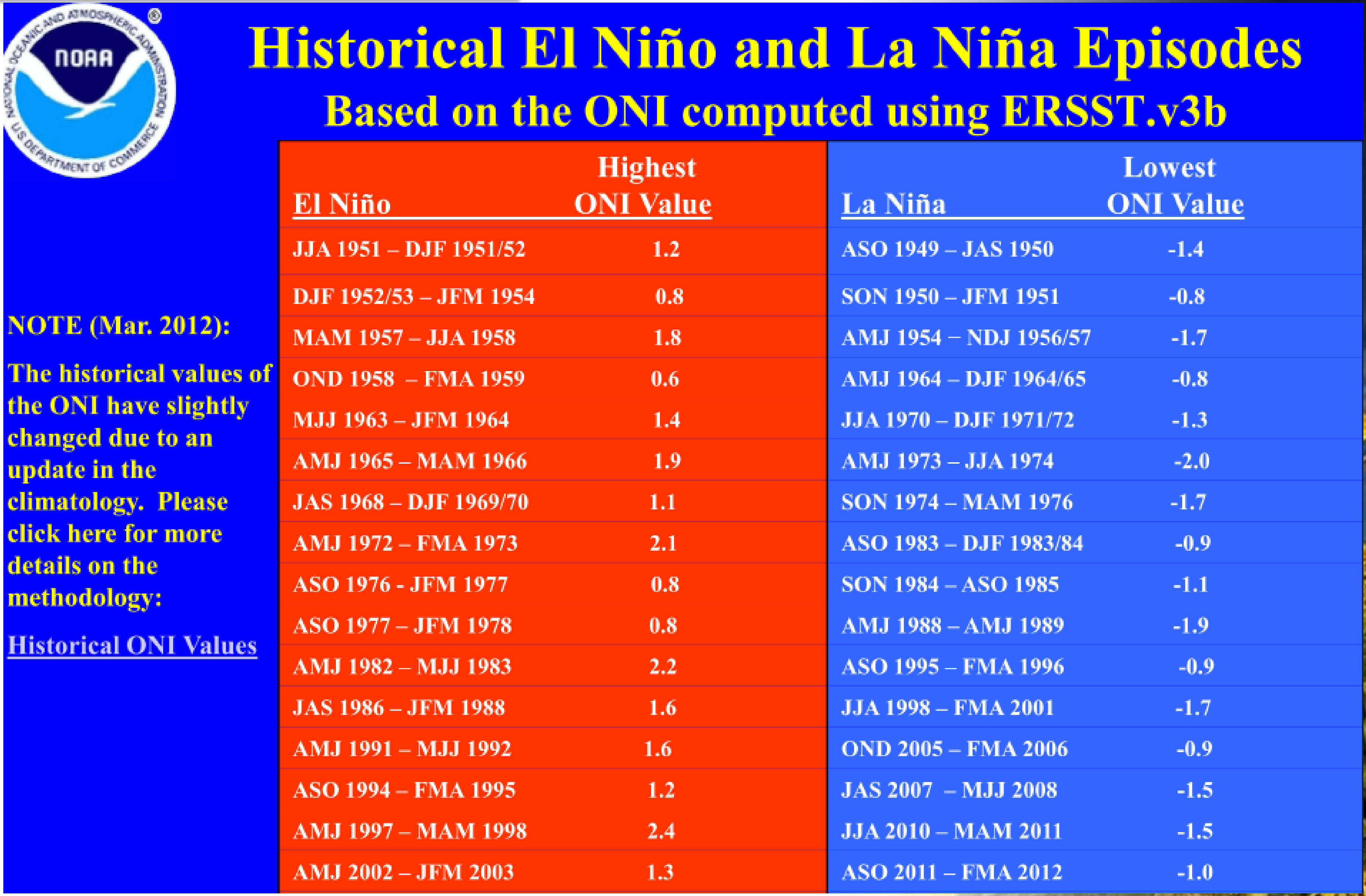
Anomalies (°C)



http://www.cpc.ncep.noaa.gov

VI. Causes of drought

El Niño Southern Oscillation (ENSO)



Historical El Niño and La Niña Episodes

Based on the ONI computed using ERSST.v3b

NOTE (Mar. 2012):

The historical values of the ONI have slightly changed due to an update in the climatology. Please click here for more details on the methodology:

Historical ONI Values

El Niño	Highest ONI Value	La Niña	Lowest ONI Value
JJA 1951 – DJF 1951/52	1.2	ASO 1949 – JAS 1950	-1.4
DJF 1952/53 – JFM 1954	0.8	SON 1950 – JFM 1951	-0.8
MAM 1957 – JJA 1958	1.8	AMJ 1954 – NDJ 1956/57	-1.7
OND 1958 – FMA 1959	0.6	AMJ 1964 – DJF 1964/65	-0.8
MJJ 1963 – JFM 1964	1.4	JJA 1970 – DJF 1971/72	-1.3
AMJ 1965 – MAM 1966	1.9	AMJ 1973 – JJA 1974	-2.0
JAS 1968 – DJF 1969/70	1.1	SON 1974 – MAM 1976	-1.7
AMJ 1972 – FMA 1973	2.1	ASO 1983 – DJF 1983/84	-0.9
ASO 1976 - JFM 1977	0.8	SON 1984 – ASO 1985	-1.1
ASO 1977 – JFM 1978	0.8	AMJ 1988 – AMJ 1989	-1.9
AMJ 1982 – MJJ 1983	2.2	ASO 1995 – FMA 1996	-0.9
JAS 1986 – JFM 1988	1.6	JJA 1998 – FMA 2001	-1.7
AMJ 1991 – MJJ 1992	1.6	OND 2005 – FMA 2006	-0.9
ASO 1994 – FMA 1995	1.2	JAS 2007 – MJJ 2008	-1.5
AMJ 1997 – MAM 1998	2.4	JJA 2010 – MAM 2011	-1.5
AMJ 2002 – JFM 2003	1.3	ASO 2011 – FMA 2012	-1.0

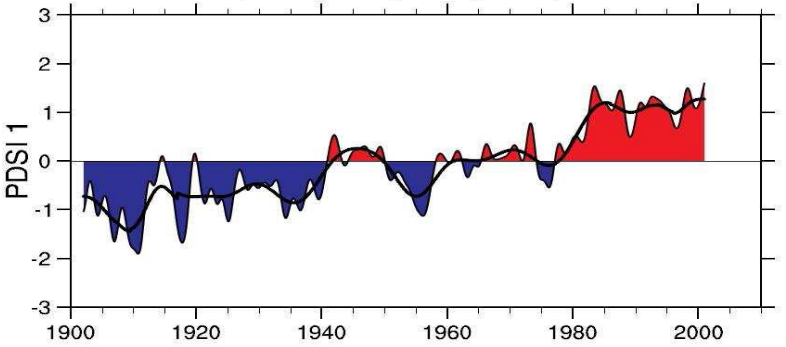
http://www.cpc.ncep.noaa.gov

VII. Drought and Climate Change

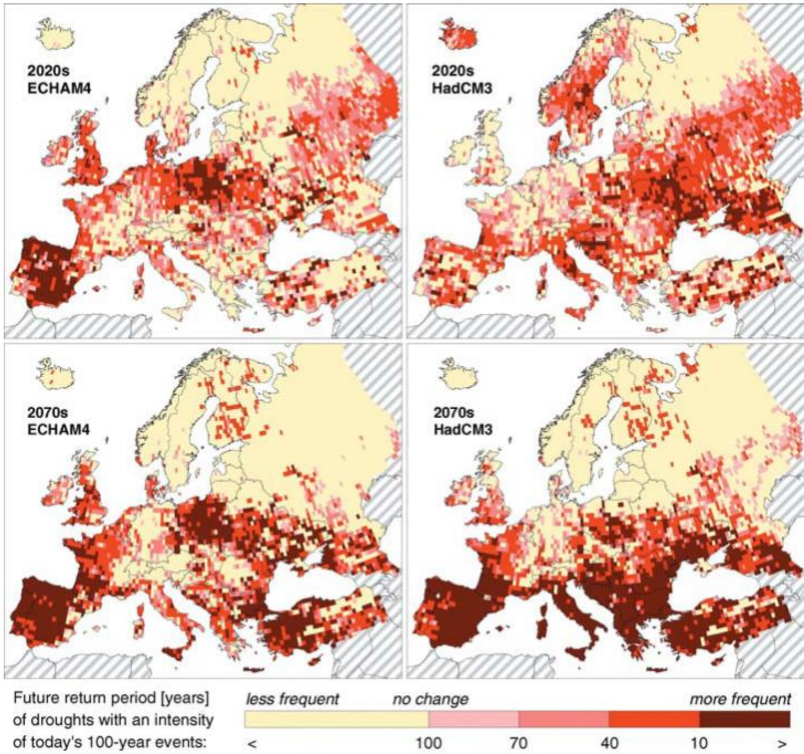
- The average global temperature has increased by +0.74°C over the past hundred years (between 1906 and 2005)
- The average global precipitation shows a slight increase over the last century
  - increased significantly in eastern parts of North and South America, northern Europe and northern and central Asia
  - declined in the Sahel, the Mediterranean, southern Africa and parts of southern Asia.
- Globally, the area affected by drought has likely increased since the 1970s.

- A large part of the recent drying is related to the shift toward more intense and frequent warm events (i.e., El Niño) of ENSO since the late 1970s. This is because El Niño often reduce precipitation over many low-latitude land areas.

- In the long-term projection for the 2070s, 100-year droughts show strong increases for large areas of southern and southeastern Europe (Portugal, all Mediterranean countries, Hungary, Bulgaria, Romania, Moldova, Ukraine, southern Russia)



Dai et al. 2004

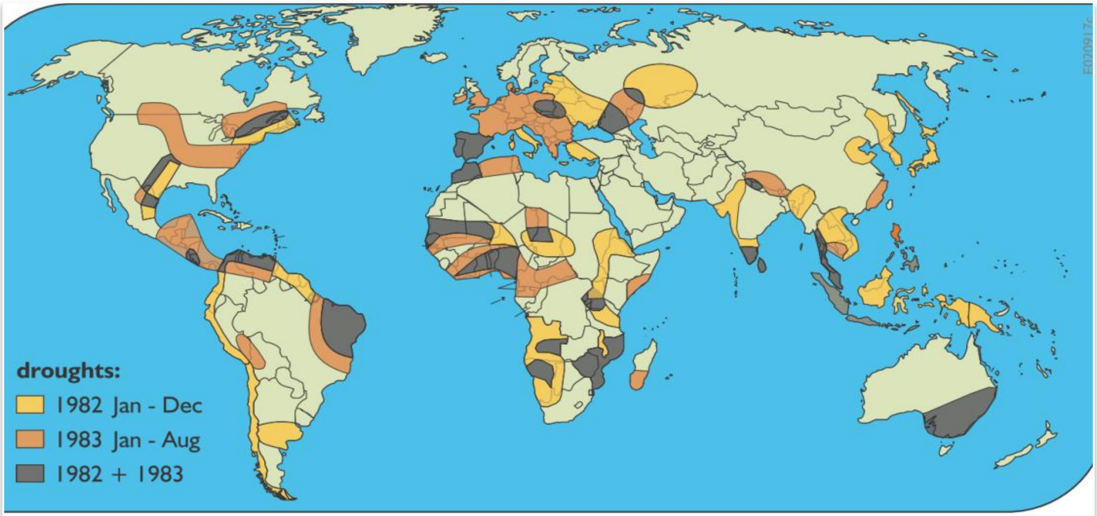


Lehner et al. 2006

VIII. Level study of drought at global, regional and local

1. At global scale

- *Trenberth (2011)* points out on a direct influence of global warming on precipitation.



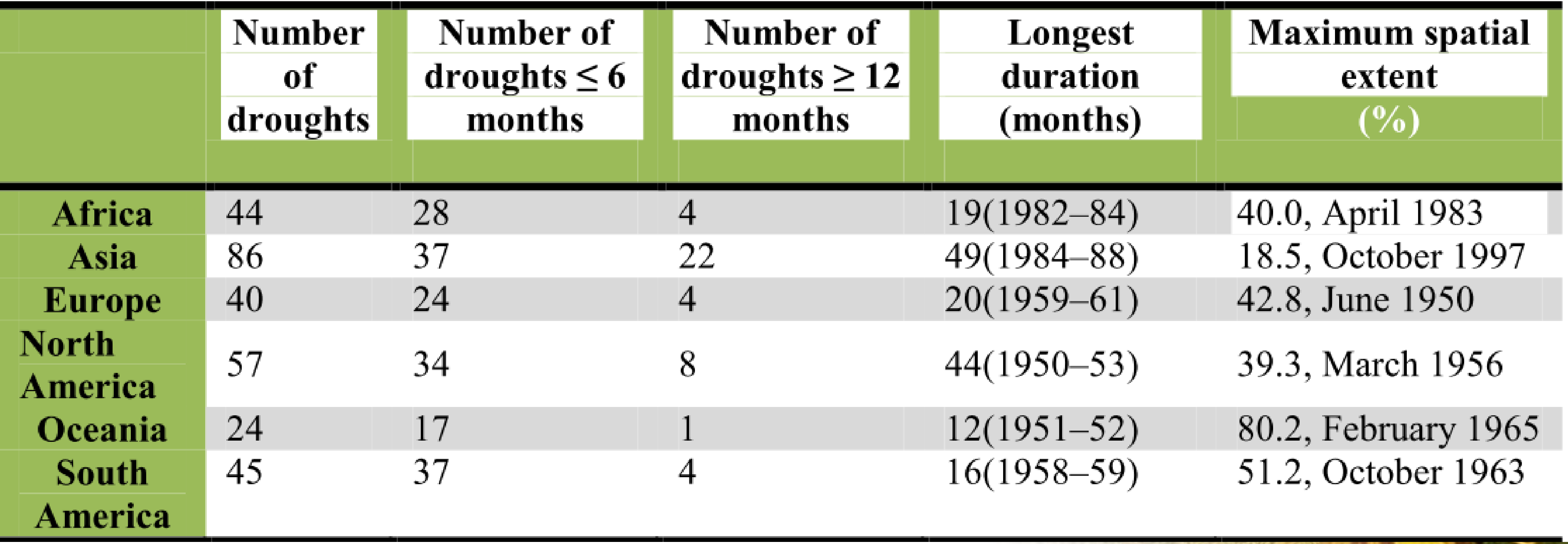
- the prolonged drought in Sahel-which was very prononced from the late-1960s to the late-1980s –continues;
- althought it is not quite as intense as it was;
- this drought has been linked, through changes in atmospheric circulation
- to changes in tropical SST patterns in the Pacific, Indian, and Atlantic basins (*Giannini et al. 2003*)
- changes in land-use is additional factor of importance
- drought has become widespread throughout much of Africa and more common in the tropics and subtropics.

- Increased heating leads to greater evaporation and thus surface drying, thereby increasing the intensity and duration of drought.
- The models project that patterns of precipitation will not change much, but will result in dry areas becoming drier (generally throughout the subtropics) and wet areas becoming wetter, especially in the mid- to high latitudes.
- So, that wet areas get wetter and dry areas get driers, giving rise to the „**rich get richer and poor get poorer' syndrome !!!!**".
- Global warming leads to increased risk of heat waves in association with drought; because once the soil moisture is depleted, all of the heating goes toward raising temperatures and wilting plants.

VIII. Level study of drought at global, regional and local

1. At global scale

Table (Sheffield et al. 2009)**:** Summary of large-scale drought occurrence for the six continents. For the last column, the extent as a percentage of total area and the date when the maximum spatial extent. Oceania is defined as Australia, New Zealand, Papua New Guinea, and the Pacific Islands



	Number of droughts	Number of droughts ≤ 6 months	Number of droughts ≥ 12 months	Longest duration (months)	Maximum spatial extent (%)
Africa	44	28	4	19(1982–84)	40.0, April 1983
Asia	86	37	22	49(1984–88)	18.5, October 1997
Europe	40	24	4	20(1959–61)	42.8, June 1950
North America	57	34	8	44(1950–53)	39.3, March 1956
Oceania	24	17	1	12(1951–52)	80.2, February 1965
South America	45	37	4	16(1958–59)	51.2, October 1963

- the Sheffield et al. note with respect to global and continental droughts:

The longest duration drought:

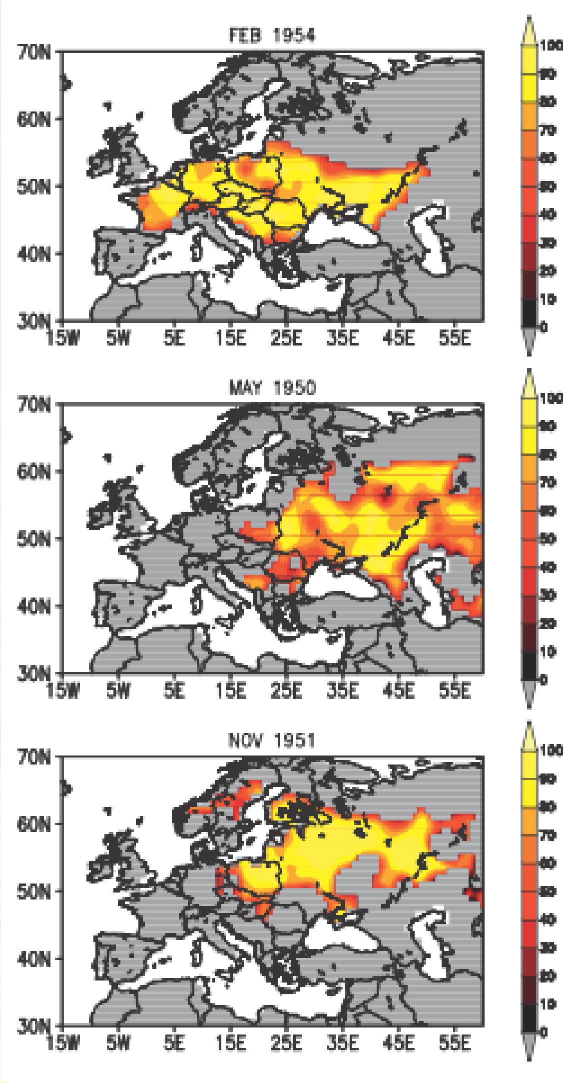
  - **Asia** - 49 months (4 yr) from 1984 to 1988 (persisted over central Siberia before migrating southeast to northern China and back again)
  - **North American** drought 44 months (1950–53)

- The Eurasian analysis identified 116 events: in Europe (40) and Asia (86).

VIII. Level study of drought at global, regional and local

1. At global scale

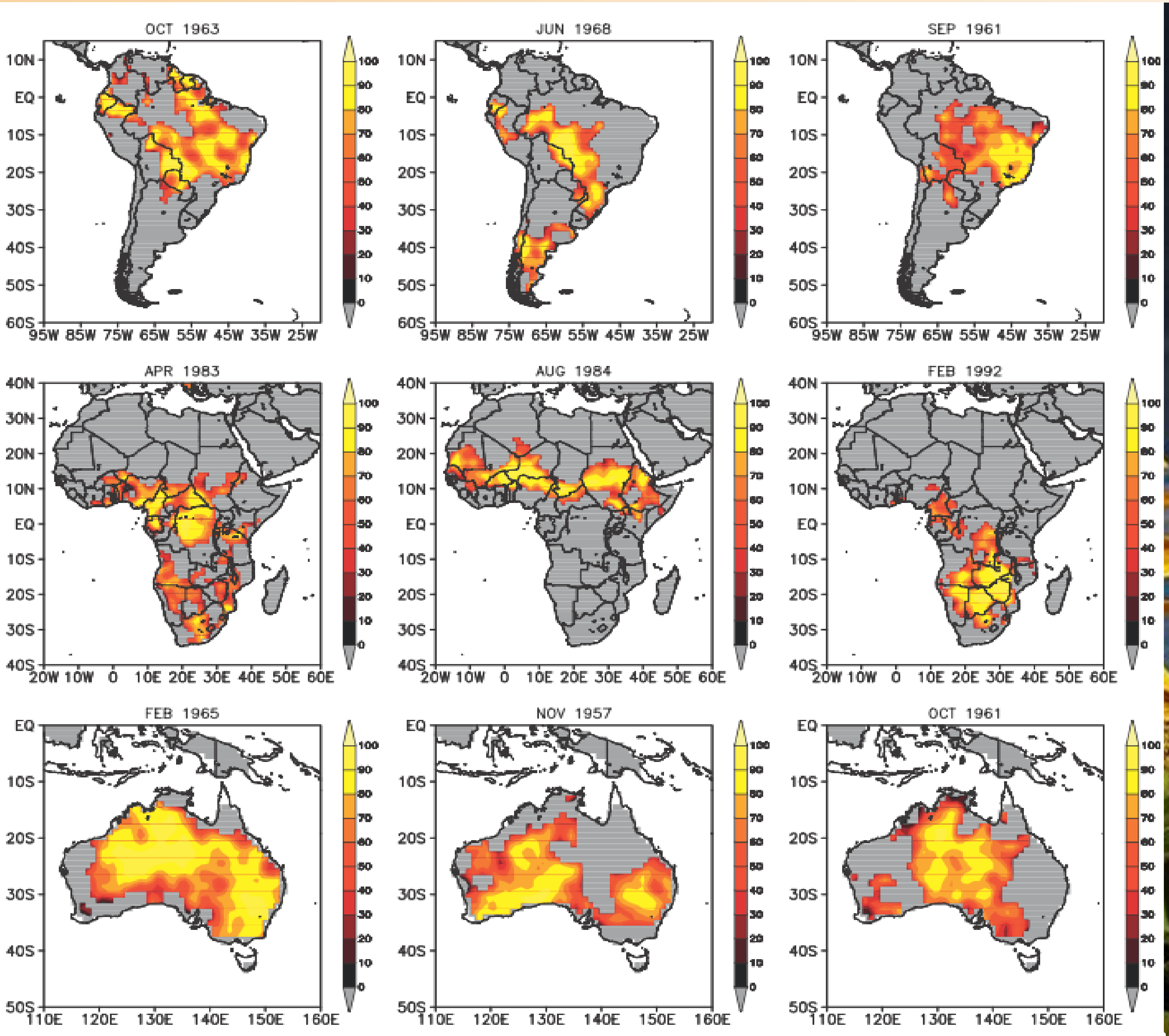
- **African**: dominated by events during the mid-1970s, 1980s
- **Asia**: 1950–52 (May 1951 centered on Kazakhstan) and **1999–2000** (are highlighted in the map for May 2000 to be very severe), **1997–98** most spatially extensive (from eastern China to central Asia); **1976** as the second driest year in the European part of the FSU (1981was the driest)
- **Europe**: high variability in the **1950s** is associated with multiple periods of large drought extent
- **North America:** the longest droughts identified for North America are in the 1950s (**1952/53** most of the United States and southern Canada), with only the 1999–2000 drought of comparable duration
- **Oceania (Australia)**: there are several events with high percentage extent in drought (e.g., 82% in 1965);the 1982–83 drought - one of the most severe and damaging events of the second half of the 20th century because it was intense causing over 3 billion Australian dollars ($AUS) in damages
- **South America:** occurred during 1958–59, 1982–83, and 1963–64 (14 months)



Source Sheffield et al. 2009 **: Severity and maximum spatial extent of selected major drought events for North America, Europe, and Asia. The events are extracted by calculating the mean severity of all grid cells in the drought multiplied by the area and searching for the maximum value.**

VIII. Level study of drought at global, regional and local

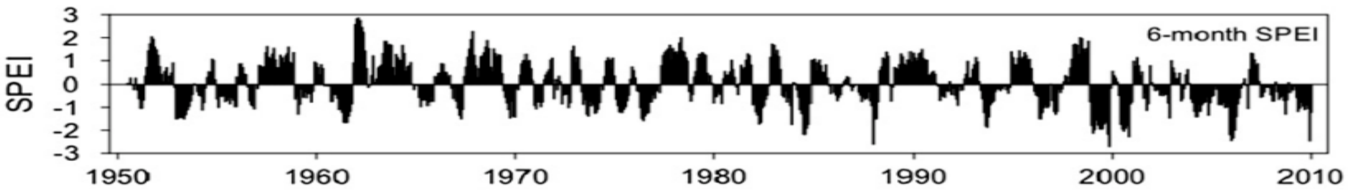
1. At global scale

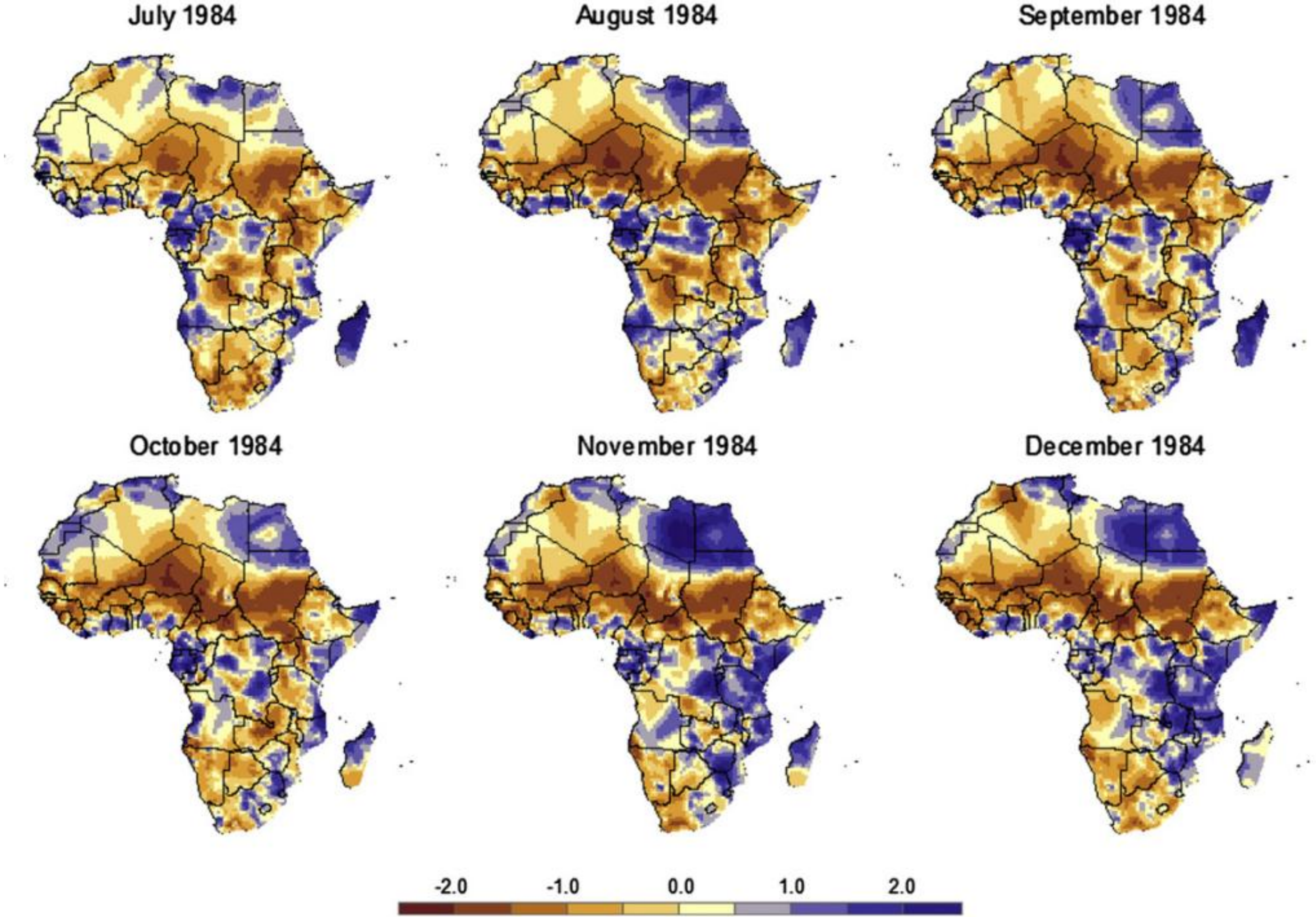


Source Sheffield et al. 2009 **: Severity and maximum spatial extent of selected major drought events for North America, Europe, and Asia. The events are extracted by calculating the mean severity of all grid cells in the drought multiplied by the area and searching for the maximum value.**

VIII. Level study of drought at global, regional and local

1. At global scale





- the evolution of the SPEI in Nairobi (Kenya) between 1950 and 2010

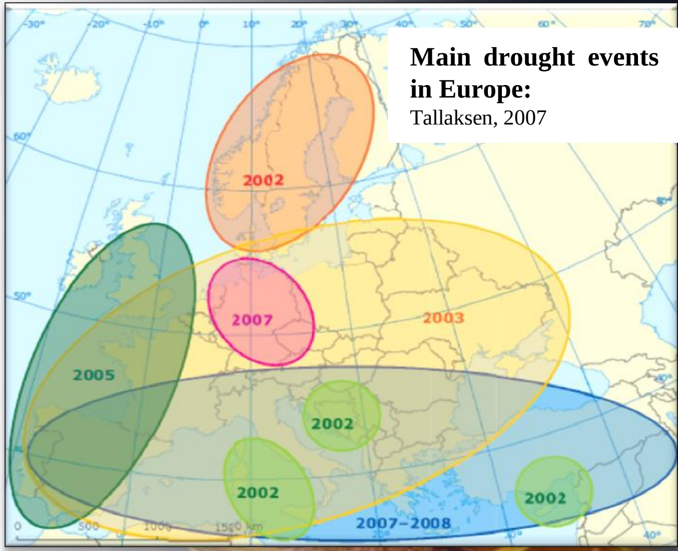
- the 6-month SPEI from July to December 1984 when very extreme drought conditions affected the Sahel and East Africa.

Source Vicente-Serrano et al. 2012: Spatial distribution of the 6-month SPEI for the entire Africa between July and December 1984.

VIII. Level study of drought at global, regional and local

2. At the European scale

- Research on drought has been particularly focused on the Iberian Peninsula, Mediterranean and Balkans which are regions mostly prone to severe drought with impacts on agriculture, water recourses and ecosystems.
- Drought situation in many European regions has become more severe (e.g., 2003 and 2006 in Central Europe, 2007 in southern and eastern Europe, and 2010 in eastern Europe).

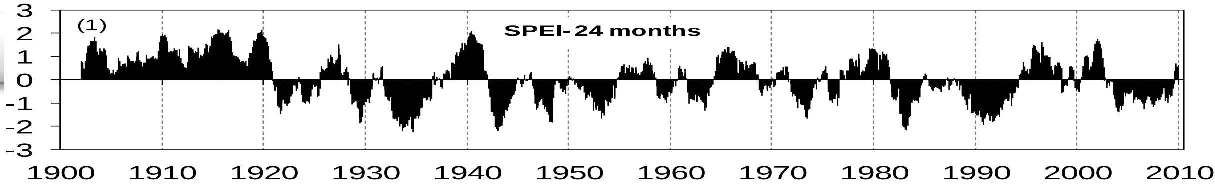


Main drought events in Europe:
Tallaksen, 2007

- High summer temperatures are responsible for the large extent of the drought conditions, in summer, over the last two decades.
- The 2003 heat wave that affected much of Europe from June to September bears a close resemblance to what many regional climate models are projecting for summers in the latter part of the 21st century.
- The 2007 European heat wave during June-August affected mostly the S and S-E Europe with record-breaking temperatures in a situation unprecedented even for the regions typically used to conditions of extreme heat.
- The summer of 2010 was exceptionally warm in eastern Europe and large parts of Russia and caused adverse impacts that exceeded in amplitude and spatial extent the previous hottest summer of 2003.

VIII. Level study of drought at global, regional and local

2.1 Drought conditions over Europe



- Droughts have occurred frequently over the last century in Europe and they are part of natural climatic cycles.
- Droughts and floods, present a strong decadal variability:
  - **very wet conditions** were found between mid 1910s and 1920s and at the beginning of 1980s.
  - **the driest conditions** were in the mid 1940s–1950s
- Drought conditions over Europe appear when the moisture transport from source regions (e.g., the subtropical Atlantic) to Europe is weak.
- Weak moisture transport + other anomalies (e.g., soil moisture content, water holding capacity of the soil, local temperature) is associated with drought conditions over Europe.
- Reduced soil moisture during winter or spring covering a midcontinental region, could help to induce and amplify a warm and dry summer over the region.
  - since soil moisture varies slowly (weeks to months) and thus carries memory from the previous month's climate, reduced soil moisture in winter, due to the lack of precipitation and cold temperatures, can affect the availability of moisture condition in summer.
- The 10 hottest and driest European summers since 1948 were systematically preceded by a winter and spring precipitation deficit over the southern part of Europe (Vautard et al. (2007).

VIII. Level study of drought at global, regional and local

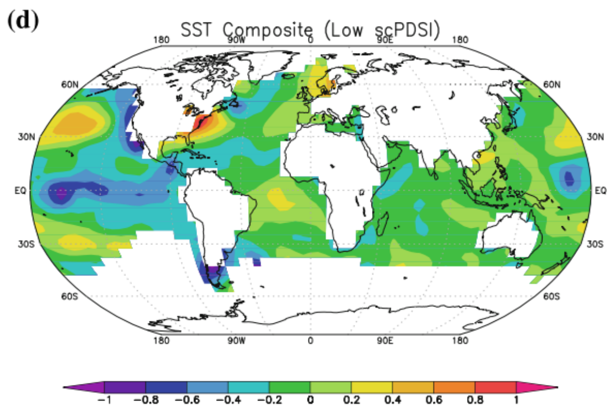
2.1 Drought conditions over Europe

- Summer drought conditions over Europe are associated with a tripole-like SST pattern (Fig. d):
  - over the North Atlantic Ocean
  - with positive anomalies over the North Sea
  - the east coast of US and negative anomalies over the Canadian coast and south of Greenland
- Dry(wet) conditions in summer over the central and southern part of Europe (Scandinavian Peninsula) are associated with a strong center of positive SLP anomalies (up to 2.5 hPa) over (Fig. a):

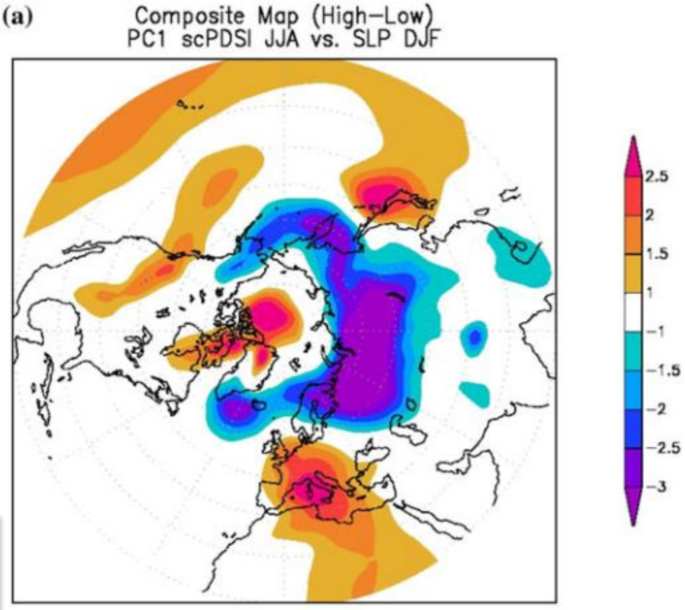
-the central part of Europe
-a center of strong negative SLP anomalies over Scandinavia and Siberia

- This pattern caries cold and dry air from the north towards Europe and inhibits precipitation over these areas
  - Cold air and reduced amount of precipitation in winter can trigger dry conditions over this area in summer, due to the fact that the soil is dry and not saturated

the variability of summer moisture conditions over Europe is strongly related to the previous winter SST anomalies, associated with large scale climate modes of variability (e.g., ENSO) and global warming



d) winter SST for the seven driest years (1921, 1938, 1947, 1949, 1950, 1975, 1976) (Ionita et al, 2011).

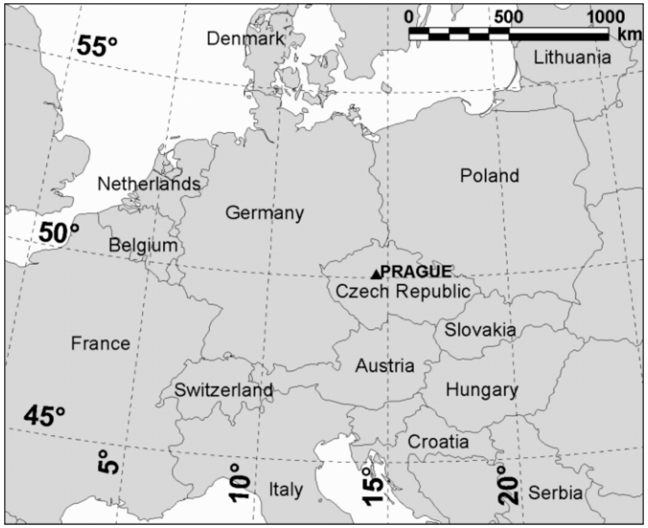


a) The composite map (High–Low) between the standardized times series of TSP1 and winter SLP (Ionita et al, 2011).

VIII. Level study of drought at global, regional and local

2.2 Drought conditions in Central Europe

- **Central Europe** is not frequently thought of as being a particularly drought-prone region in the European context with the exception being the Panonian Basin (eastern Austria and a large part of Hungary).
- Only recently has the importance of a systematic research of drought climatology been recognized in countries like the Czech Republic.



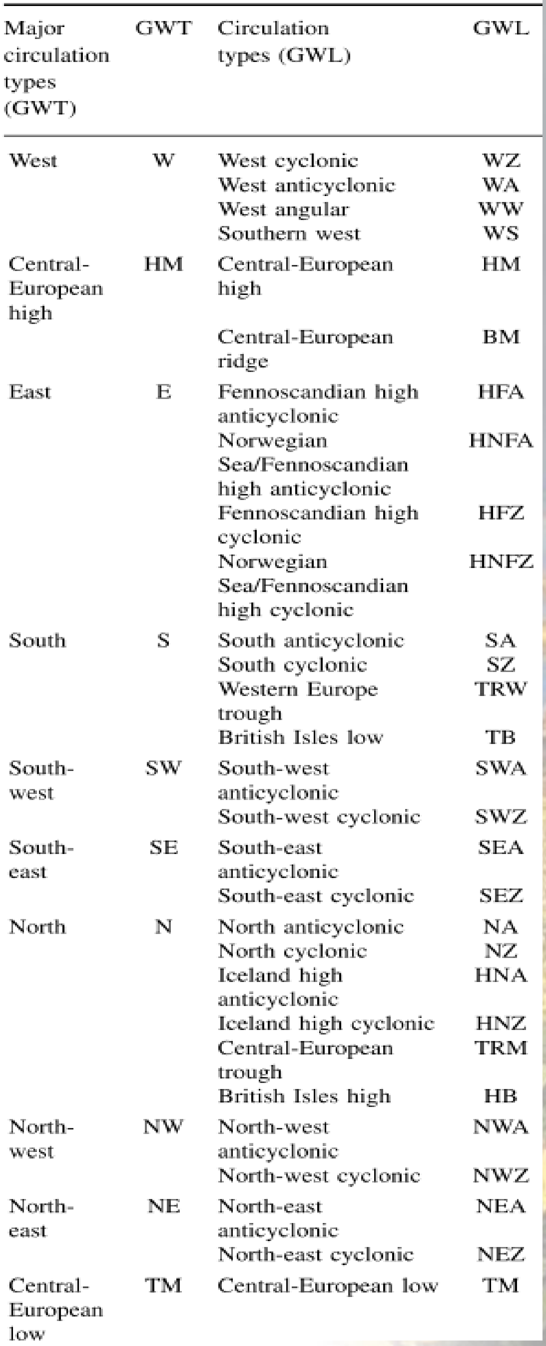
- Drought conditions in the central part of Europe are related to the occurrence of different circulation patterns and that drought is very pronounced during the early vegetation season (AMJ) (Trnka et al. 2009)
- Specific circulation types are associated with higher drought occurrence
- **Hess–Brezowsky catalogue of large-scale circulation patterns** (Hess and Brezowsky, 1952; Gerstengarbe et al., 1999) is commonly used to describe the atmospheric flow over Europe

- Three groups of the circulation (**zonal, half-meridional**, and **meridional**) are divided into **ten major types** [Grosswettertypen (GWT)] and **29 types** [Grosswetterlagen(GWL)].

VIII. Level study of drought at global, regional and local

2.2 Drought conditions in Central Europe

- The patterns conducive to drought during large-scale drought events were in:
    - **MAM** - the **Central-European high**, **east types** (HFA, HNFA), **south** and **south-west types** (TRW, SWA), **south-east types** (SEA and SEZ) and partially also **north-east types** (NEA)
    - **JJA** - as conducive to drought are associated with above normal temperatures or below average precipitation, or both (**the Central-European high, east types, south types, south-east types** and **south-west types**)
- **AMJ** - the **Central-European high** (HM, BM), **east types** (HFA, HNFA, HFZ), **south types** (TRW, SA, SZ) and **south-east types** (SEA) being the most important.

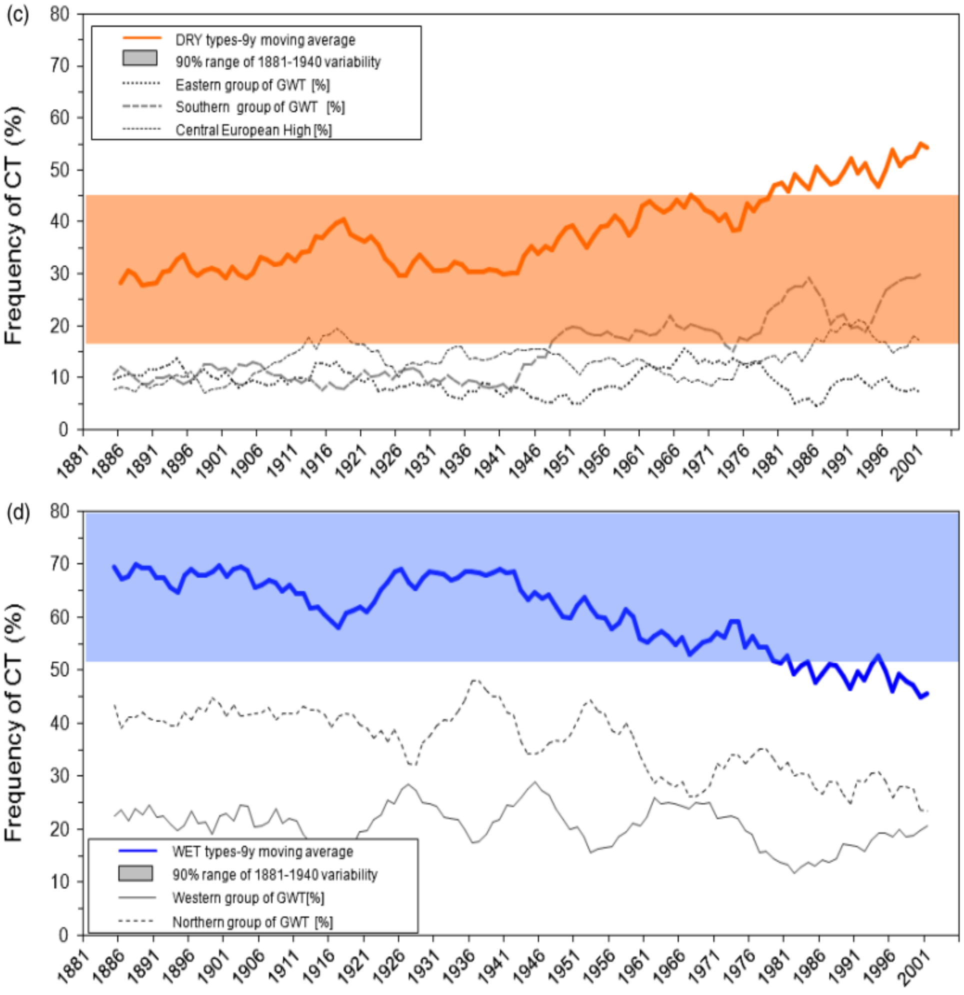


Major circulation types (GWT)	GWT	Circulation types (GWL)	GWL
West	W	West cyclonic	WZ
		West anticyclonic	WA
		West angular	WW
		Southern west	WS
Central-European high	HM	Central-European high	HM
		Central-European ridge	BM
East	E	Fennoscandian high anticyclonic	HFA
		Norwegian Sea/Fennoscandian high anticyclonic	HNFA
		Fennoscandian high cyclonic	HFZ
		Norwegian Sea/Fennoscandian high cyclonic	HNFZ
South	S	South anticyclonic	SA
		South cyclonic	SZ
		Western Europe trough	TRW
		British Isles low	TB
South-west	SW	South-west anticyclonic	SWA
		South-west cyclonic	SWZ
South-east	SE	South-east anticyclonic	SEA
		South-east cyclonic	SEZ
North	N	North anticyclonic	NA
		North cyclonic	NZ
		Iceland high anticyclonic	HNA
		Iceland high cyclonic	HNZ
		Central-European trough	TRM
		British Isles high	HB
North-west	NW	North-west anticyclonic	NWA
		North-west cyclonic	NWZ
North-east	NE	North-east anticyclonic	NEA
		North-east cyclonic	NEZ
Central-European low	TM	Central-European low	TM

VIII. Level study of drought at global, regional and local

2.2 Drought conditions in Central Europe

- conducive to drought during AMJ that are east types, south types, and Central-European high
- those conducive to wet conditions west types, north types, and Central-European low
- at the end of the 19th century the ratio of dry to wet GWT was 30 : 70, this ratio has changed to being close to 50 : 50 a hundred years later
- this change in favour of the drought-conducive patterns took place after 1940 and has continued ever since
- this phenomenon is particularly strong during the AMJ period
- the increasing frequency of south GWL (associated with higher temperatures and lower rainfall) at the expense of north types might contribute to Central Europe drying in addition to the regional warming that cannot be related to changes in atmospheric circulation

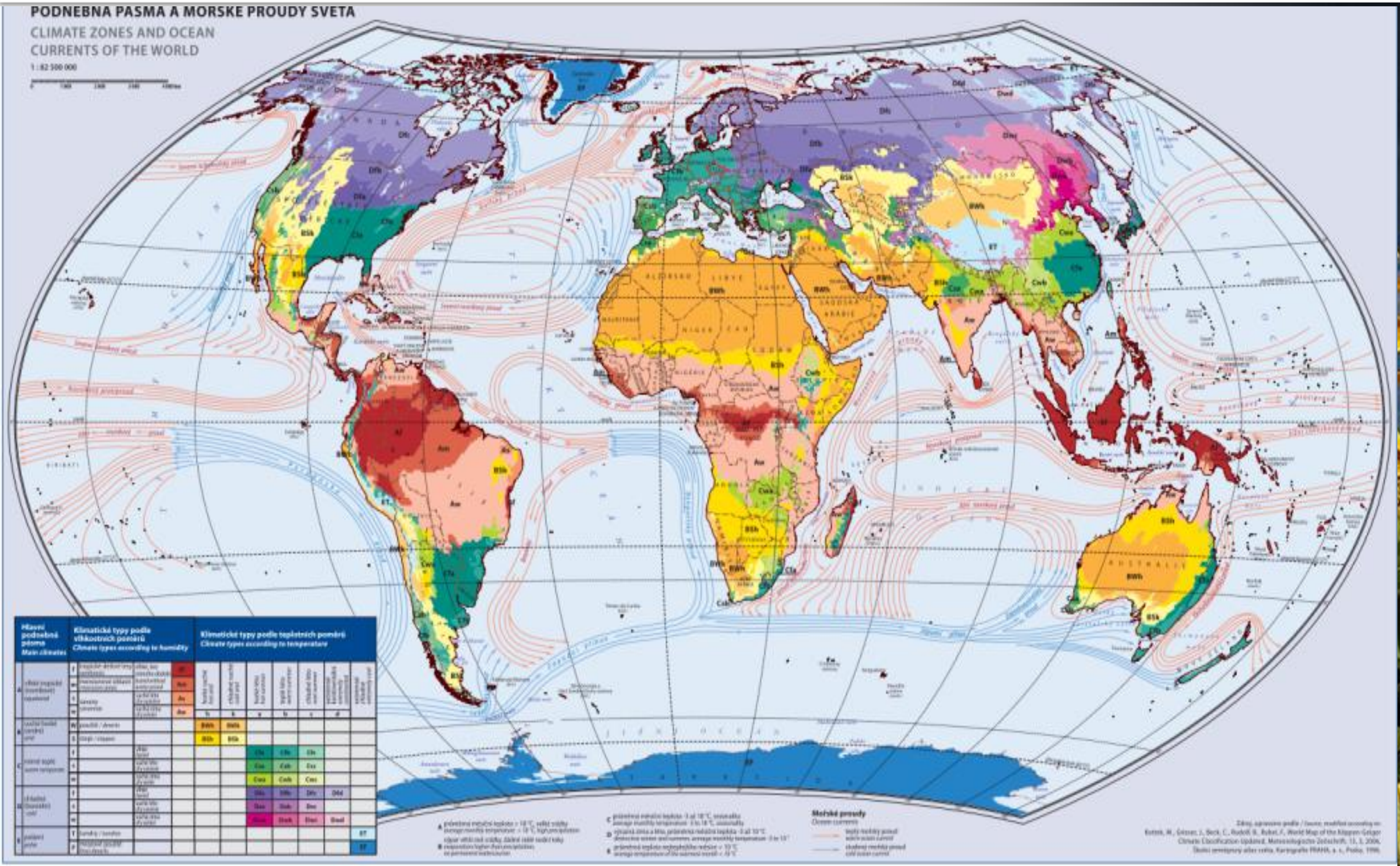


Source Trnka et al 2009: Long-term variability of GWT conducive to drought (c) and to wet (d) conditions is also expressed as 9-year moving averages of the aggregated frequency of the dry and wet circulation types during the AMJ period. The shading represent the 99% confidence intervals of the dry/wet circulation-type frequencies during the 1881–1940 reference period.

The Czech Republic

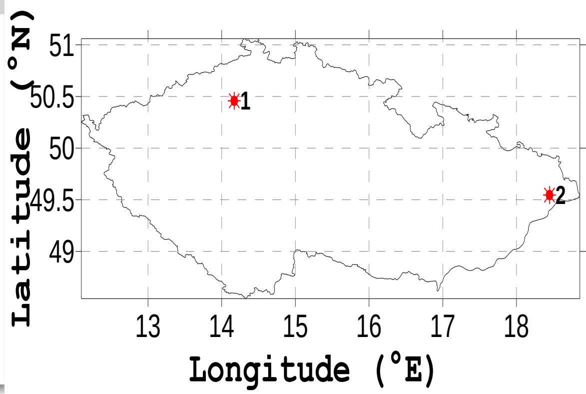
3.1 Physical geography of Czechia

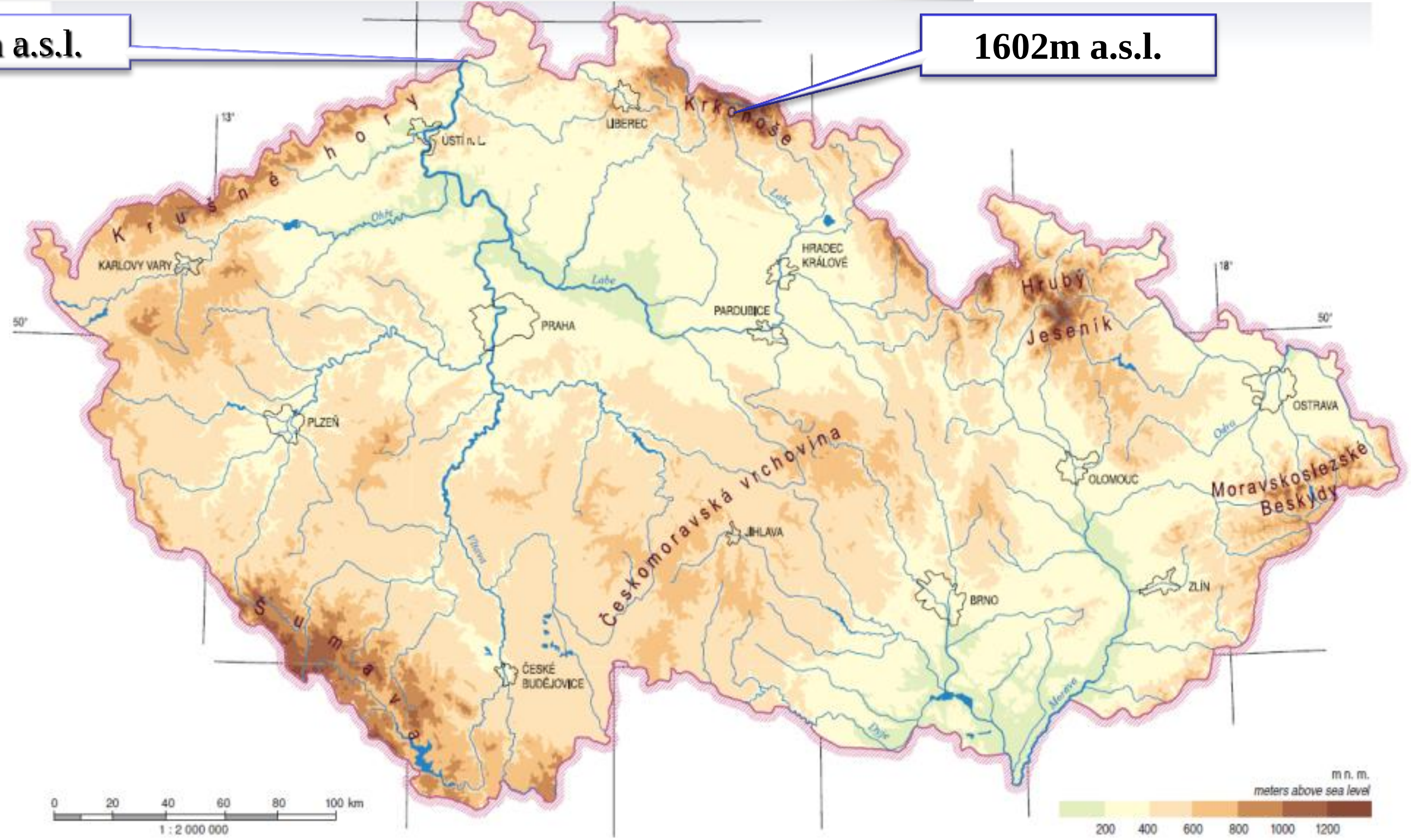
- CR has a surface area of 78.866 km^2 located in central Europe within the temperate climate zone
- Characterized by a moderate humide climate - 4 alternating seasons.



3.1 Physical geography of Czechia

- The country’s territory extends along the 50th paralell
- The maximum lenght in the longitudional direction – 452 km.
- The maximum latitudional width is 276 km.
- CR is traversed by the 15th meridian, which determines CET.
- Mt. Snežka - highest point (1,602m a.s.l.) in the Giant Mt. range
- Hřensko – lowest point (115m a.s.l) at the Elbe River





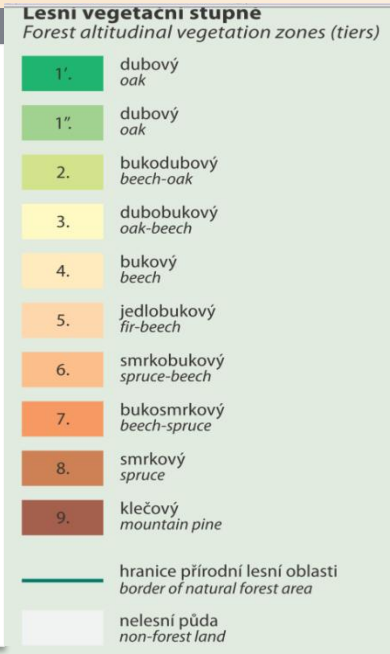
115 m a.s.l.

1602m a.s.l.

3.1 Physical geography of Czechia

Vegetation is determined by the merging of the Hercynian and Carpathian forest areas and the warm Pannonian steppe.

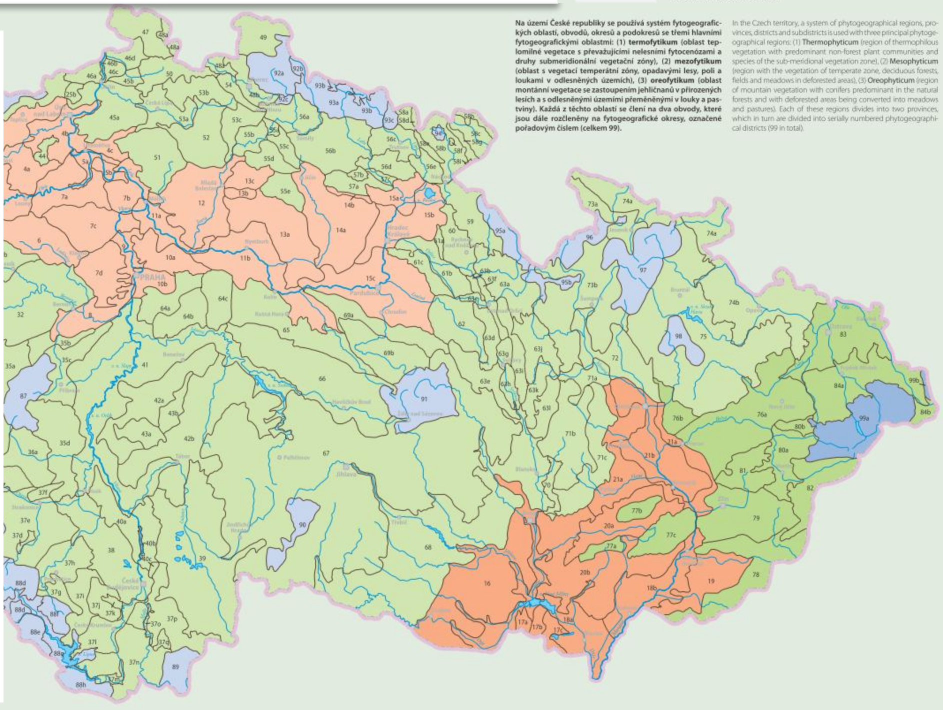
- With increasing elevation there are successive vegetation levels –the oak, oak-beech, beech-fir, spruce levels and the sub-alpine level above the timberline.
- Three floristic areas:
  - Central European forest flora (most of the Bohemian Upland)
  - Pannonian flora area (the Moravian grabens, Ohře Basin, Labe Basin and lower Vltava Basin)
  - Western Carpathian flora area (eastern part of the country)



8. lesní vegetační stupeň smrkový: V klimatických smrčinách již nedochází k tvorbě plného korunového zápoje, čehož využívá přimíšený jeřáb. Národní přírodní rezervace Praděd (zářez Bílé Opavy).

Forest altitudinal vegetation zone 8 spruce: *Climatic spruce stands do not develop a full crown canopy at these elevations any more and the advantage is used by the admixed European mountain ash. National Nature Reserve Praděd (incision of the Bílá Opava River).*

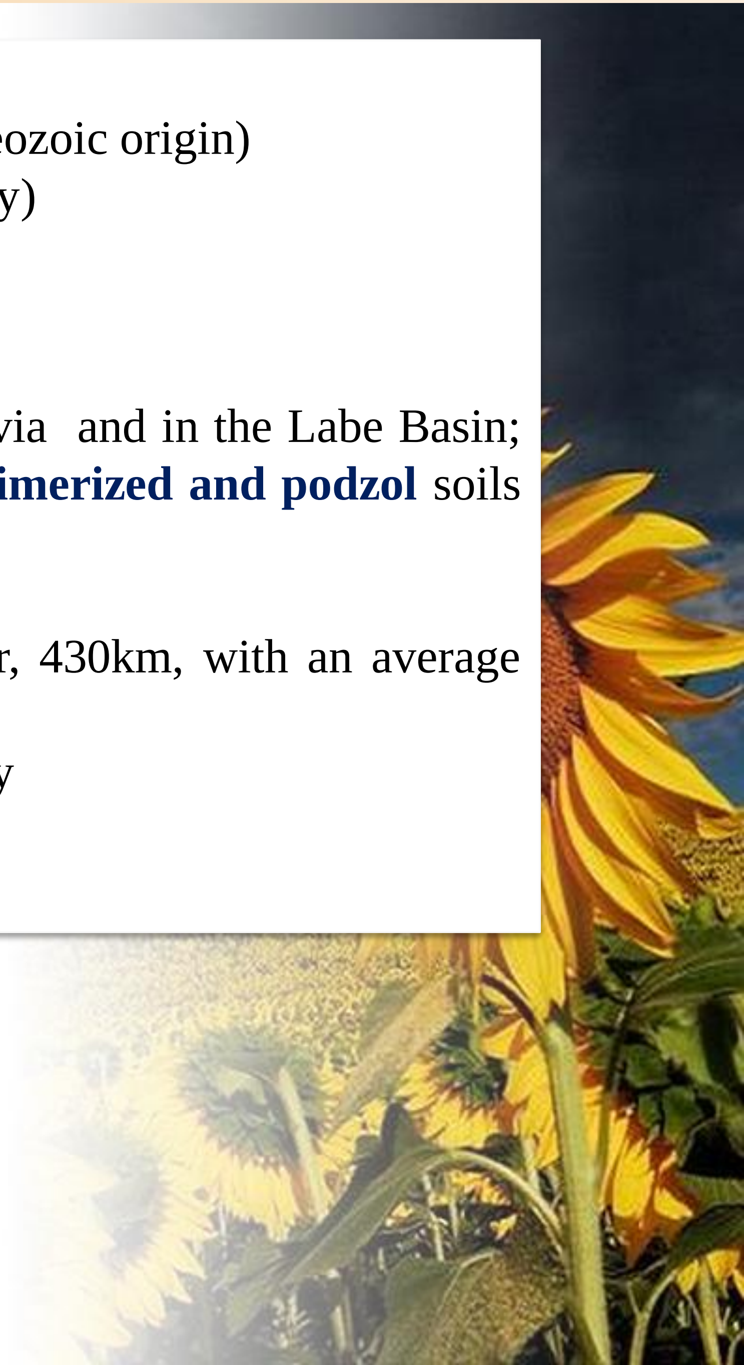
Foto / *Photo:* Tomáš Vrška



Na území České republiky se používá systém fytogeografických oblastí, obvodů, okresů a podokresů se třemi hlavními fytogeografickými oblastmi: (1) **termofytikum** (oblast teplomilné vegetace s převažujícími nelesními fytocenózami a druhy submeridionální vegetační zóny), (2) **mezofytikum** (oblast s vegetací temperátní zóny, opadavými lesy, poli a loukami v odlesněných územích), (3) **oreofytikum** (oblast montánní vegetace se zastoupením jehličnanů v přirozených lesích a s odlesněnými územími přeměněnými v louky a pastviny). Každá z těchto oblastí se člení na dva obvody, které jsou dále rozčleněny na fytogeografické okresy, označené pořadovým číslem (celkem 99).

In the Czech territory, a system of phytogeographical regions, provinces, districts and subdistricts is used with three principal phytogeographical regions: (1) **Thermophyticum** (region of thermophilous vegetation with predominant non-forest plant communities and species of the sub-meridional vegetation zone), (2) **Mesophyticum** (region with the vegetation of temperate zone, deciduous forests, fields and meadows in deforested areas), (3) **Oreophyticum** (region of mountain vegetation with conifers predominant in the natural forests and with deforested areas being converted into meadows and pastures). Each of these regions divides into two provinces, which in turn are divided into serially numbered phytogeographical districts (99 in total).

3.1 Physical geography of Czechia



Four geomorphologic provinces:

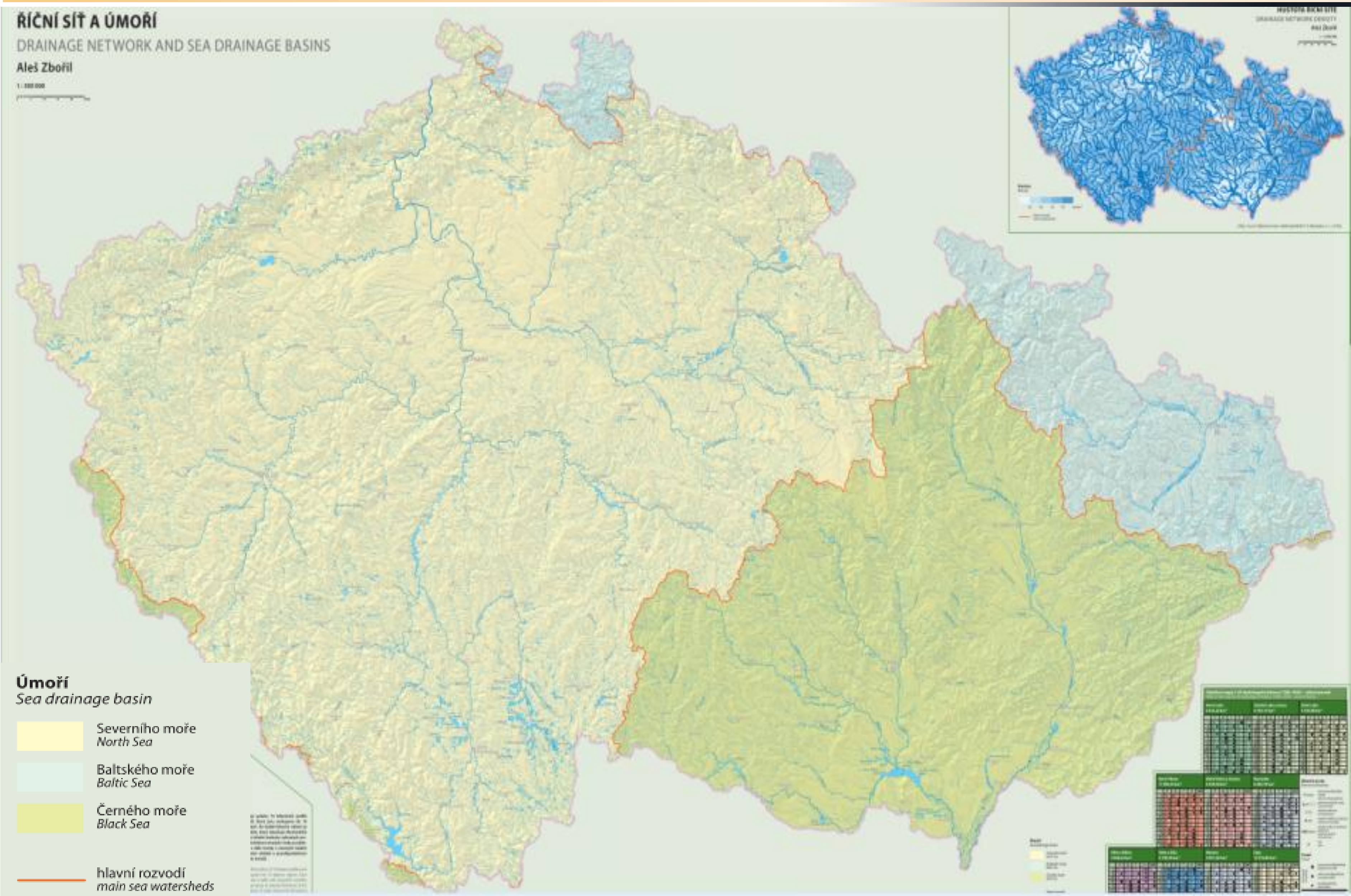
- **The Bohemian Upland** (western and central parts, Paleozoic origin)
- **Western Carpathians** (east of Czechia – Alpine orogeny)
- **Central European Lowland**
- **West Pannonian Basin**.

Soils: (1) fertile **chernozems -** in the lowlands of S Moravia and in the Labe Basin; (2) **brown earths** – dominate at medium elevations; (3) **illimerized and podzol** soils are prevailed at higher elevations.

Water – three main river basins (**Vltava**–the longest river, 430km, with an average flow rate of $150m^3.s^{-1}$ in Mělnik):

- **The Labe Basin** includes 63% of Czechia’s territory
- **Morava Basin** makes up 27%
- **Odra Basin** - 9%.

3.1 Physical geography of Czechia



3.2 Natural landscapes in the Czech Republic

20 Zemědělská krajina sníženin (Hostěrádky-Rešov a okolí, Vyškovská brána) Foto / *Photo:* Jan Vondra

Agricultural landscape of depressions (Hostěrádky-Rešov and surroundings, Vyškovská brána Gate)

perceived by people, whose character is the result of the action and interaction of natural and/or human factors (*European Landscape Convention, 2000*)

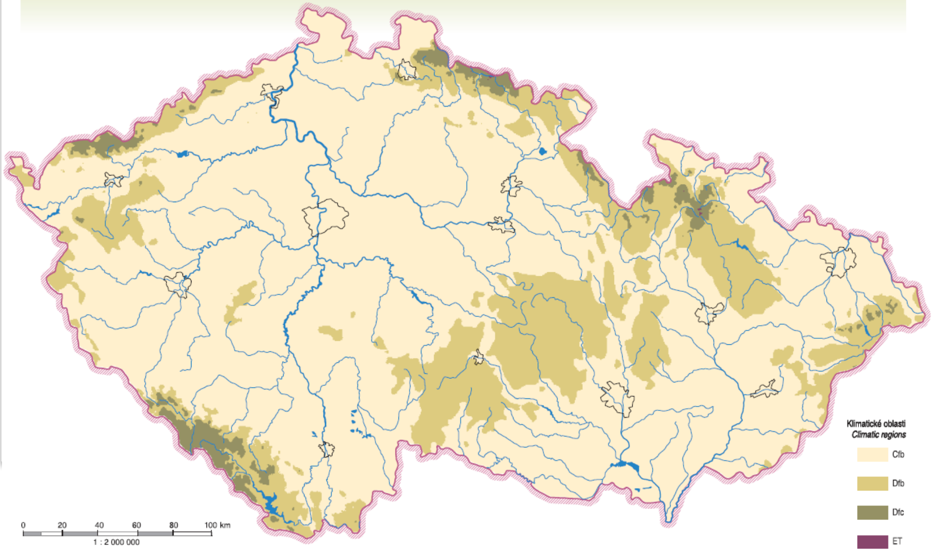
3.3 Climate classes occur in the CR

- The climate is on the borderline between continental and oceanic;
- A continental climate is characterised by high values of the Gorczynsky’s index of thermic continentality (full continentality is 100% and it is valid for Central Siberia);
- **Continentality** increasing from W to E and is greater in the lowlands than at higher locations (19-31%).

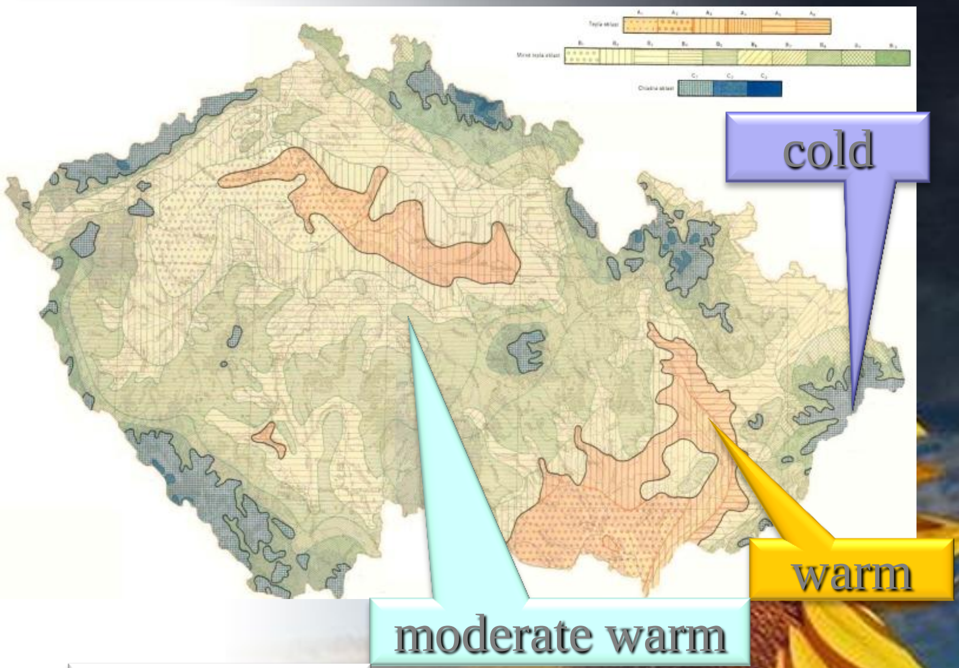
Climatic classes occur in CR by Köppen (1900):

- **temperate broadleaf deciduous forest (Cfb)**
- **boreal climate (Dfb and Dfc)**
- **tundra (ET) at the highest elevations**

KLIMATICKÉ OBLASTI PODLE KÖPPENOVY KLASIFIKACE / CLIMATIC REGIONS ACCORDING TO KÖPPEN´S CLASSIFICATION

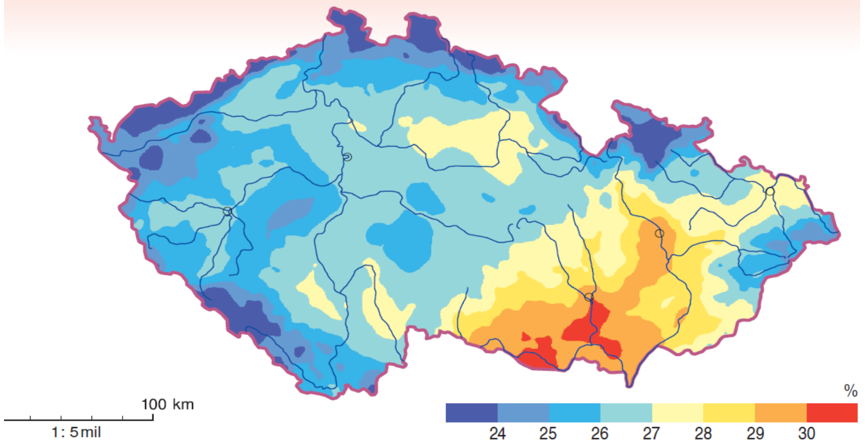


Climatic classification according to *Quitt* (1971)



Continentality

TERMICKÁ KONTINENTALITA PODNEBÍ PODLE GORCZYŃSKÉHO / THERMAL CONTINENTALITY ACCORDING TO GORCZYŃSKI

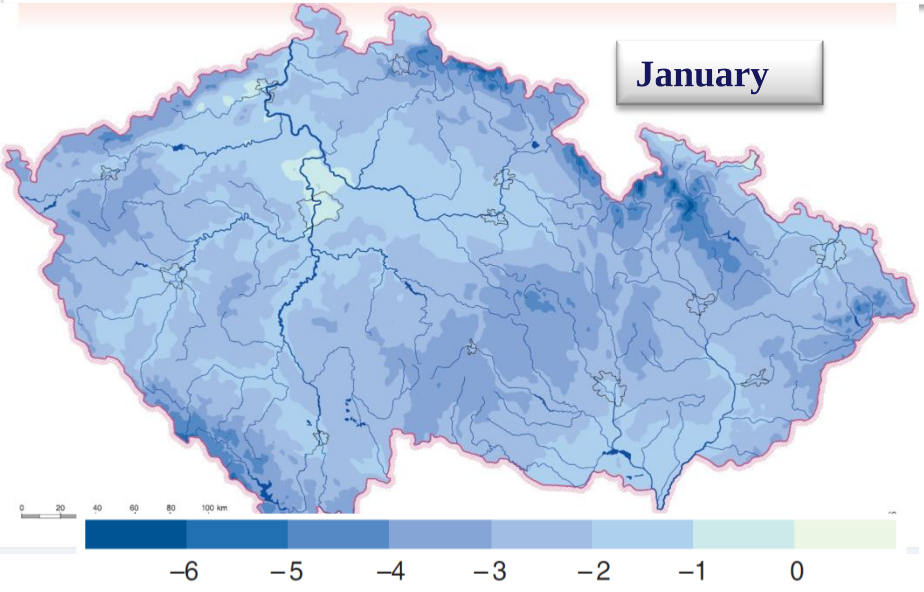


3.4 Climate of the CR

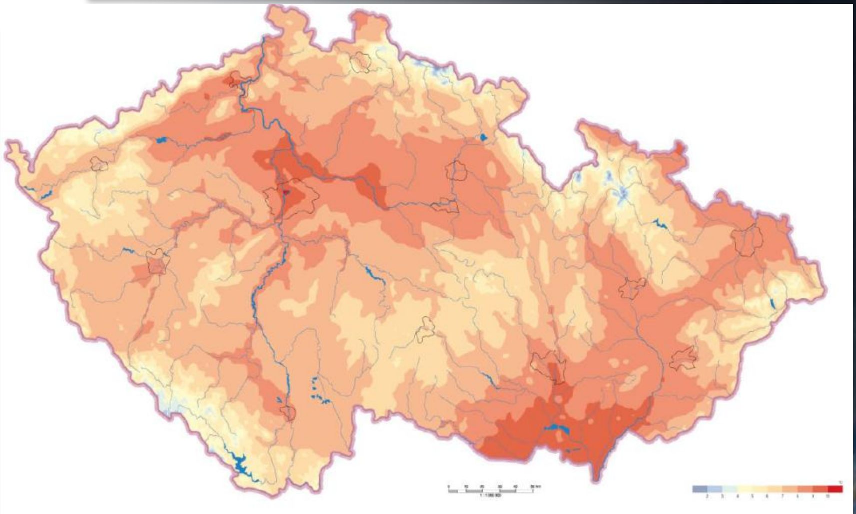
Temperature patterns

- Elevation has a greather impact on the spatial T°C distribution than the horizontal temperature differences in any of the synoptical situations;
- Temperature characteristics decrease in line with elevation **(0.61°C/100m);**
- Annual temperature:
  - **from 0°C (Sněžka) to 10°C (South Moravia),**
- **absolut maximum: (4O.4°C 20th August 2012)**
  (4O.2°C 27th August 1983)
- **absolut minimum: – 42.2°C (11th February 1929)**
- **the coldest month: January**
- **the warmest month: July**

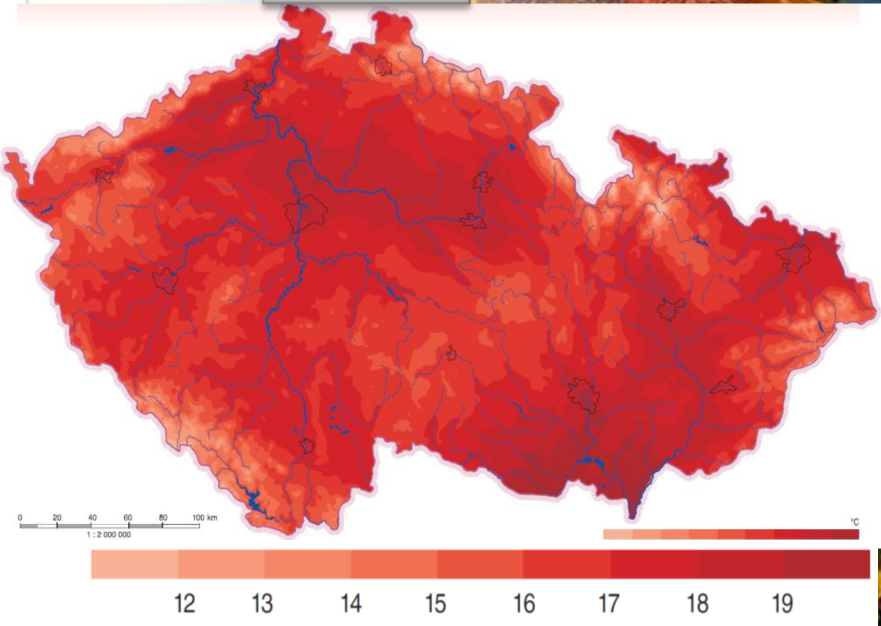
January



Average annual air temperature in the CR



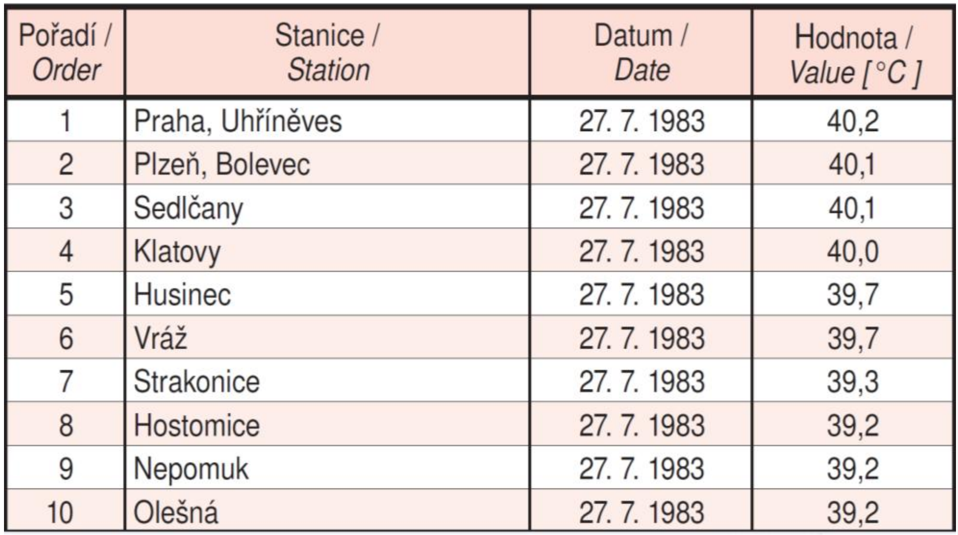
July



3.4 Climate of the CR

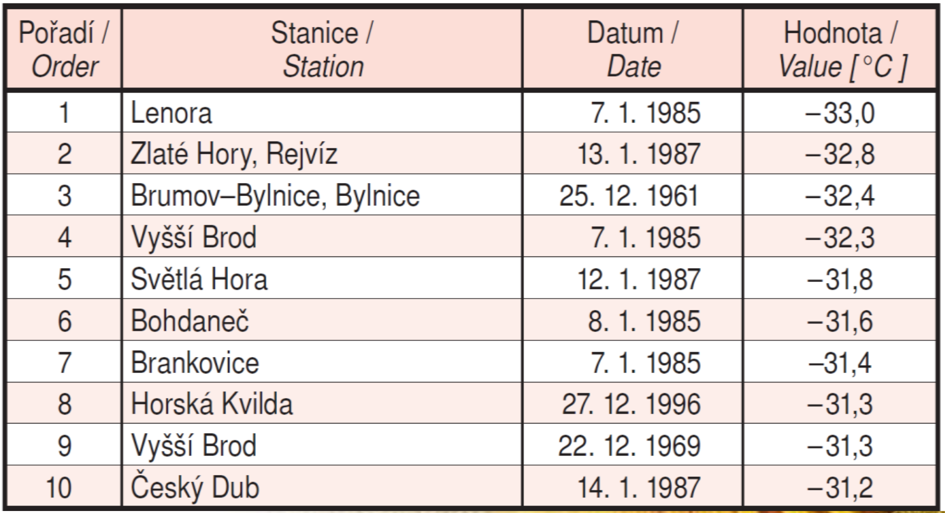
Temperature patterns

The highest maximum air temperature measured by maximum thermometer (1961-2000)



Pořadí / *Order*	Stanice / *Station*	Datum / *Date*	Hodnota / *Value [°C]*
1	Praha, Uhříněves	27. 7. 1983	40,2
2	Plzeň, Bolevec	27. 7. 1983	40,1
3	Sedlčany	27. 7. 1983	40,1
4	Klatovy	27. 7. 1983	40,0
5	Husinec	27. 7. 1983	39,7
6	Vráž	27. 7. 1983	39,7
7	Strakonice	27. 7. 1983	39,3
8	Hostomice	27. 7. 1983	39,2
9	Nepomuk	27. 7. 1983	39,2
10	Olešná	27. 7. 1983	39,2

The lowest minimum air temperature measured by minimum thermometer (1961-2000)

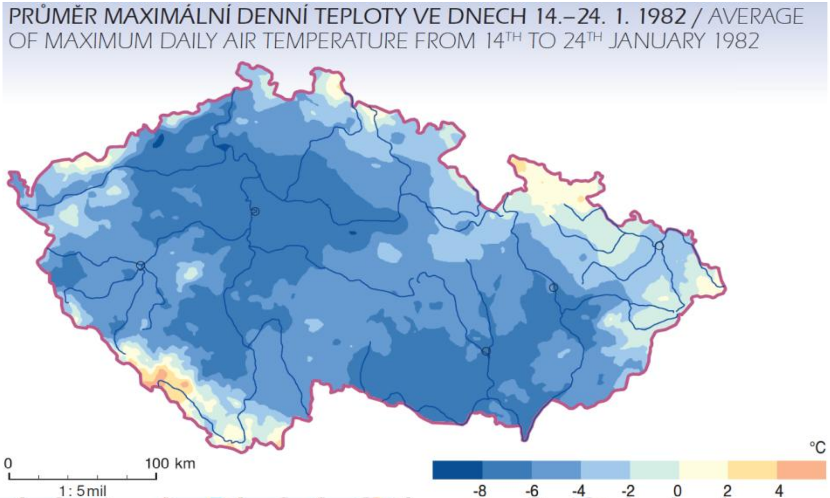


Pořadí / *Order*	Stanice / *Station*	Datum / *Date*	Hodnota / *Value [°C]*
1	Lenora	7. 1. 1985	–33,0
2	Zlaté Hory, Rejvíz	13. 1. 1987	–32,8
3	Brumov–Bylnice, Bylnice	25. 12. 1961	–32,4
4	Vyšší Brod	7. 1. 1985	–32,3
5	Světlá Hora	12. 1. 1987	–31,8
6	Bohdaneč	8. 1. 1985	–31,6
7	Brankovice	7. 1. 1985	–31,4
8	Horská Kvilda	27. 12. 1996	–31,3
9	Vyšší Brod	22. 12. 1969	–31,3
10	Český Dub	14. 1. 1987	–31,2

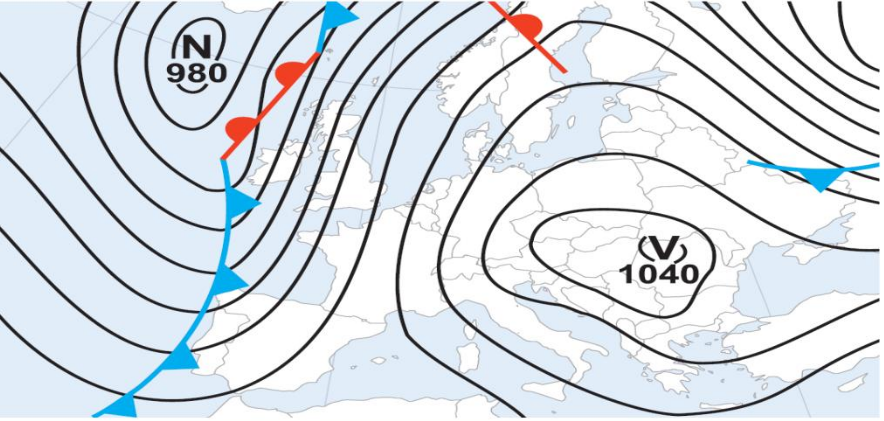
3.4 Climate of the CR

Temperature patterns

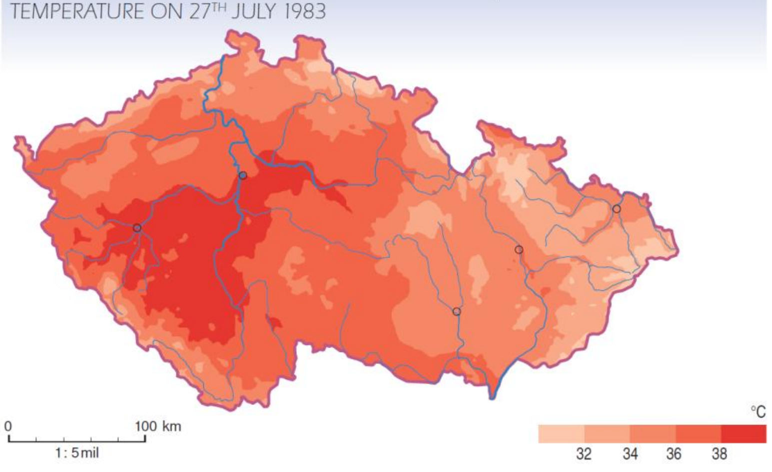
- During winter radiation inversions, which develop in the central part of high-pressure zones, T°C distribution is somewhat different.
  - e.g., in January 1982 – extreme both as regards its duration and the T°C difference between the cold lowlands and the relatively warm mountain locations.



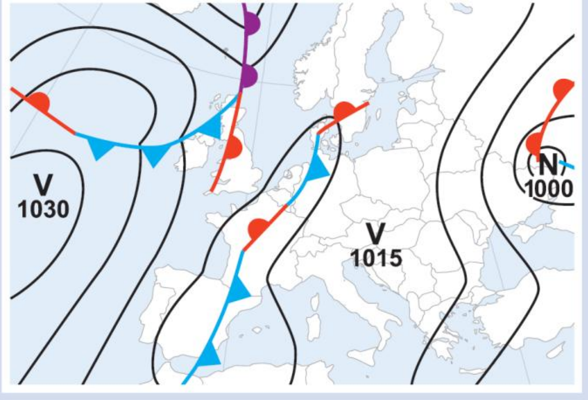
PRŮMĚR MAXIMÁLNÍ DENNÍ TEPLOTY VE DNECH 14.–24. 1. 1982 / AVERAGE OF MAXIMUM DAILY AIR TEMPERATURE FROM 14TH TO 24TH JANUARY 1982



Air temperature during extreme situations



MAXIMÁLNÍ TEPLOTA VZDUCHU DNE 27. 7. 1983 / MAXIMUM AIR TEMPERATURE ON 27TH JULY 1983

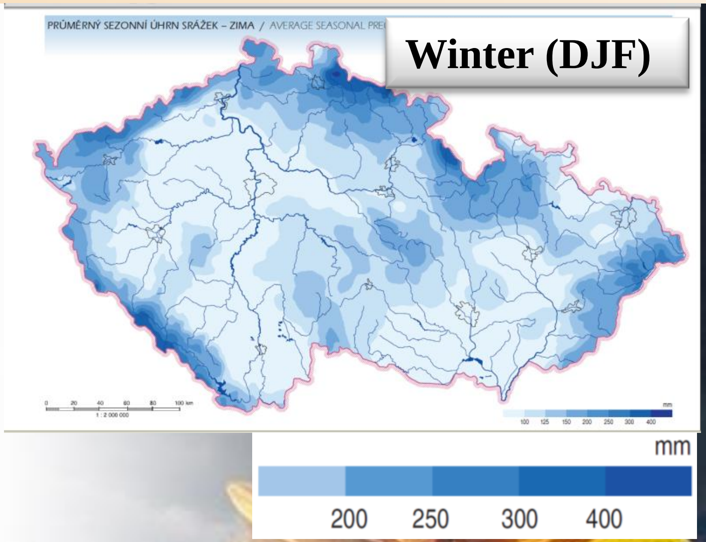


- Extreme maximum air temperature is the situation on July 27th, 1983, when most of the territory of CR experienced the highest temperatures ever recorded there.

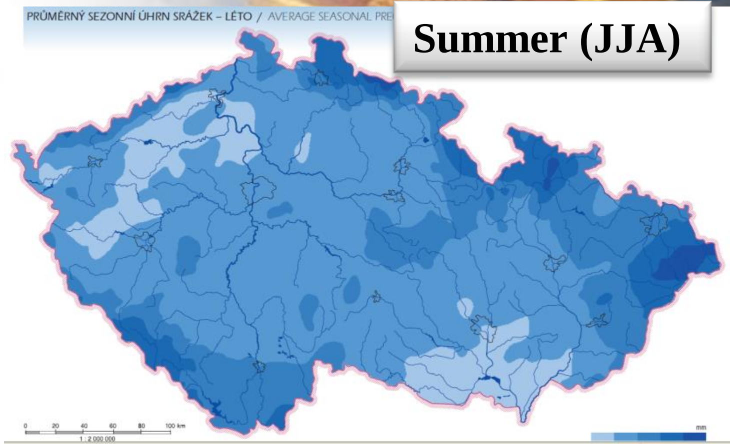
3.4 Climate of the CR

Precipitation patterns

- determined by the dominant circulation patterns in Central Europe and orographic conditions in the CR
- **elevation gradient:** 50 to 60mm/100m
- **the highest** values of precipitation totals occur along the border of mountain ranges ⇒ they could be attributed to the strong effect of their windward location on precipitation and to „precipitation-forming“ cyclones
- **the lowest** values of precipitation are associated with leeward areas in the foothills of the Ore Mountains (N-W) and Southern Moravia
- the windward and leeward effects may bias the expected dependence of dry (wet) episodes on the elevation
- **Annual distribution of precipitation:**
  - summer 40%, spring 25%, autumn 20% and winter 15%
- **The lowest** annual precipitation totals: 410mm (Libědice)
- **the highest** annual precipitation totals: 1705mm (Bílý Potok)



Winter (DJF)



Summer (JJA)

- A significant excess of precipitation during some periods can result in flooding (1997, 2002) while, on the other hand, a long-term lack of precipitation contributes to the incidence of drought spells (2000, 2003 and 2006).

3.4 Climate of the CR

Precipitation patterns

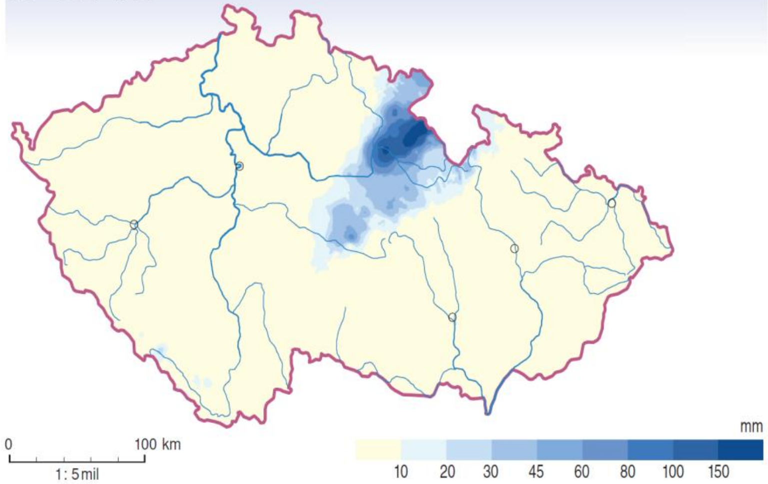
- Distribution of precipitation over time and at various locations within the territory of CR thus depends on the trajectory and speed of the advance of the low-pressure zone or related frontal system

- Extreme heavy precipitation is usually divided into 2 basic types:
  - **I. Long-lasting, widespread (regional) heavy rain**
  - **II: Short-term, local torrential rain**

- I: **The meto conditions that led to the heaviest large-scale precipitation events have one feature in common:**
  - the advance of **low-pressure zone** from the northern **Mediterranean into Central Europe**.
  - At high altitudes, CR is dominated by south-easterly to north-easterly flows, while the flows at lower levels are mostly northerly
- In August 2002 (two precipitation waves followed in quick succession), this affected the western part of the country, whereas in July 1997 it was mainly concentrated in north-eastern Moravia
- Orography played an important role in these events, expressing itself in increased precipitation on the windward sides of the mountains
- II: **has different meteorological origins, connected to the formation of massive convection (thunder) clouds and can be accompanied by dangerous effects (hailstorms and /or strong winds)**
  - Most often in warm, moist, and unstably stratified air in front of or along the advancing cold fronts or frontal waves

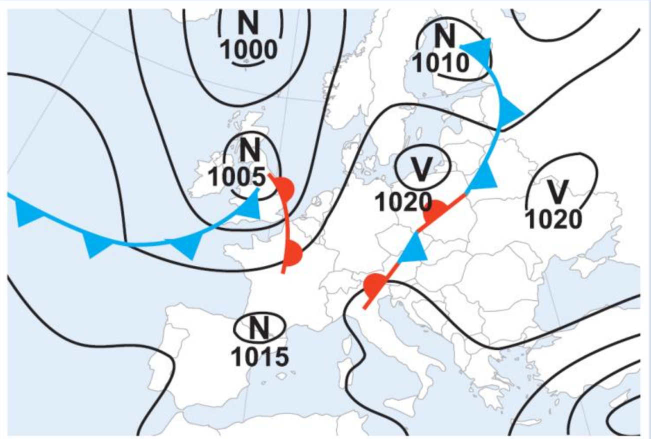
Precipitation total during extreme situations

PŘI BOUŘKOVÉ SITUACI DNE 22. 7. 1998 / DURING THUNDERSTORM ON 22ND JULY 1998



POVĚTRNOSTNÍ SITUACE DNE 12. 8. 2002 / METEOROLOGICAL SITUATION ON 12TH AUGUST 2002

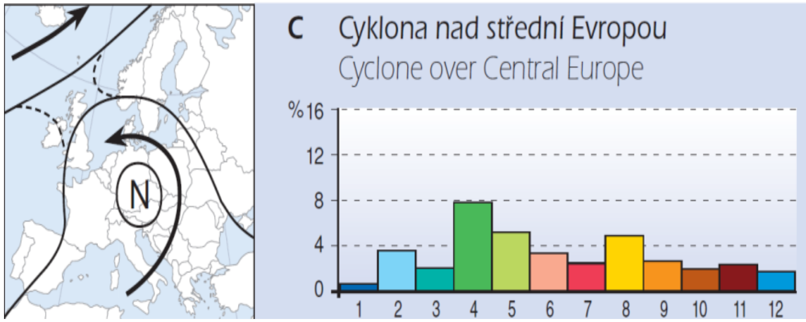
POVĚTRNOSTNÍ SITUACE DNE 22. 7. 1998 / METEOROLOGICAL SITUATION ON 22ND JULY 1998

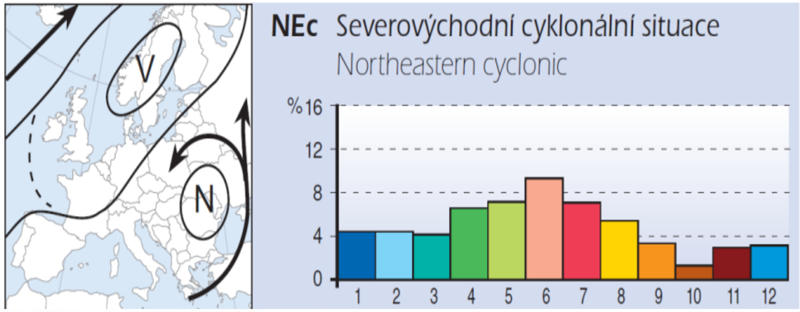


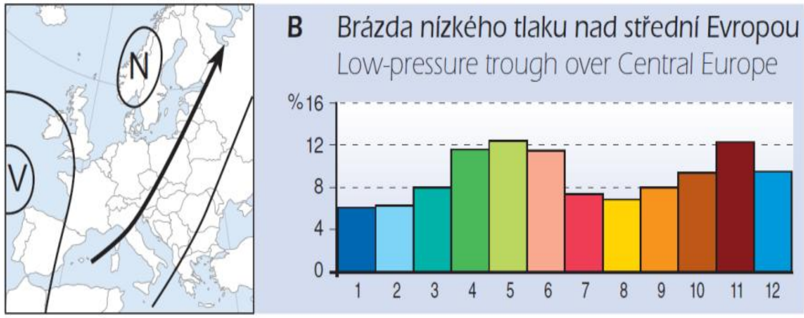
3.4 Climate of the CR

Precipitation patterns

- Extreme summer heavy precipitation is usually associated with C, NEc or B synoptical situations.

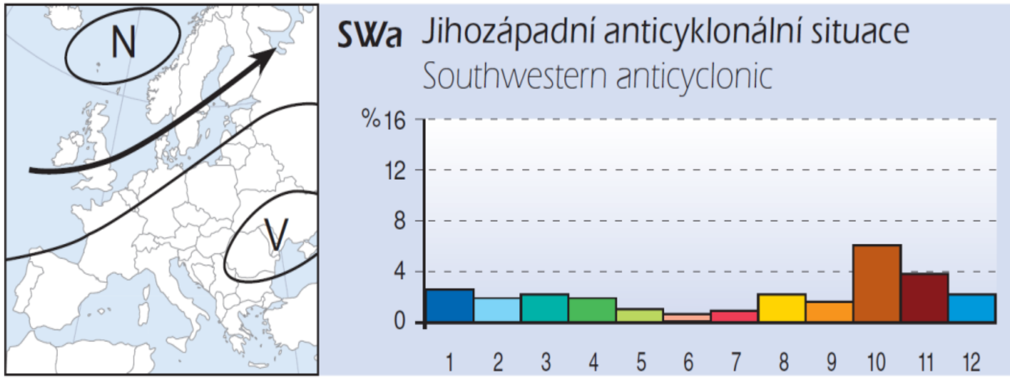


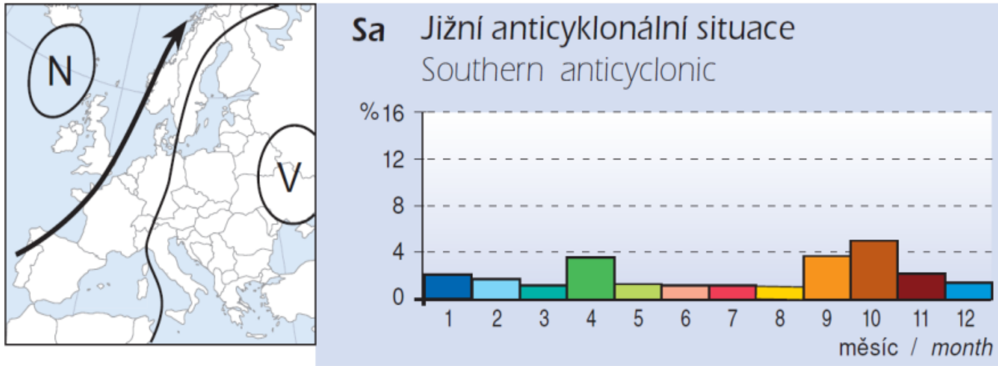




Precipitation total during extreme situations

- Lack of precipitation is associated with longer lasting anticyclone-type conditions.
- If the atmosphere is also dominated by a warm air supply, then summer air temperature can reach extremely high values: Sa or Swa.



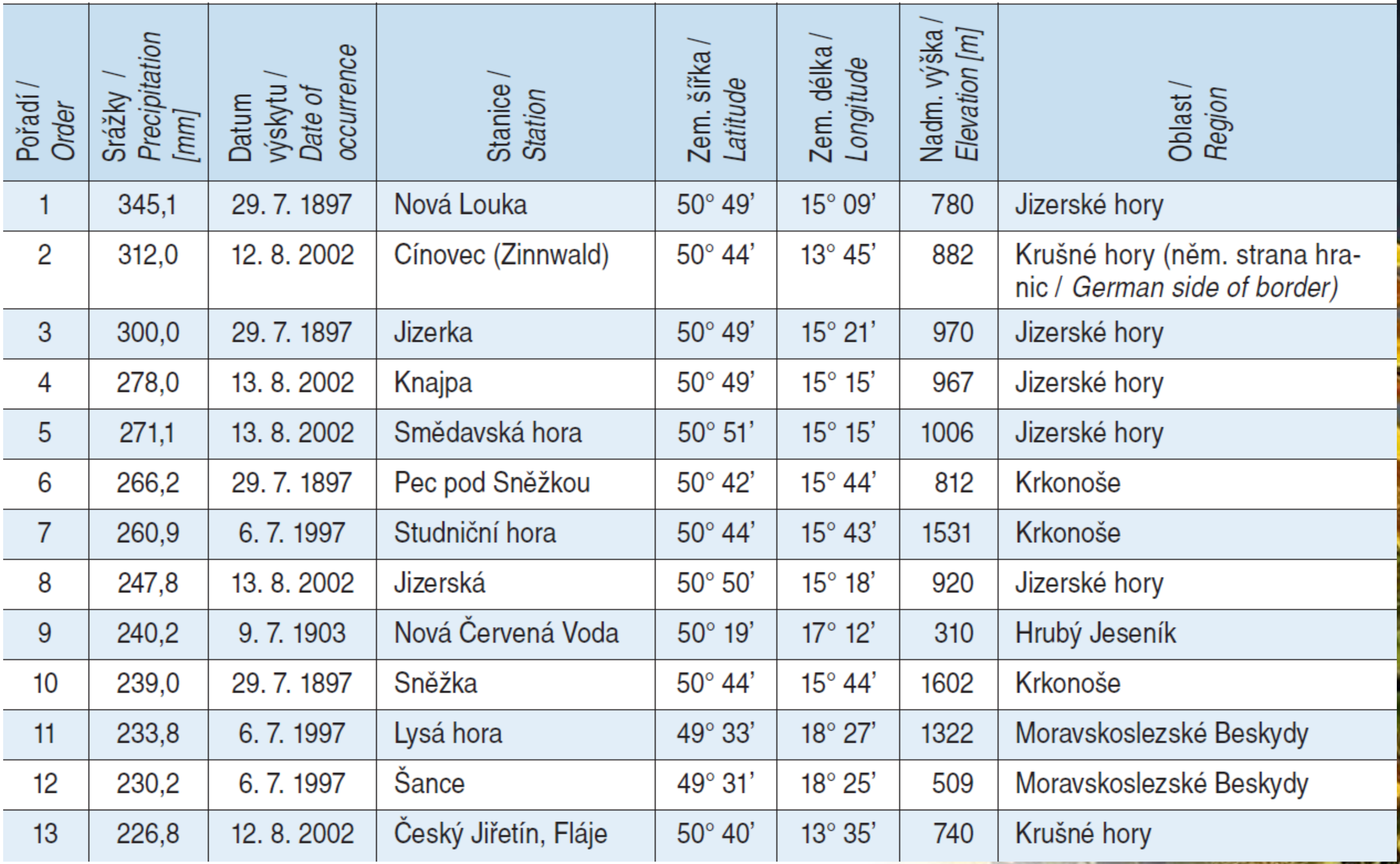


3.4 Climate of the CR

Precipitation patterns

Daily precipitation totals ≥210 mm for Czechia in the period 1879-2004

(data before 1961 adopted from Štekl J., Brázdil R., Kakos V., Jež J., Tolasz R., Sokol Z., 2001)



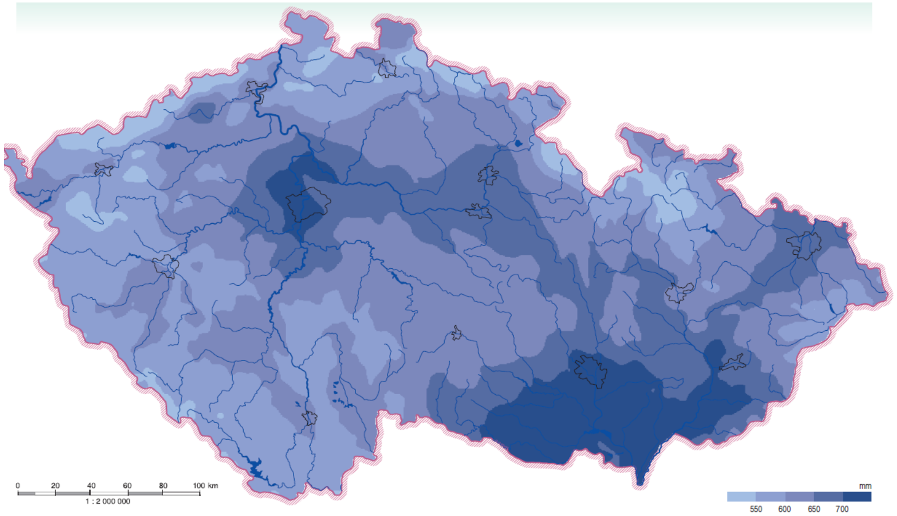
Pořadí / *Order*	Srážky / *Precipitation [mm]*	Datum výskytu / *Date of occurrence*	Stanice / *Station*	Zem. šířka / *Latitude*	Zem. délka / *Longitude*	Nadm. výška / *Elevation [m]*	Oblast / *Region*
1	345,1	29. 7. 1897	Nová Louka	50° 49’	15° 09’	780	Jizerské hory
2	312,0	12. 8. 2002	Cínovec (Zinnwald)	50° 44’	13° 45’	882	Krušné hory (něm. strana hranic / *German side of border)*
3	300,0	29. 7. 1897	Jizerka	50° 49’	15° 21’	970	Jizerské hory
4	278,0	13. 8. 2002	Knajpa	50° 49’	15° 15’	967	Jizerské hory
5	271,1	13. 8. 2002	Smědavská hora	50° 51’	15° 15’	1006	Jizerské hory
6	266,2	29. 7. 1897	Pec pod Sněžkou	50° 42’	15° 44’	812	Krkonoše
7	260,9	6. 7. 1997	Studniční hora	50° 44’	15° 43’	1531	Krkonoše
8	247,8	13. 8. 2002	Jizerská	50° 50’	15° 18’	920	Jizerské hory
9	240,2	9. 7. 1903	Nová Červená Voda	50° 19’	17° 12’	310	Hrubý Jeseník
10	239,0	29. 7. 1897	Sněžka	50° 44’	15° 44’	1602	Krkonoše
11	233,8	6. 7. 1997	Lysá hora	49° 33’	18° 27’	1322	Moravskoslezské Beskydy
12	230,2	6. 7. 1997	Šance	49° 31’	18° 25’	509	Moravskoslezské Beskydy
13	226,8	12. 8. 2002	Český Jiřetín, Fláje	50° 40’	13° 35’	740	Krušné hory

3.4 Climate of the CR

Evaporation

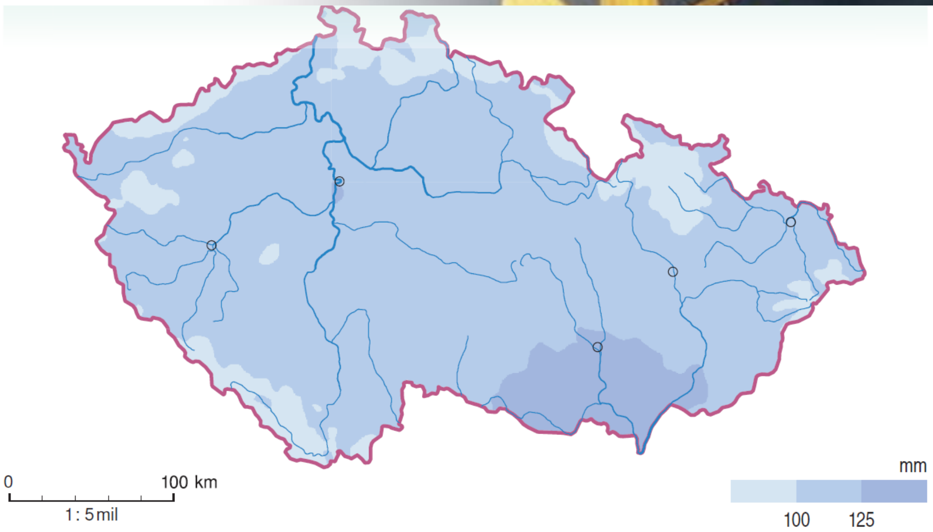
- Evaporation from surface of water, soil and wet vegetation
- Transpiration – physiological evaporation from plants
- Evapotranspiration – total evaporation from soil and vegetation
- Evapotranspiration can be measured or modeled by more or less complex techniques. Now, no universal method may be found.

Average annual PET (Climate Atlas, 2007)



- Annual long-term PET ranges from 450 to 750 mm
- July – the month with the highest water surface evapotranspiration and has a long-term average evaporation values of over 120 mm

July (Climate Atlas, 2007)

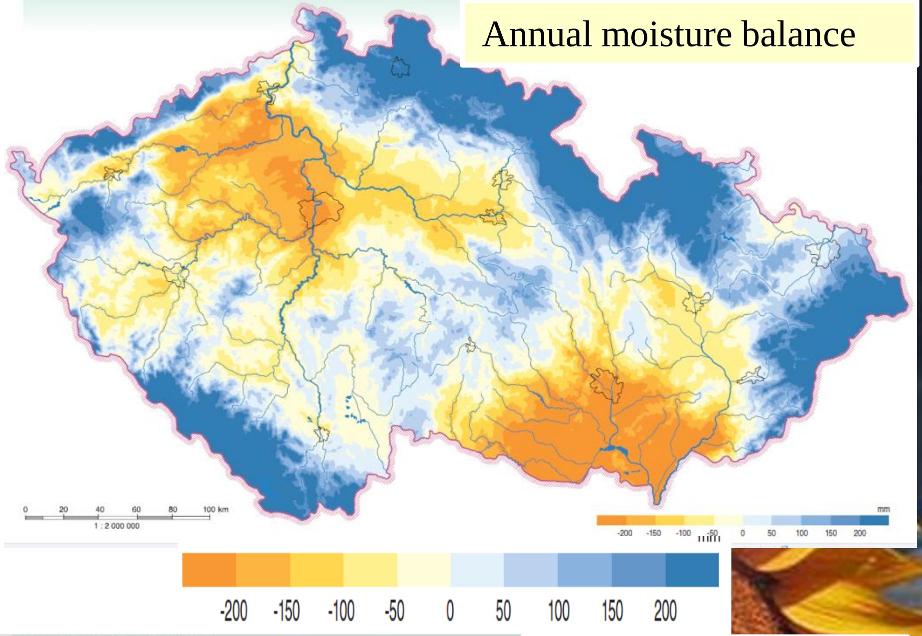


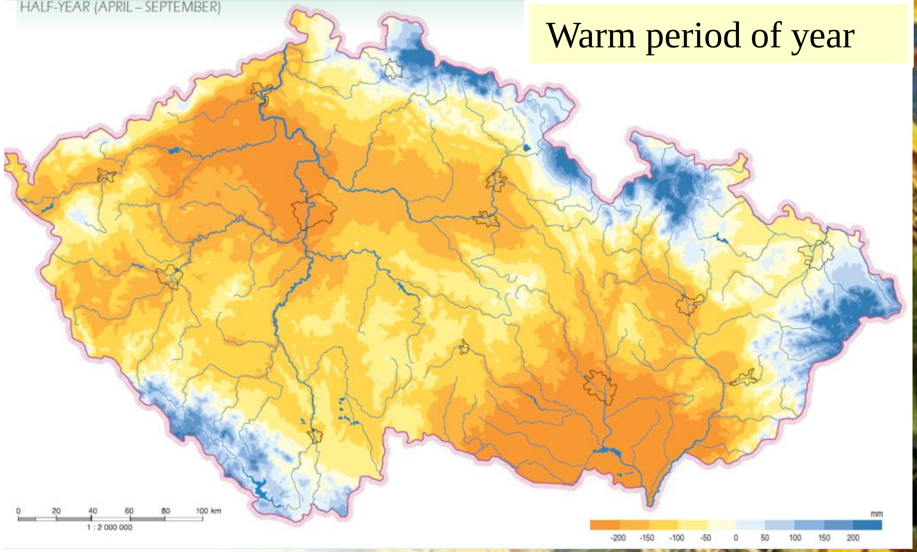
3.4 Climate of the CR

Moisture Balance (MB)

- The difference between precipitation (the input of water into circulation within the landscape) and total evaporation (the water output component)

  $\Rightarrow MB = P - PET$
- Other components such as surface and ground runoff and changes in underground water storage are not taken into consideration
- Serves as suitable indicator when comparing individual sites or years
- A positive MB value means a surplus of precipitation while a negative balance means a lack of it
- This fact allows us to employ the MB value as an indicator of drought
- Annual values below -150mm indicate areas of frequently occurring precipitation deficiencies
- In agricultural areas, MB is zero or „-“ even during years of high precipitation – precipitation is weaker than evaporation ⇒ that there are drought conditions during certain parts of such years
- In years of low precipitation, MB is only „+“ all year round at the highest locations, i.e., mountain areas
- Severe drought occurs in the warmest areas because the extreme MB values come close to -500mm


Annual moisture balance

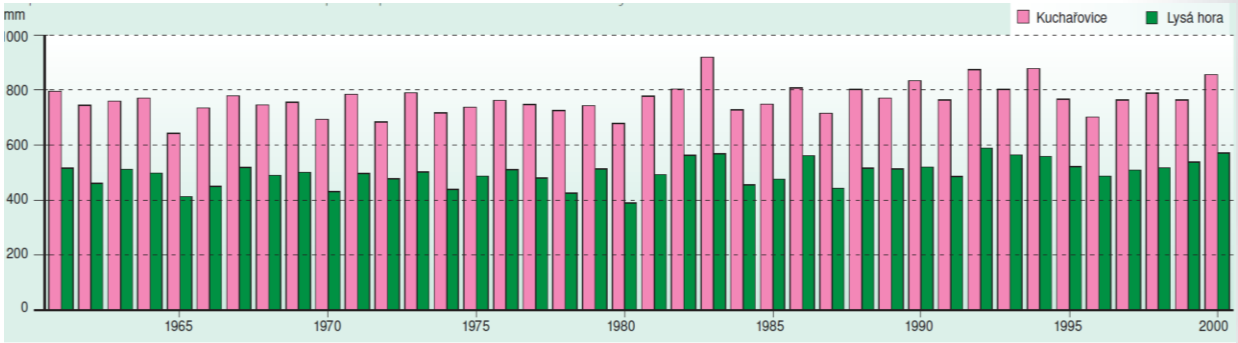

HALF-YEAR (APRIL – SEPTEMBER)

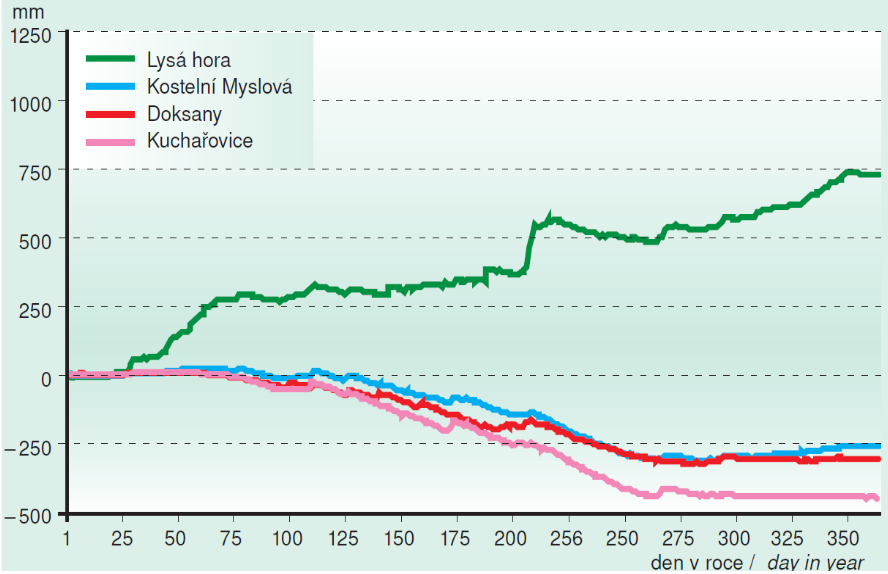
Warm period of year

(Climate Atlas of Czechia, 2007)

3.4 Climate of the CR

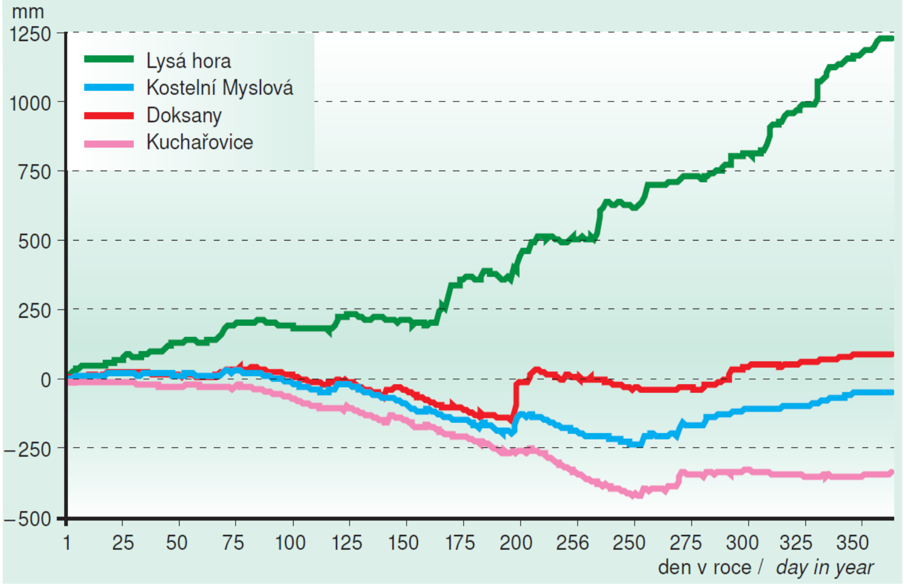
Variation of annual PET at Kuchařovice (lowland station) and Lysa hora (mountain station)





Graf 4.19 Roční vláhová bilance v roce na srážky chudém (1973)

Graph 4.19 Annual moisture balance in a year poor in precipitation (1973)



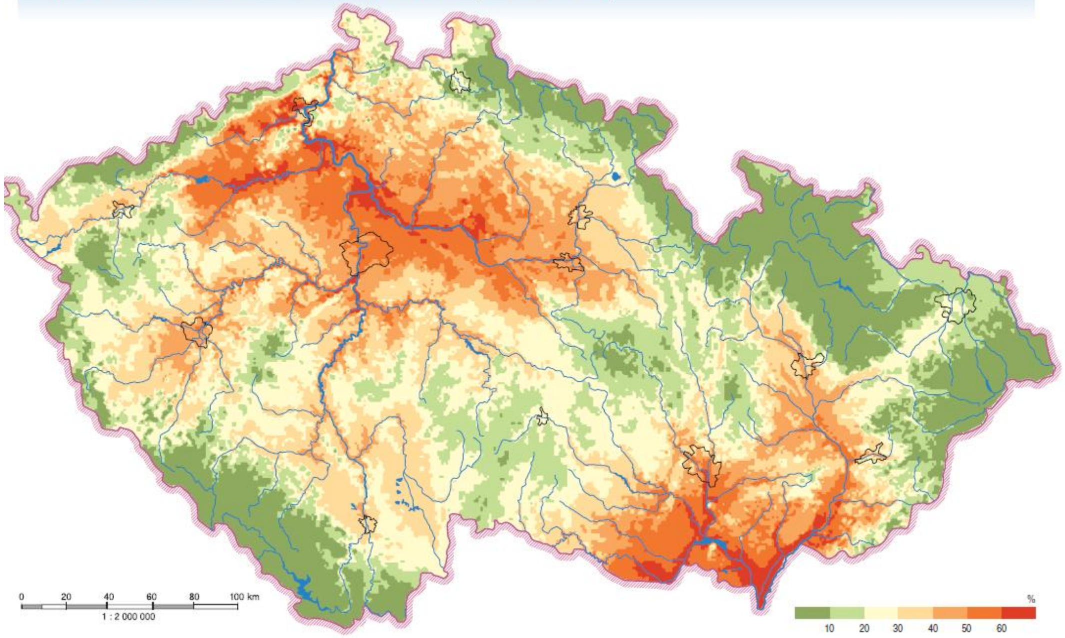
Graf 4.20 Roční vláhová bilance v roce na srážky bohatém (1981)

Graph 4.20 Annual moisture balance in a year rich in precipitation (1981)

3.4 Climate of the CR

Drought episodes in the CR

- the number of dry episodes rises significantly with decreasing altitude (Tolasz et al., 2007).
- there are two driest areas in Czechia:
  - The first zone extends from the foothills of the Ore mountain (Krušné Hory) into the Elbe (Labe) River lowland and Central Bohemia as well as into Western and Southern Bohemia.
  - The second driest area is in Moravia, mainly South-Moravia.



PODÍL MĚSÍCŮ ZASAŽENÝCH EPIZODAMI SUCHA PODLE HODNOT PALMEROVA Z-INDEXU (DUBEN–ZÁŘÍ) / RATIO OF MONTHS WITH DROUGHT EPISODES ACCORDING TO PALMER Z-INDEX (APRIL–SEPTEMBER)

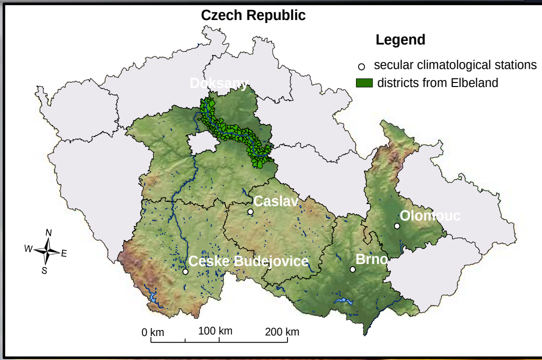
Drought indices in the CR

- The predominant drought indices usually used to establish drought conditions in the CR are SPI, PDSI, Palmer's Z index, and Lang's rain factor.
- The SPI is an index used with a suite of tools for regional classifications of drought climatology within the territory of Czechia
- Lang's rain factor - one of the oldest and most frequently used indices for the identification of dry and/or wet areas, which is also the most popular in the CR (*Tolasz et al. 2007*).
- Its popularity is mainly due to its simplicity, which is based on the ratio of the average annual precipitation total to the average annual air temperature.
- At the same time, both indices, PDSI and Z index, have become two of the most widely used tools for the drought assessment in Czechia.

3.5 Drought climatology in the Czech Republic

Objective:

- To determine how effectively the SPEI represented drought patterns in the CR, we compared the obtained results to the SPI;
- To identified differences between the effects of precipitation variability and evapotranspiration on drought severity, frequency and duration.



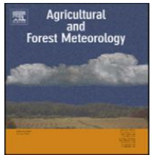
Data sets

- Long-term secular series (1901-2010) of daily values for PET, P and T were used to assess centennial-scale drought severities, durations and frequencies;
- 5 secular st. - their geographical locations represent the most agriculturally productive lowland areas and receive the most irregular precipitation and are most often affected by drought episodes

List of secular stations with annual temperature and precipitation data from 1901–2010

	Name station	Longitude, N	Latitude, E	Altitude, m.a.s.l.	Mean annual temperature, °C	Annual amount of precipitation, mm
1.	Čáslav	49° 54’	15° 23’	251	8.8	568
2.	Doksany	50° 27’	14° 10’	158	8.7	449
3.	Brno	49° 09’	16° 42’	245	8.9	515
4.	České Budějovice	48° 57’	14° 28’	394	8.4	587
5.	Olomouc	49° 34’	17° 17’	210	8.8	557

Source:



Drought evolution at various time scales in the lowland regions and their impact on vegetable crops in the Czech Republic

Vera Potop[a,*], Martin Možný[b], Josef Soukup[a]

3.5 Drought climatology in the Czech Republic

Calculation of Standardized Precipitation Evapotranspiration Index (SPEI) and its input parameters

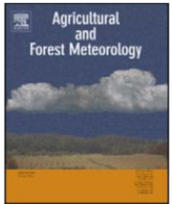
- the quantification of the SPEI was based on the following steps:
  - a calculation of potential evapotranspiration (PET);
  - a simple monthly water balance, calculated as the difference between monthly precipitation (P_i) and potential evapotranspiration (PET_i) at different time scales:

$$\mathbf{D_i = P_i - PET_i;}$$

  - a normalisation of the water balance into a log-logistic probability distribution to obtain the SPEI index series.
- **Input data for PET**:
  - **daily precipitation,**
  - **saturation vapour pressure**,
  - **vapour pressure**,
  - **the vapour pressure deficit**
  - **mean air temperature** at 2 p.m. local time.
- **Input data for SPEI: $D_i = P_i – PET_i$**
- **Time scales**: 1- to 24-month, for each month of the year and 24 accumulated lags during the period 1901-2010.

This study also has for the first time analysed in detail the evolution of drought episodes for lowland regions in the Central Europe by the multi-scalar SPEI

Source:



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3.5 Drought climatology in the Czech Republic

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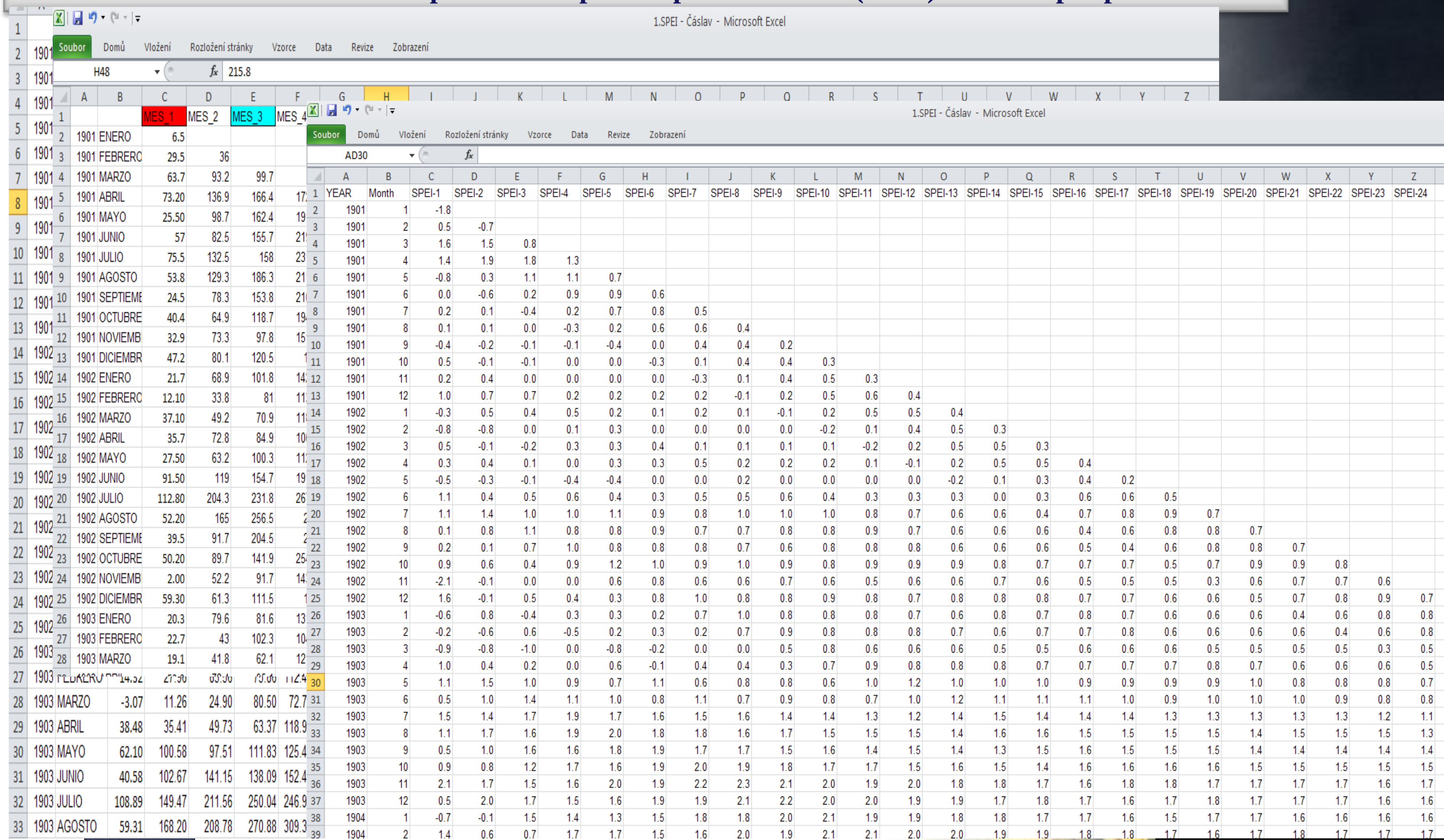


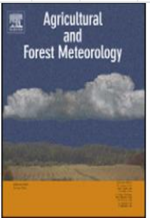
28	1903	MARZO	-3.07	11.26	24.90	80.50
29	1903	ABRIL	38.48	35.41	49.73	63.37
30	1903	MAYO	62.10	100.58	97.51	111.83
31	1903	JUNIO	40.58	102.67	141.15	138.09
32	1903	JULIO	108.89	149.47	211.56	250.04
33	1903	AGOSTO	59.31	168.20	208.78	270.88

	A	B	C	D	E
1			MES_1	MES_2	MES_3
2	1901	ENERO	6.5		
3	1901	FEBRERO	29.5	36	
4	1901	MARZO	63.7	93.2	99.7
5	1901	ABRIL	73.20	136.9	166.4
6	1901	MAYO	25.50	98.7	162.4
7	1901	JUNIO	57	82.5	155.7
8	1901	JULIO	75.5	132.5	158
9	1901	AGOSTO	53.8	129.3	186.3
10	1901	SEPTIEMB	24.5	78.3	153.8
11	1901	OCTUBRE	40.4	64.9	118.7
12	1901	NOVIEMB	32.9	73.3	97.8
13	1901	DICIEMBR	47.2	80.1	120.5
14	1902	ENERO	21.7	68.9	101.8
15	1902	FEBRERO	12.10	33.8	81
16	1902	MARZO	37.10	49.2	70.9
17	1902	ABRIL	35.7	72.8	84.9
18	1902	MAYO	27.50	63.2	100.3
19	1902	JUNIO	91.50	119	154.7
20	1902	JULIO	112.80	204.3	231.8
21	1902	AGOSTO	52.20	165	256.5
22	1902	SEPTIEMB	39.5	91.7	204.5
23	1902	OCTUBRE	50.20	89.7	141.9
24	1902	NOVIEMB	2.00	52.2	91.7
25	1902	DICIEMBR	59.30	61.3	111.5
26	1903	ENERO	20.3	79.6	81.6
27	1903	FEBRERO	22.7	43	102.3
28	1903	MARZO	19.1	41.8	62.1

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z
1	YEAR	Month	SPEI-1	SPEI-2	SPEI-3	SPEI-4	SPEI-5	SPEI-6	SPEI-7	SPEI-8	SPEI-9	SPEI-10	SPEI-11	SPEI-12	SPEI-13	SPEI-14	SPEI-15	SPEI-16	SPEI-17	SPEI-18	SPEI-19	SPEI-20	SPEI-21	SPEI-22	SPEI-23	SPEI-24
2	1901	1	-1.8																							
3	1901	2	0.5	-0.7																						
4	1901	3	1.6	1.5	0.8																					
5	1901	4	1.4	1.9	1.8	1.3																				
6	1901	5	-0.8	0.3	1.1	1.1	0.7																			
7	1901	6	0.0	-0.6	0.2	0.9	0.9	0.6																		
8	1901	7	0.2	0.1	-0.4	0.2	0.7	0.8	0.5																	
9	1901	8	0.1	0.1	0.0	-0.3	0.2	0.6	0.6	0.4																
10	1901	9	-0.4	-0.2	-0.1	-0.1	-0.4	0.0	0.4	0.4	0.2															
11	1901	10	0.5	-0.1	-0.1	0.0	0.0	-0.3	0.1	0.4	0.4	0.3														
12	1901	11	0.2	0.4	0.0	0.0	0.0	0.0	-0.3	0.1	0.4	0.5	0.3													
13	1901	12	1.0	0.7	0.7	0.2	0.2	0.2	0.2	-0.1	0.2	0.5	0.6	0.4												
14	1902	1	-0.3	0.5	0.4	0.5	0.2	0.1	0.2	0.1	-0.1	0.2	0.5	0.5	0.4											
15	1902	2	-0.8	-0.8	0.0	0.1	0.3	0.0	0.0	0.0	0.0	-0.2	0.1	0.4	0.5	0.3										
16	1902	3	0.5	-0.1	-0.2	0.3	0.3	0.4	0.1	0.1	0.1	0.1	-0.2	0.2	0.5	0.5	0.3									
17	1902	4	0.3	0.4	0.1	0.0	0.3	0.3	0.5	0.2	0.2	0.2	0.1	-0.1	0.2	0.5	0.5	0.4								
18	1902	5	-0.5	-0.3	-0.1	-0.4	-0.4	0.0	0.0	0.2	0.0	0.0	0.0	0.0	-0.2	0.1	0.3	0.4	0.2							
19	1902	6	1.1	0.4	0.5	0.6	0.4	0.3	0.5	0.5	0.6	0.4	0.3	0.3	0.3	0.0	0.3	0.6	0.6	0.5						
20	1902	7	1.1	1.4	1.0	1.0	1.1	0.9	0.8	1.0	1.0	1.0	0.8	0.7	0.6	0.6	0.4	0.7	0.8	0.9	0.7					
21	1902	8	0.1	0.8	1.1	0.8	0.8	0.9	0.7	0.7	0.8	0.8	0.9	0.7	0.6	0.6	0.6	0.4	0.6	0.8	0.8	0.7				
22	1902	9	0.2	0.1	0.7	1.0	0.8	0.8	0.8	0.7	0.6	0.8	0.8	0.8	0.6	0.6	0.6	0.5	0.4	0.6	0.8	0.8	0.7			
23	1902	10	0.9	0.6	0.4	0.9	1.2	1.0	0.9	1.0	0.9	0.8	0.9	0.9	0.9	0.8	0.7	0.7	0.7	0.5	0.7	0.9	0.9	0.8		
24	1902	11	-2.1	-0.1	0.0	0.0	0.6	0.8	0.6	0.6	0.7	0.6	0.5	0.6	0.6	0.7	0.6	0.5	0.5	0.5	0.3	0.6	0.7	0.7	0.6	
25	1902	12	1.6	-0.1	0.5	0.4	0.3	0.8	1.0	0.8	0.8	0.9	0.8	0.7	0.8	0.8	0.8	0.7	0.7	0.6	0.6	0.5	0.7	0.8	0.9	0.7
26	1903	1	-0.6	0.8	-0.4	0.3	0.3	0.2	0.7	1.0	0.8	0.8	0.8	0.7	0.6	0.8	0.7	0.8	0.7	0.6	0.6	0.6	0.4	0.6	0.8	0.8
27	1903	2	-0.2	-0.6	0.6	-0.5	0.2	0.3	0.2	0.7	0.9	0.8	0.8	0.8	0.7	0.6	0.7	0.7	0.8	0.6	0.6	0.6	0.6	0.4	0.6	0.8
28	1903	3	-0.9	-0.8	-1.0	0.0	-0.8	-0.2	0.0	0.0	0.5	0.8	0.6	0.6	0.6	0.5	0.5	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.3	0.5
29	1903	4	1.0	0.4	0.2	0.0	0.6	-0.1	0.4	0.4	0.3	0.7	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.8	0.7	0.6	0.6	0.6	0.5
30	1903	5	1.1	1.5	1.0	0.9	0.7	1.1	0.6	0.8	0.8	0.6	1.0	1.2	1.0	1.0	1.0	0.9	0.9	0.9	0.9	1.0	0.8	0.8	0.8	0.7
31	1903	6	0.5	1.0	1.4	1.1	1.0	0.8	1.1	0.7	0.9	0.8	0.7	1.0	1.2	1.1	1.1	1.1	1.0	0.9	1.0	1.0	1.0	0.9	0.8	0.8
32	1903	7	1.5	1.4	1.7	1.9	1.7	1.6	1.5	1.6	1.4	1.4	1.3	1.2	1.4	1.5	1.4	1.4	1.4	1.3	1.3	1.3	1.3	1.3	1.2	1.1
33	1903	8	1.1	1.7	1.6	1.9	2.0	1.8	1.8	1.6	1.7	1.5	1.5	1.5	1.4	1.6	1.6	1.5	1.5	1.5	1.5	1.4	1.5	1.5	1.5	1.3
34	1903	9	0.5	1.0	1.6	1.6	1.8	1.9	1.7	1.7	1.5	1.6	1.4	1.5	1.4	1.3	1.5	1.6	1.5	1.5	1.5	1.4	1.4	1.4	1.4	1.4
35	1903	10	0.9	0.8	1.2	1.7	1.6	1.9	2.0	1.9	1.8	1.7	1.7	1.5	1.6	1.5	1.4	1.6	1.6	1.6	1.6	1.5	1.5	1.5	1.5	1.5
36	1903	11	2.1	1.7	1.5	1.6	2.0	1.9	2.2	2.3	2.1	2.0	1.9	2.0	1.8	1.8	1.7	1.6	1.8	1.8	1.7	1.7	1.7	1.7	1.6	1.7
37	1903	12	0.5	2.0	1.7	1.5	1.6	1.9	1.9	2.1	2.2	2.0	2.0	1.9	1.9	1.7	1.8	1.7	1.6	1.7	1.8	1.7	1.7	1.7	1.6	1.6
38	1904	1	-0.7	-0.1	1.5	1.4	1.3	1.5	1.8	1.8	2.0	2.1	1.9	1.9	1.8	1.8	1.7	1.7	1.6	1.5	1.7	1.7	1.6	1.6	1.6	1.6
39	1904	2	1.4	0.6	0.7	1.7	1.7	1.5	1.6	2.0	1.9	2.1	2.1	2.0	2.0	1.9	1.9	1.8	1.8	1.7	1.6	1.7	1.8	1.7	1.7	1.7

SPEI calculate in Excel

Source:



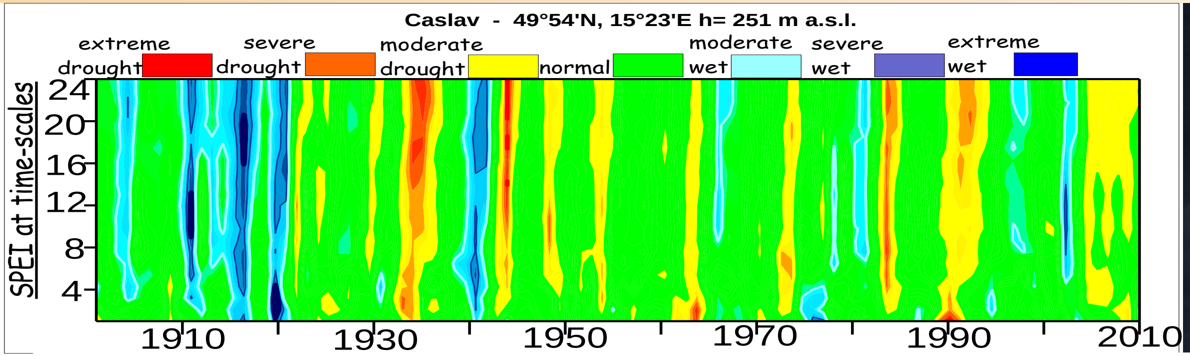
Drought evolution at various time scales in the lowland regions and their impact on vegetable crops in the Czech Republic

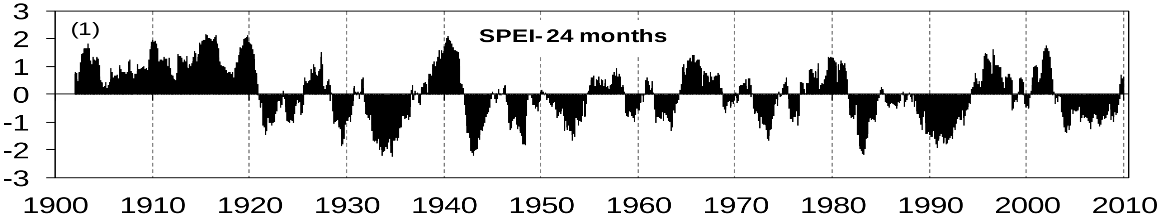
Vera Potop[a,*], Martin Možný[b], Josef Soukup[a]

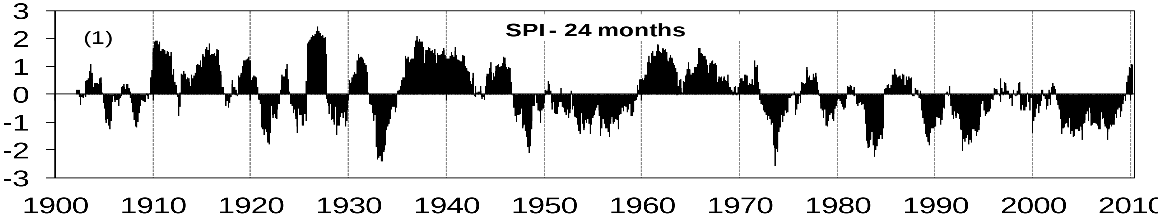
3.5 Drought climatology in the Czech Republic

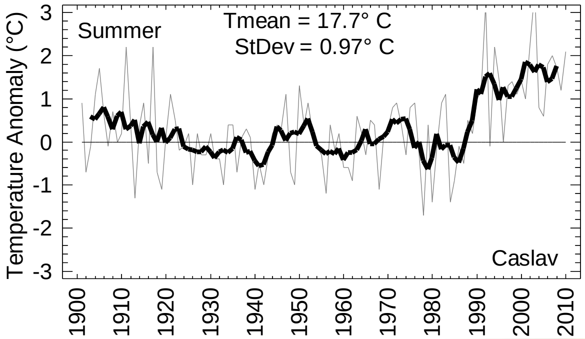
The comparison between SPEI and SPI secular series

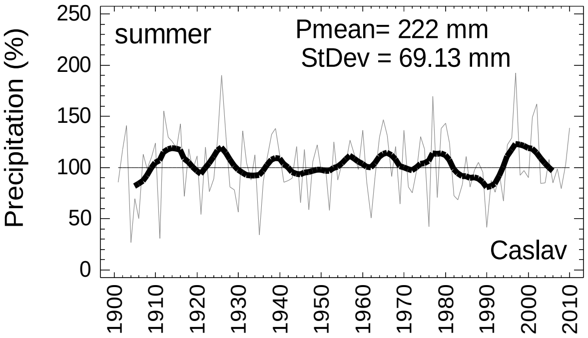
- the SPEI and SPI were calculated for short-term (1 to 2 months), medium-term (3 to 12 months) and long-term droughts (13 to 24 months)
- the evolution of the variability of temperature and precipitation anomalies during the 20th century was allow us to assess their impact on the frequency of drought events
- Although precipitation is the main driver of drought conditions, the rapidly increasing temperature can also play a notable role in drought by increasing the severity of the episodes as a consequence of water loss by evapotranspiration









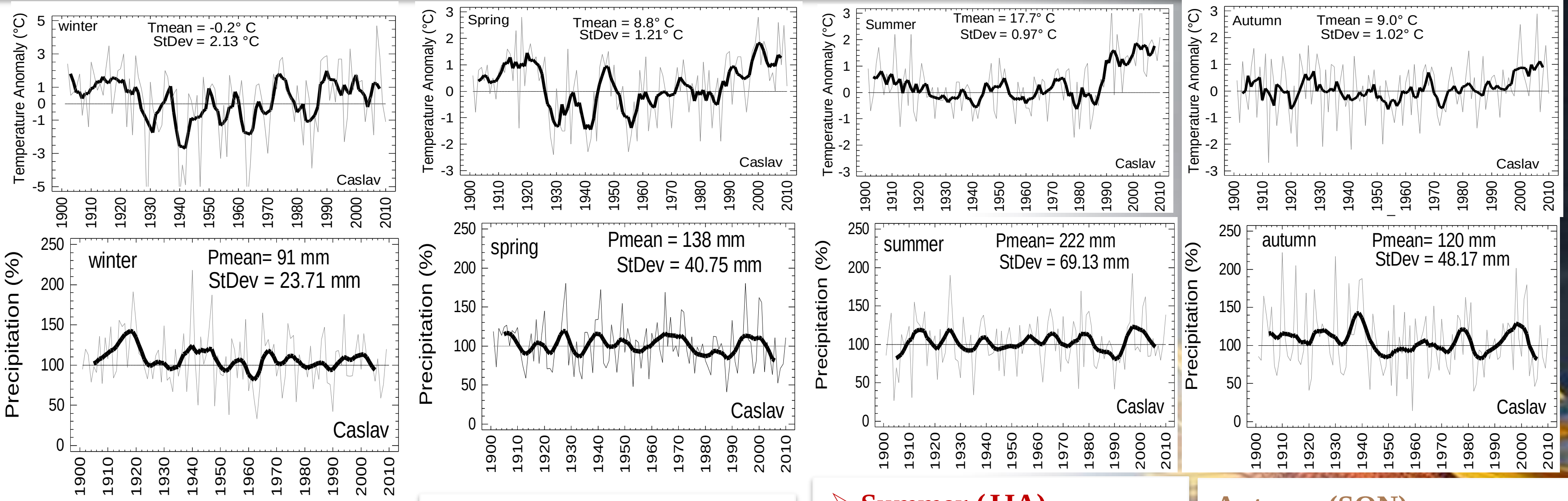


the long-term changes in both the temperature and precipitation secular series were represented by a smoothed 10-year seasonal air temperature deviation and percentage of precipitation, respectively, from the baseline climate.

Drought evolution at various time scales in the lowland regions and their impact on vegetable crops in the Czech Republic (Potop et al., 2012)

3.5 Drought climatology in the Czech Republic

Temporal evolution of seasonal air temperature and precipitation at the secular stations (1901-2010)



Winter (DJF)

- the warmest periods were recorded at the beginning of the 20th century in the 1910s and 1920s, and the coldest period was measured in the 1940s ;
- 1928/1929 (-42.2°C, $\delta T/\sigma = 3.5$) was the coldest winter recorded since the beginning of meteorological measurements.

Spring (MAM)

- 2 warm periods, the first at the beginning of the 20th century with high positive T°C anomalies and P; (**warm** and **wet**) and the second at the end of the 20th century with **warm** and **dry** conditions;
- significant trends: high as 0.7°C/decade.

Summer (JJA)

- the 1970s had the coolest summer in 1978 (σ=-1.7°C);
- The warmest summer was in 2003 (σ = 4.0°C);
- rapidly rising T°C since the mid-1980s (as much as +0.6°C decade^{-1});
- in the first two decades of the 20th century the lowest P were recorded.

Autumn (SON)

- 2000s - the warmest and driest period;
- the majority of autumn seasons with P less than 40% below normal simultaneously had normal T°C;
- shortage of P was the primary cause of drought development during the autumn.

T (°C) - a statistically significant increase has been observed since the 1980s, but we did not find any significant growth or decrease in the trend of the annual, seasonal or monthly amounts of rainfall during the 20th century.

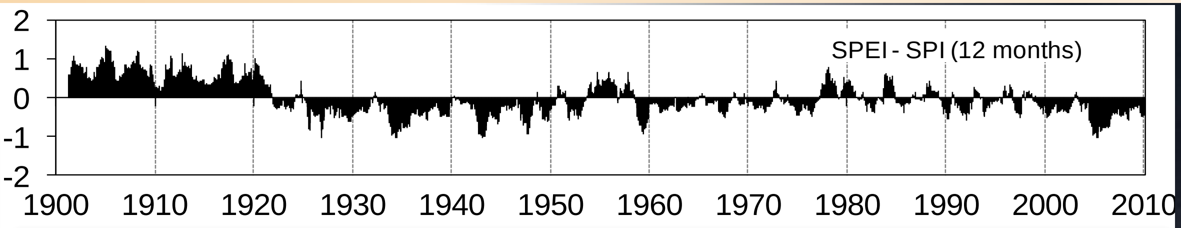
3.5 Drought climatology in the Czech Republic

The difference among the two indices (SPEI-SPI)

- **Similarities** in drought representation with SPI and SPEI were identified during the decades showing:

1) high positive temperature anomalies in spring associated with below normal precipitation (**warm** and **dry**; 1950s, 1990s and 2000s);

2) extremely long sunshine durations associated with large number of consecutive dry days.



- The comparison between SPEI and SPI **showed differences** in representing severe drought records during the decades with

1) the lowest summer negative temperature anomalies combined with the lowest negative precipitation anomalies (**cold** and **dry**; during the first two decades of the 20th century),

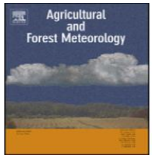
2) the highest summer positive temperature anomalies (the end of the 20th century),

3) both high spring positive temperature and precipitation anomalies (**warm** and **wet**; at the beginning of the 20th century)

4) the lowest deficit of water balance (1947, 2003, 1994, 1983 and 1933) (Potop et al. 2012).

- The first two decades of the 20th century clearly exhibited more wet events than drought events using the SPEI, by SPI qualified as dry.
- This can be explained by the fact that in those decades, lower precipitation and negative temperature anomalies were recorded. This perspective is then transferred to the SPI, which is based only on precipitation.
- The number of dry episodes detected by the SPEI was greater than those detected by the SPI during the last 20 years due to increasing temperatures (0.6°C per decade) and no significant change in precipitation.
- Drying in this period may also be attributed to a combination of both increased T and PET not balanced by the changes in precipitation.
- The use of a precipitation-based index does not take into account the changes in PET.

Source:



Drought evolution at various time scales in the lowland regions and their impact on vegetable crops in the Czech Republic

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3.5 Drought climatology in the Czech Republic

Secular chronology of drought episodes per seasons by SPEI

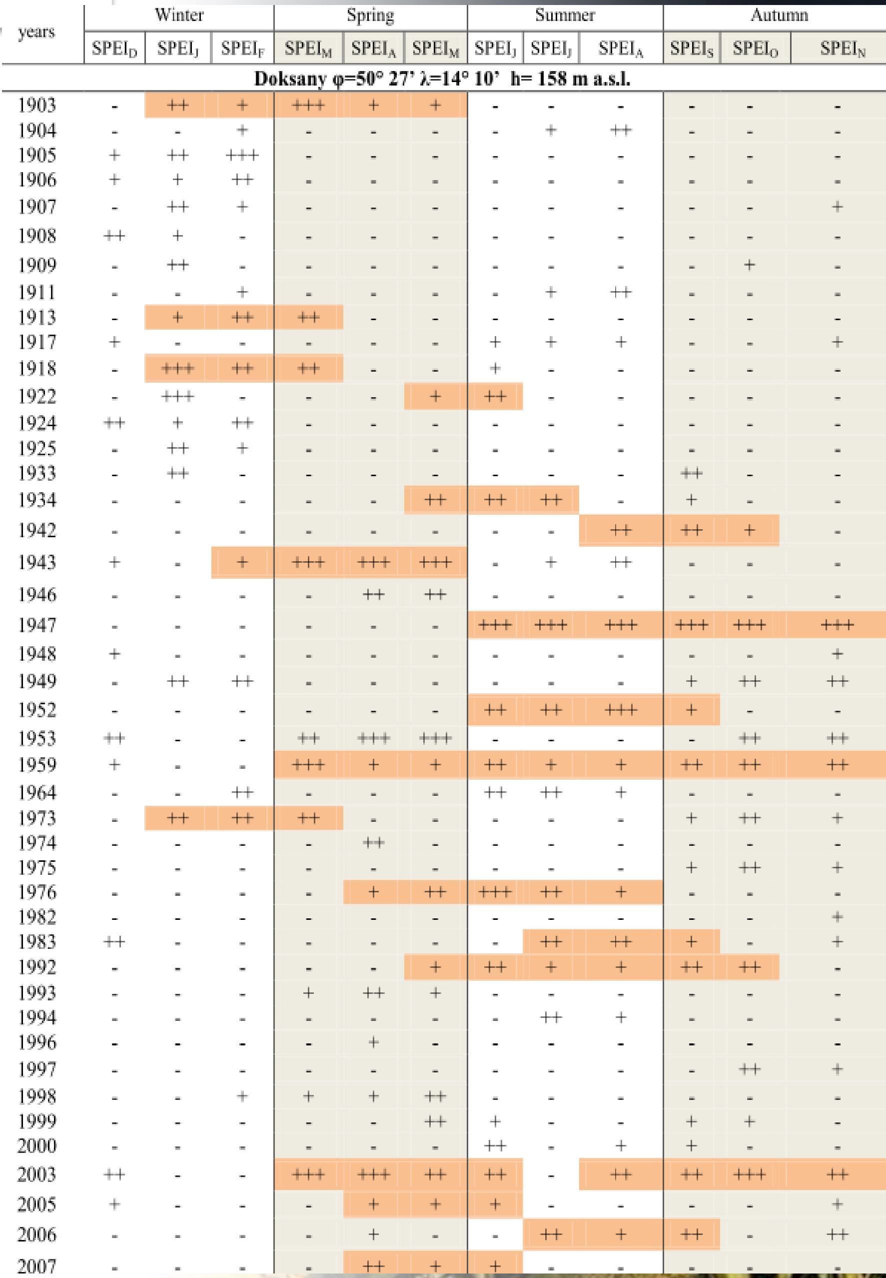
Winter drought events were concentrated in the period from 1900-1960, whereas the period from 1960 to 2010 contained only 6 cases. -associated with the intensification of the Siberian High ridge in Central Europe, resulting in a flow of dry continental air.

Spring droughts were non-existent in the decades of 1961-1970 and 1981-1990, and the 1910s and 1930s were marked by low drought incidence. Spring droughts gained in persistence during the last 20 years, with a greater number and duration occurring in the periods of 2001-2010.

Summer droughts tended to be longer and more severe, extending into autumn with a greater frequency in the 1950s, 1990s and 2000s.

Autumn droughts - the periods 1941-1950 (the extreme and persistent drought of 1947) and 2001-2010 (note the drought of 2003 and 2006) were ranked as having a large number of long severe drought events.

Frequent and long **winter droughts** occurred at the beginning of the 20th century, while spring and summer droughts prevailed at the end of the century. **Summer droughts** appear due to an increasing sea level pressure for western and central Europe where a more pronounced Azores High and its ridge to Central Europe are then reflected



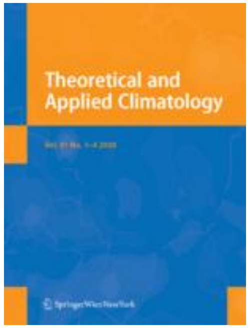
years	Winter			Spring			Summer			Autumn		
	$\mathrm{SPEI_D}$	$\mathrm{SPEI_J}$	$\mathrm{SPEI_F}$	$\mathrm{SPEI_M}$	$\mathrm{SPEI_A}$	$\mathrm{SPEI_M}$	$\mathrm{SPEI_J}$	$\mathrm{SPEI_J}$	$\mathrm{SPEI_A}$	$\mathrm{SPEI_S}$	$\mathrm{SPEI_O}$	$\mathrm{SPEI_N}$
Doksany φ=50° 27' λ=14° 10' h= 158 m a.s.l.												
1903	-	++	+	+++	+	+	-	-	-	-	-	-
1904	-	-	+	-	-	-	-	+	++	-	-	-
1905	+	++	+++	-	-	-	-	-	-	-	-	-
1906	+	+	++	-	-	-	-	-	-	-	-	-
1907	-	++	+	-	-	-	-	-	-	-	-	+
1908	++	+	-	-	-	-	-	-	-	-	-	-
1909	-	++	-	-	-	-	-	-	-	-	+	-
1911	-	-	+	-	-	-	-	+	++	-	-	-
1913	-	+	++	++	-	-	-	-	-	-	-	-
1917	+	-	-	-	-	-	+	+	+	-	-	+
1918	-	+++	++	++	-	-	+	-	-	-	-	-
1922	-	+++	-	-	-	+	++	-	-	-	-	-
1924	++	+	++	-	-	-	-	-	-	-	-	-
1925	-	++	+	-	-	-	-	-	-	-	-	-
1933	-	++	-	-	-	-	-	-	-	++	-	-
1934	-	-	-	-	-	++	++	++	-	+	-	-
1942	-	-	-	-	-	-	-	-	++	++	+	-
1943	+	-	+	+++	+++	+++	-	+	++	-	-	-
1946	-	-	-	-	++	++	-	-	-	-	-	-
1947	-	-	-	-	-	-	+++	+++	+++	+++	+++	+++
1948	+	-	-	-	-	-	-	-	-	-	-	+
1949	-	++	++	-	-	-	-	-	-	+	++	++
1952	-	-	-	-	-	-	++	++	+++	+	-	-
1953	++	-	-	++	+++	+++	-	-	-	-	++	++
1959	+	-	-	+++	+	+	++	+	+	++	++	++
1964	-	-	++	-	-	-	++	++	+	-	-	-
1973	-	++	++	++	-	-	-	-	-	+	++	+
1974	-	-	-	-	++	-	-	-	-	-	-	-
1975	-	-	-	-	-	-	-	-	-	+	++	+
1976	-	-	-	-	+	++	+++	++	+	-	-	-
1982	-	-	-	-	-	-	-	-	-	-	-	+
1983	++	-	-	-	-	-	-	++	++	+	-	+
1992	-	-	-	-	-	+	++	+	+	++	++	-
1993	-	-	-	+	++	+	-	-	-	-	-	-
1994	-	-	-	-	-	-	-	++	+	-	-	-
1996	-	-	-	-	+	-	-	-	-	-	-	-
1997	-	-	-	-	-	-	-	-	-	-	++	+
1998	-	-	+	+	+	++	-	-	-	-	-	-
1999	-	-	-	-	-	++	+	-	-	+	+	-
2000	-	-	-	-	-	-	++	-	+	+	-	-
2003	++	-	-	+++	+++	++	++	-	++	++	+++	++
2005	+	-	-	-	+	+	+	-	-	-	-	+
2006	-	-	-	-	+	-	-	++	+	++	-	++
2007	-	-	-	-	++	+	+	-	-	-	-	-

3.5 Drought climatology in the Czech Republic

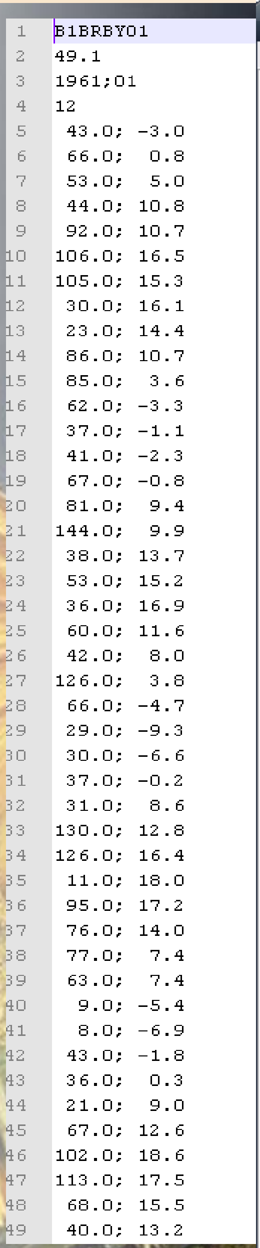
The application of the SPEI in dense network of climatological stations in Czech Republic

- In order to give more insight on the expansion of drought during the growing season, the dry months have been counted for the SPEI series with various lags at each station, every year
- the SPEI was calculated from monthly records of temperature means and precipitation totals for the period 1961-2010
- for calculation the SPEI, the algorithm developed by Vicente-Serrano et al. (2010) was used
- a batch script was created and used for optimizing the calculation of the SPEI for the 184 stations and five accumulated periods: 1, 3, 6, 12 and 24 months

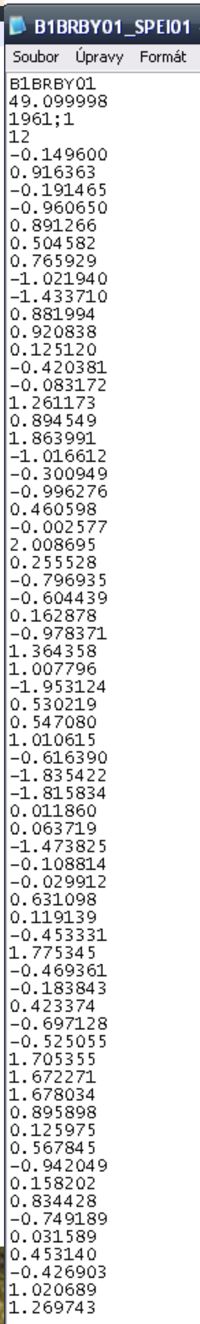
The first line contains the name of the station, and is only used for identification purposes.
The second line is the latitude of the stations, in degrees.
The third line contains the year and month of the first record in the time series, separated by a semi-colon (;).
The fourth line contains the seasonality of the time series, and must be set to 12.
Finally, from the fifth line the data series of monthly precipitation and mean temperature, separated by a semi-colon (;). (spei_manual_en).



```
Usage
spei [timeInterval] [inputFile] [outputFile]
D:\SPEI>spei.exe 1 station_model.txt B1BRBY01_SPEI01.txt
series:    B1BRBY01
latitude:   49.0999
initial date: 1/1961
seasonality: 12
600 registers
calculating SPEI at 1 months
```



```
B1BRBY01
49.1
1961;01
12
 43.0; -3.0
 66.0;  0.8
 53.0;  5.0
 44.0; 10.8
 92.0; 10.7
106.0; 16.5
105.0; 15.3
 30.0; 16.1
 23.0; 14.4
 86.0; 10.7
 85.0;  3.6
 62.0; -3.3
 37.0; -1.1
 41.0; -2.3
 67.0; -0.8
 81.0;  9.4
144.0;  9.9
 38.0; 13.7
 53.0; 15.2
 36.0; 16.9
 60.0; 11.6
 42.0;  8.0
126.0;  3.8
 66.0; -4.7
 29.0; -9.3
 30.0; -6.6
 37.0; -0.2
 31.0;  8.6
130.0; 12.8
126.0; 16.4
 11.0; 18.0
 95.0; 17.2
 76.0; 14.0
 77.0;  7.4
 63.0;  7.4
  9.0; -5.4
  8.0; -6.9
 43.0; -1.8
 36.0;  0.3
 21.0;  9.0
 67.0; 12.6
102.0; 18.6
113.0; 17.5
 68.0; 15.5
 40.0; 13.2
```



```
B1BRBY01
49.099998
1961;1
12
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0.916363
-0.191465
-0.960650
0.891266
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0.765929
-1.021940
-1.433710
0.881994
0.920838
0.125120
-0.420381
-0.083172
1.261173
0.894549
1.863991
-1.016612
-0.300949
-0.996276
0.460598
-0.002577
2.008695
0.255528
-0.796935
-0.604439
0.162878
-0.978371
1.364358
1.007796
-1.953124
0.530219
0.547080
1.010615
-0.616390
-1.835422
-1.815834
0.011860
0.063719
-1.473825
-0.108814
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0.119139
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-0.183843
0.423374
-0.697128
-0.525055
1.705355
1.672271
1.678034
0.895898
0.125975
0.567845
-0.942049
0.158202
0.834428
-0.749189
0.031589
0.453140
-0.426903
1.020689
1.269743
```

Source: Vera Potop, Constanța Boroneanț, Martin Možný, Petr Štěpánek, Petr Skalák (2012)**Observed characteristics of drought over the Czech Republic and its link with the large scale circulation. TAC**

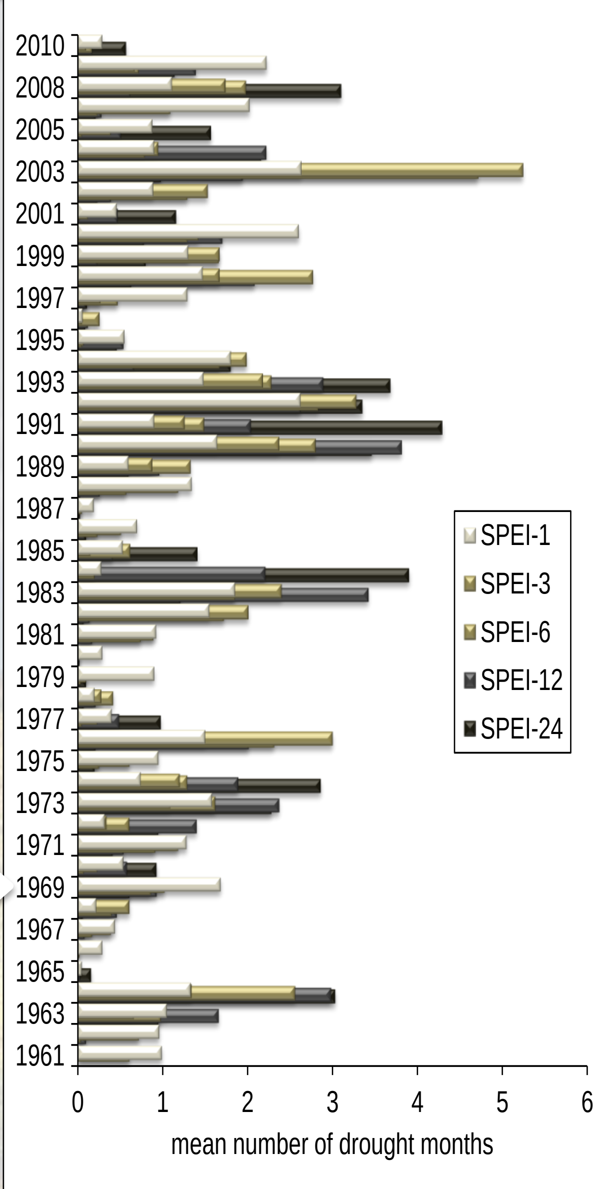
3.5 Drought climatology in the Czech Republic

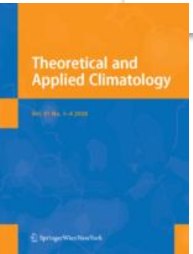
The application of the SPEI in dense network of climatological stations in CR

- The largest number of dry months (meteorological and agricultural drought) during the growing season was recorded, chronologically, in the following years: 1964, 1976, 1983, 1990, 1992, 1994, 1998, 2000, 2003 and 2007.
- The most persistent agricultural drought during the growing season was in 2003 when on average 5.2 dry months were recorded.
- It terms of persistence it was followed by the years 1992 (3.3 months) and 1976 (3.0 months).
- The most persistent hydrological drought during the growing season was recorded in 1990 when on average 3.8 dry months

-represents the evolution of the mean number of dry months

-graph also reflect the transition of meteorological drought (SPEI-1) to agricultural drought (SPEI-3 and SPEI-6) and hydrological drought (SPEI-12 and SPEI-24).





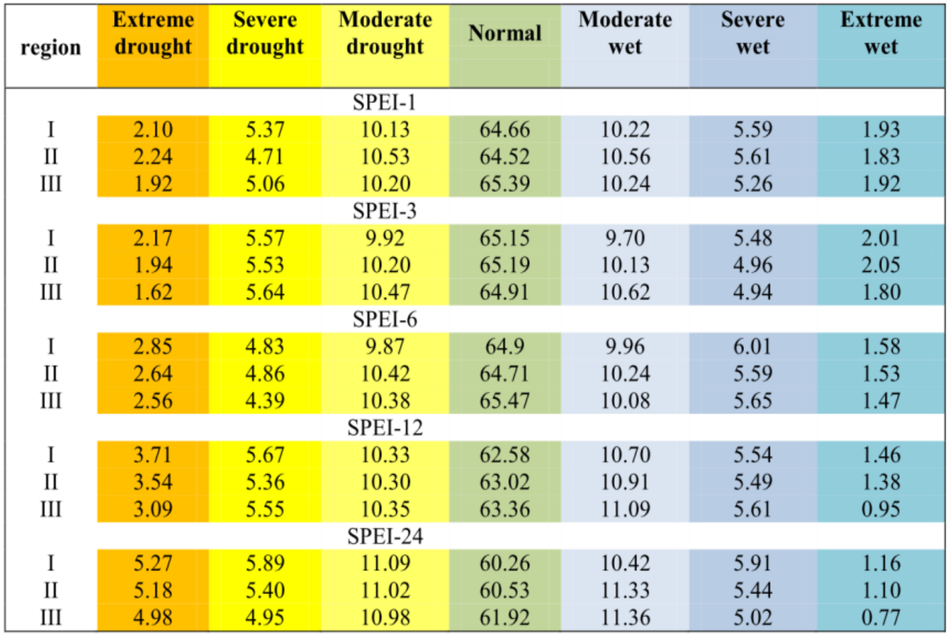
Source: Vera Potop, Constanța Boroneanț, Martin Možný, Petr Štěpánek, Petr Skalák (2012) **Observed characteristics of drought over the Czech Republic and its link with the large scale circulation.** Theor Appl Climatol (submitted).

3.5. Drought climatology in the Czech Republic

The application of the SPEI in dense network of climatological stations in CR

Frequency distribution of the SPEI

- drought occurrence is investigated on the basis of frequency distribution of the SPEI values in 7 classes (see Table)
- the normal conditions represent around 65% out of the total values of SPEI for all lags, in all three regions, while moderate drought and moderate wet conditions are almost equally distributed around 10.5%
- differences in extremely dry conditions (5%) compared to extremely wet conditions (1.5%) were observed when increasing the SPEI lags
- the occurrence of extreme moisture conditions (the SPEI values outside ±2) has a slight tendency toward dry conditions, especially for the SPEI calculated with longer lags (12 and 24 months)



region	Extreme drought	Severe drought	Moderate drought	Normal	Moderate wet	Severe wet	Extreme wet
			SPEI-1				
I	2.10	5.37	10.13	64.66	10.22	5.59	1.93
II	2.24	4.71	10.53	64.52	10.56	5.61	1.83
III	1.92	5.06	10.20	65.39	10.24	5.26	1.92
			SPEI-3				
I	2.17	5.57	9.92	65.15	9.70	5.48	2.01
II	1.94	5.53	10.20	65.19	10.13	4.96	2.05
III	1.62	5.64	10.47	64.91	10.62	4.94	1.80
			SPEI-6				
I	2.85	4.83	9.87	64.9	9.96	6.01	1.58
II	2.64	4.86	10.42	64.71	10.24	5.59	1.53
III	2.56	4.39	10.38	65.47	10.08	5.65	1.47
			SPEI-12				
I	3.71	5.67	10.33	62.58	10.70	5.54	1.46
II	3.54	5.36	10.30	63.02	10.91	5.49	1.38
III	3.09	5.55	10.35	63.36	11.09	5.61	0.95
			SPEI-24				
I	5.27	5.89	11.09	60.26	10.42	5.91	1.16
II	5.18	5.40	11.02	60.53	11.33	5.44	1.10
III	4.98	4.95	10.98	61.92	11.36	5.02	0.77

Regions:
I-mostly intensive agriculture (altitude below 400 m)
II-less intensive agriculture (altitudes between 401m and 700 m)
III-limited agricultural production and mostly forested (altitudes above 700 m)

Source: Vera Potop, Constanța Boroneanț, Martin Možný, Petr Štěpánek, Petr Skalák (2012) **Observed characteristics of drought over the Czech Republic and its link with the large scale circulation.** Theor Appl Climatol (submitted).

European Geosciences Union, General Assembly 2012, Vienna, Austria, 23-27 April 2012

Projected changes in the evolution of drought assessed with the SPEI over the Czech Republic

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Introduction:

In previous studies (*Potop et al.*, 2011, 2012) drought was extensively analyzed by comparing results from the most advanced drought indices (e.g. the SPI and SPEI), which take into account the role of antecedent conditions in quantifying drought severity in the lowland regions of the Czech Republic. Decadal trend in drought extent detected by the SPEI are apparent, however, with higher values of drought incidences in the 1940s, early 1950s and the 1990s and fewer drought episodes in the 1910s, 1930s and 1980s.

The SPEI and SPI showed a large differences in the evolution drought severity during decades with the lowest summer negative temperature anomalies combined with the lowest precipitation (cold and dry; the first two decades of the 20th century), the highest summer positive temperature anomalies (the end of the 20th century), both high spring positive temperature and precipitation anomalies (warm and wet; at the beginning of the 20th century) and the lowest deficit of water balance (1947, 2003, 1994, 1983 and 1933) (*Potop et al.*, 2012). Conversely, similarity between two indices were recorded in decades with high fluctuations of positive spring temperature deviations and lower precipitation (warm and dry; 1950s, 1990s and 2000s); extremely long sunshine durations (155% of the normal amount in extremely dry June of 2006 and August 2003, up to twice the norm for April of 2007 and 2009) and consecutive dry days. Therefore, the role of temperature was evident in summer drought episodes that depend on temperature anomalies, contributing to a higher water demand by potential evapotranspiration at the end of the century (Box 2).

New detailed results about the temporal evolution of the SPEI at different timescales and its impact on vegetable crops are discussed and presented in broader climatological and European contexts. However, more in-depth analysis is required to explore the vulnerability to drought in the context of climate change and then, to calculate the SPEI for denser station network to better represent different climate conditions which manifest across the Czech Republic.

Data and methods:

- In the present study, the Standardized Precipitation Evapotranspiration Index (SPEI) was adopted to assess and project drought characteristics in the Czech Republic based on the regional climate model ALADIN-Climate/CZ simulated data.
- The simulations were conducted at high resolution for the current (1961-1990) and two future climates (2021-2050 and 2071-2100).
- First, the observed data of air temperature and precipitation totals was transferred into a regular grid of ALADIN-Climate/CZ model.
- The bias correction was applied on the scenario runs. The bias correction method is based on variable correction using individual percentiles whose relationship is derived from observations and control RCM simulation. After the correction, the model outputs are fully compatible with measured data.
- The SPEI was calculated based on observed monthly data of mean temperature and precipitation totals for the period 1961-1990, as reference period, and for the periods 2021-2050 and 2071-2100, as future climates under A1B SRES scenario.
- Monthly series of temperature and precipitation were taken from the Czech Hydrometeorological Institute CLIDATA database.
- The SPEI calculated for each grid point (789) was analysed in terms of temporal evolution and frequency distribution for the scenario runs in comparison with control run.
- The gridding and all data processing including the presented analysis were done by ProClimDB database software (free download from http://wwww.climahom.eu) for processing of climatological datasets (Štěpánek, 2010).
- For calculation the SPEI, the algorithm developed by Vicente-Serrano et al. (2010) was used. The documentation and executable files are freely available at http://digital.csic.es/handle/10261/10002.
- The SPEI were calculated with various lags, 1, 3, 6, 12 and 24 months because the drought at these time scales is relevant for agricultural, hydrological and socio-economic impact, respectively. The study refers at the warm season of the year (April to September).
- As in the case of observational study, we have identified three climatically homogeneous regions, corresponding to the altitudes below 400 m, between 401 and 700 m and, above 700 m.
- For these three regions the frequency distribution of the SPEI values in 7 classes of drought category (%) were calculated based on grid point data falling in each region, both for the observed data and scenario runs.
- The paper presents the projected changes in frequency distribution of SPEI at various time scales, in intensity, duration and spatial distribution of drought over the territory of the Czech Republic under A1B scenario for the middle and the end of 21st century.

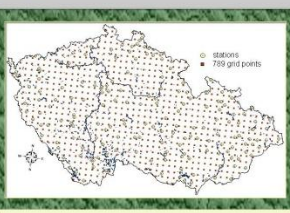
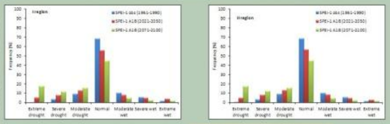


Fig. 1
Map of location of the climatological stations and 789 grid points used for the calculation of SPEI drought index in Czechia.

Summary: „ Projected changes in the evolution of drought assessed with the SPEI over the Czech Republic"

In the present study, the Standardized Precipitation Evapotranspiration Index (SPEI) was adopted to assess and project drought characteristics in the Czech Republic based on the regional climate model ALADIN-Climate/CZ simulated data. The simulations were conducted at high resolution (10km) for the current (1961-2000) and two future climates (2021-2050 and 2071-2100). First, the observed data of air temperature and precipitation totals was transferred into a regular grid of ALADIN-Climate/CZ model. The bias correction was applied on the scenario runs. The bias correction method is based on variable correction using individual percentiles whose relationship is derived from observations and control RCM simulation. The SPEI was calculated based on observed monthly data of mean temperature and precipitation totals for the period 1961-1990, as reference period, and for the periods 2021-2050 and 2071-2100, as future climates under A1B SRES scenario. The SPEI were calculated with various lags, 1, 3, 6, 12 and 24 months because the drought at these time scales is relevant for agricultural, hydrological and socio-economic impact, respectively. The study refers at the warm season of the year (April to September). As in the case of observational study, we have identified three climatically homogeneous regions, corresponding to the altitudes below 400 m, between 401 and 700 m and, above 700 m. For these three regions the frequency distribution of the SPEI values in 7 classes of drought category (%) were calculated based on grid point data falling in each region, both for the observed data and scenario runs. The paper presents the projected changes in frequency distribution of SPEI at various time scales, in intensity, duration and spatial distribution of drought over the territory of the Czech Republic under A1B scenario for the middle and the end of 21st century.

Key words: Standardized precipitation evapotranspiration index, frequency distribution, climate change scenario, Czech Republic.



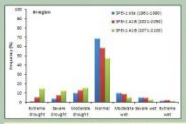


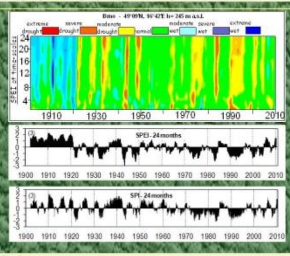
Table 1. The 7 classes of SPEI category according to its value.

SPEI	Drought category	Probability
≥2.0	Extreme wet	0.02
1.50 – 1.99	Severe wet	0.06
1.49 - 1.00	Moderate wet	0.10
0.99 - -0.99	Normal	0.65
-1.00 – -1.49	Moderate drought	0.10
-1.50 - -1.99	Severe drought	0.05
≤-2.00	Extreme drought	0.02

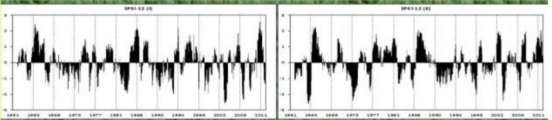
Table 2. Frequency distribution (%) of the SPEI values during the growing season in 7 classes of moisture category at time scales of 1 month per regions.
Region I: the altitudes below 400 m, region II: between 401 and 700 m and region III: above 700 m.

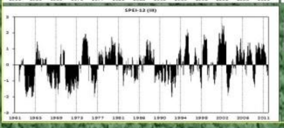
regions	Extreme drought	Severe drought	Moderate drought	Normal	Moderate wet	Severe wet	Extreme wet
			SPEI-1 obs	1961-1990			
[illegible]	0.26	3.81	9.31	68.45	10.46	[illegible]	[illegible]
[illegible]	0.47	3.64	9.39	68.50	10.32	[illegible]	[illegible]
[illegible]	0.60	3.96	10.06	68.65	9.86	[illegible]	[illegible]
			SPEI-1 A1B	2021-2050			
[illegible]	5.49	8.07	13.12	55.92	8.13	[illegible]	[illegible]
[illegible]	5.10	8.26	13.27	58.80	8.69	[illegible]	[illegible]
[illegible]	5.27	7.66	12.79	58.89	8.83	[illegible]	[illegible]
			SPEI-1 A1B	2071-2100			
[illegible]	17.70	11.86	15.72	44.81	5.06	[illegible]	[illegible]
[illegible]	17.48	12.46	15.78	44.93	4.85	[illegible]	[illegible]
[illegible]	14.83	12.53	15.51	47.46	5.36	[illegible]	[illegible]

Box 1.
Frequency distribution of the the SPEI for 1 month during growing seazon (April-September) based on measured monthly temperature and precipitation and simulated by the A1B scenario runs.



Box 2.
Secular temporal evolution (1901-2010) for data series of :
upper panel) *SPEI at time scales from 1 to 24 months;* ***bottom panel)*** *SPEI and SPI at 24-months associated with hydrological drought;*





Box 3.
Temporal evolution of the SPEI for 12 months for three regions: I - the altitude below 400 m, II - 400-700 m, and II – above 700 m.

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Štěpánek P (2010) ProClimDB – software for processing climatological datasets. CHMI, regional office Brno. http://www.climahom.eu/ProcData.html
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Bioclimate 2012-Bioclimatology of ecosystems 29-31 August 2012, Ústí nad Labem, Czech Republic

Temporal evolution of dry and wet conditions in the Czech Republic during the growing season

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Abstract. In the present study, the Standardized Precipitation Evapotranspiration Index (SPEI) was adopted to assess temporal evolution of wet and dry months during growing season (April to September) in the Czech Republic based on a dense network of 184 climatological stations for the period 1961-2010. The SPEI were calculated with various lags, 1, 3, 6, 12 and 24 months because the drought at these time scales is relevant for agricultural, hydrological and socio-economic impact, respectively. To assess the temporal evolution of dry and wet conditions during the growing season, first, the monthly time series of the SPEI for the months April to September were averaged at each station for each SPEI accumulation period (1, 3, 6, 12 and 24 months, respectively). Then, these SPEI time series were averaged over all 184 stations to get a time series of drought index at country level. The characteristics of drought were analyzed in terms of temporal evolution of SPEI, frequency distribution and duration of drought at country level and for three regions delimited on station altitude. The frequency distribution of the SPEI values in 7 classes of drought category (%) was calculated based on station records. The temporal evolution of the SPEI with one month lag represents the year by year moisture characteristic of the current growing season. In this respect, at country level, during the second half of the 20th century and the first decade of 21st century, the hierarchy of the driest years during the growing season was 2003, followed by 1992, 2000, 1983, 1982, 1976, 2009 and 1999. On the other hand, the wettest years during the growing seasons were 1965, 2010, 1977, 1996, 1966, 2001, 1972, 1980 and 1995.

Key words: Drought, Standardized Precipitation Evapotranspiration Index, frequency distribution, empirical orthogonal function, Czech Republic

Data description and methods

- The SPEI was calculated from monthly records of temperature means and precipitation totals for the period 1961-2010, using a dense network of 184 climatological stations uniformly covering the territory of Czech Republic. The station elevation ranges between 158 and 1490 m above sea level (Fig. 1).
- Monthly series of temperature and precipitation were selected from the Czech Hydrometeorological Institute CLIDATA database based on spatial distribution and completeness of observation time series.
- The quality control of the data was carried out by combining several methods: (i) by analyzing difference series between candidate and neighboring stations – i.e. pairwise comparisons (ii) by applying limits derived from interquartile ranges and (iii) by comparing the series values tested with "expected" values – technical series created by means of statistical methods for spatial data (e.g. IDW, kriging).
- For calculation the SPEI, the algorithm developed by Vicente-Serrano et al. (2010) was used. The documentation and executable files are freely available at http://digital.csic.es/handle/10261/10002.
- A batch script was created and used for optimizing the calculation of the SPEI for the 184 stations and five accumulated periods: 1, 3, 6, 12 and 24 months.
- The SPEI was calculated for each month of the year but this study refers only at the warm season (April to September). The drought at these time scales is relevant for agriculture (1, 3 and 6 months), hydrology (12 months) and socio-economic impacts (24 months), respectively. Drought categories according to the SPEI are presented in Table 1.
- Averaged number of drought episodes during growing season determined by SPEI≤-1 at various time scales for three SPEI series: (1) each station, (2) each climatic region and (3) the entire territories of country.
- To identify the principal modes of variability of the SPEI over the territory of the Czech Republic the Empirical Orthogonal Functions (EOF) analysis have been performed at various time scales (Box 1).
- The frequency distribution was calculated as the ratio between the number of occurrences in each SPEI category and the total number of events counted for all stations in a given region and for a given time scale (1, 3, 6, 12 and 24 months) (Table 2).
- To give more insight on the duration of drought during the growing season the number of dry months (SPEI≤-1) has been counted for each SPEI series with various lag at each station and then averaged at country and at region level (Fig. 2).
- The temporal evolution of the percentage of stations with drought (SPEI≤-1) during growing season (April-September) at five lags of SPEI for the entire territory of the Czech Republic is shown in Fig. 3.
- The spatial evolution of the SPEI could be associated to some extend with the three regions, corresponding to the altitudes below 400 m, between 401 and 700 m and, above 700 m (Box 2).

Table 1. The 7 classes of SPEI category according to its value.

SPEI	Drought category	Probability
≥2.0	Extreme wet	0.02
1.50 – 1.99	Severe wet	0.06
1.49 - 1.00	Moderate wet	0.10
0.99 - -0.99	Normal	0.65
-1.00 – -1.49	Moderate drought	0.10
-1.50 - -1.99	Severe drought	0.05
≤-2.00	Extreme drought	0.02

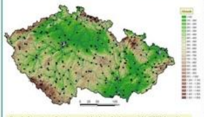
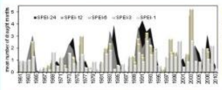


Fig. 1. Location of stations used for the calculation of the SPEI drought index in the Czech Republic.

Table 2. Frequency distribution (%) of the SPEI values during the growing season in 7 classes of moisture category at time scales of 1, 3, 6, 12 and 24 months per regions.
Region I: the altitudes below 400 m, region II: between 401 and 700 m and region III: above 700 m.

region	Extreme drought	Severe drought	Moderate drought	Normal	Moderate wet	Severe wet	Extreme wet
				SPEI-1			
I	2.1	5.37	10.13	64.66	10.22	5.59	1.93
II	2.24	4.71	10.53	64.52	10.56	5.61	1.83
III	1.92	5.06	10.2	65.39	10.24	5.26	1.92
				SPEI-3			
I	2.17	5.57	9.92	65.15	9.7	5.48	2.01
II	1.94	5.53	10.2	65.19	10.13	4.96	2.05
III	1.62	5.64	10.47	64.91	10.62	4.94	1.8
				SPEI-6			
I	2.85	4.83	9.87	64.9	9.96	6.01	1.58
II	2.64	4.86	10.42	64.71	10.24	5.59	1.53
III	2.56	4.39	10.38	65.47	10.08	5.65	1.47
				SPEI-12			
I	3.71	5.67	10.33	62.58	10.7	5.54	1.46
II	3.54	5.36	10.3	63.02	10.91	5.49	1.38
III	3.09	5.55	10.35	63.36	11.09	5.61	0.95
				SPEI-24			
I	5.27	5.89	11.09	60.26	10.42	5.91	1.16
II	5.18	5.4	11.02	60.53	11.33	5.44	1.1
III	4.98	4.95	10.98	61.92	11.36	5.02	0.77



The most persistent hydrological drought during the growing season was recorded in 1990 when on average 3.8 dry months during the growing season were reported at country level.
The most persistent agricultural drought during the growing season was in 2003 when on average 5.2 dry months were recorded. It terms of persistence it was followed by the years 1992 (3.3 months) and 1976 (3.0 months).

Fig. 2 The mean number of dry months (SPEI≤-1) at various lags (1, 3, 6, 12 and 24 months) for the entire territory of the Czech Republic during the growing season (1961-2010).

These graphs also reflect the transition of meteorological drought (SPEI-1) to agricultural drought (SPEI-3 and SPEI-6) and hydrological drought (SPEI-12 and SPEI-24).
Interestingly to note that during 1990 the prevalence of drought was high (at around 85% of the stations) at all SPEI timescales.
This means that the meteorological drought gradually developed into agricultural and hydrologic drought, which turned out into a significant socio-economic impact.

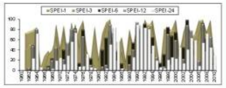
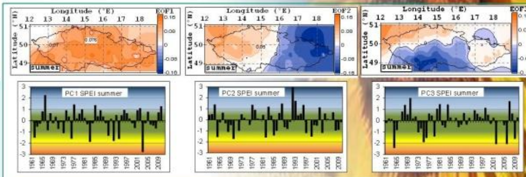


Fig. 3. Percentage of stations (%) with the SPEI≤-1 at various lags (1, 3, 6, 12 and 24 months) for the entire territory of the Czech Republic during the growing season (1961-2010).



Box 1.
The spatial patterns of the first three EOFs of summer SPEI at 1 month lag over the Czech Republic (upper panel) and the corresponding temporal PC series normalized by its standard deviation (lower panel).

upper panel:

- The spatial coefficients of EOF1 have positive loadings at all stations. This fact points out on the large scale factors that might drive the SPEI variability.
- The distribution of the spatial coefficients of EOF2 delimitates two regions with opposite signs of loadings in the eastern and western halves of the country.
- The spatial distribution of EOF3 coefficients roughly delimitates the lowland in the north-western and south-eastern parts of the country and the highland in the southern half of the country where the loadings have opposite signs.
- These spatial distributions of EOF2 and EOF3 correspond to some extend to the regionalization previously used in other studies (Potop et al., 2012) which identified three climatically homogeneous regions, corresponding to the altitudes below 400 m, between 401 and 700 m and, above 700 m (Fig. 1).

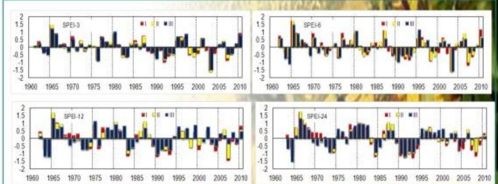
lower panel:

- The PC expansion coefficient time series of summer SPEI at one month lag is presented in the lower panel of Box 1.
- The PC time series show the temporal evolution of EOFs identifying the dry and wet years and the intensity of their anomalies in terms of normalized values of PC time series.
- According to the magnitudes of the PC1 of summer SPEI at one month lag, the year 2003 was the driest during the period 1961-2010 at country level, this characteristic being induced by the large scale factors.
- The PC2 and PC3 time series show the temporal evolution of summer SPEI variability which mostly depend on regional and local factors.

Conclusions

The characteristics of drought have been analyzed both at country level (184 stations) and at regional level of the three regions defined on station altitude: region I (89 stations with altitude below 400 m) characterized by mostly intensive agriculture, region II (73 stations with altitudes between 401m and 700 m) less intensive agriculture and region III (22 stations with altitudes above 700 m) mostly forested and limited agricultural production.
The main results can be summarized as follows:

- The temporal evolution of the averaged SPEI during the growing season at country level for various lags (1, 3, 6, 12 and 24 months) highlight the year by year moisture characteristics of this season. For the SPEI calculated at 1 month lag the hierarchy of the driest growing seasons was 2003 followed by 1992, 2000, 1983, 1982, 1976, 2009 and 1999. The temporal evolutions of the averaged SPEI calculated for 3, 6, 12 and 24 months lags point out on the persistence of moisture characteristics.
- On the other hand the wettest periods were 1965-1968, 1975-1982, 1986-1988 and 1996-1997.
- According to the SPEI values for all lags and mostly during the last decade, the intensity of drought in the region III (stations above 700 m) was lower than in the rest of the country at lower altitude (Box 2).
- As in the case of country level, the number of dry (wet) growing seasons at regional level increases as the SPEI lag increases from 1 to 6 months in all three regions and then slightly decreases as the SPEI lag increases from 12 to 24 months.



Box 2.
Temporal evolution of the averaged SPEI during the growing season (April-September) at various lags (3, 6, 12 and 24 months) for the three regions defined on station altitude: region I (below 400 m), region II (between 400 and 700 m), and region III (above 700 m).

Acknowledgements:
The research on drought conditions in the Czech Republic was supported by S grant of MSMT CR and projects 6046070901 and OC10010.

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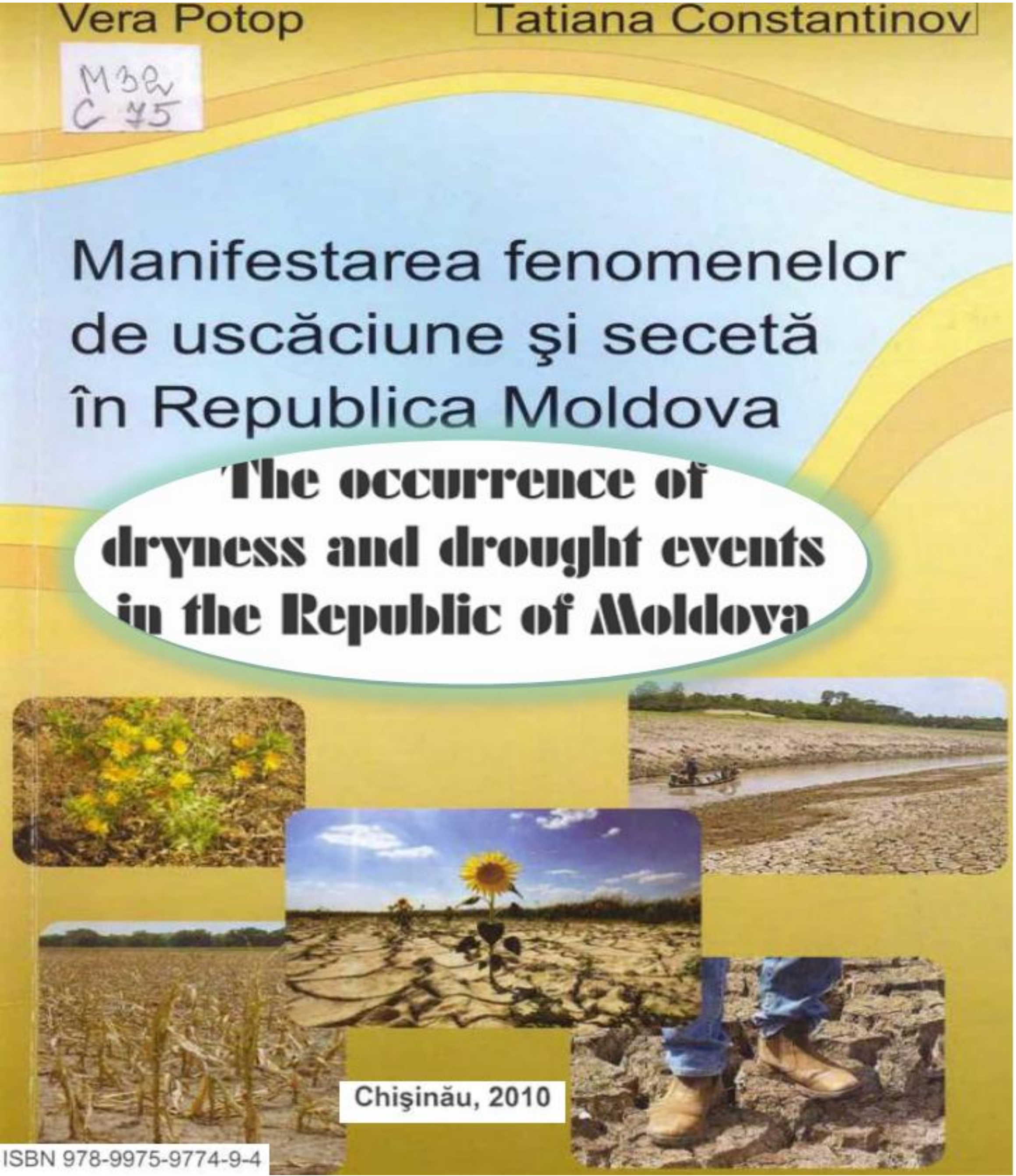
4. Drought climatology in the Republic of Moldova (South-eastern Europe)



Vera Potop Tatiana Constantinov

Manifestarea fenomenelor
de uscăciune şi secetă
în Republica Moldova

The occurrence of
dryness and drought events
in the Republic of Moldova

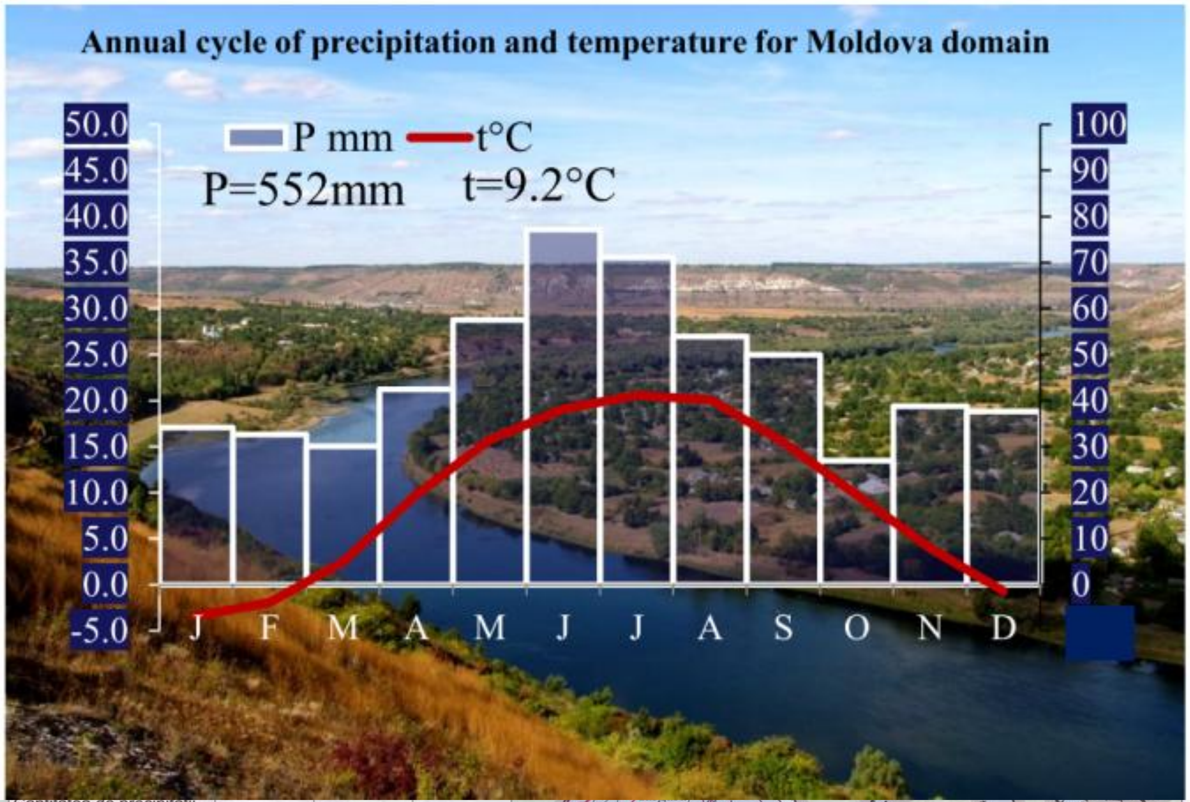
Chişinău, 2010

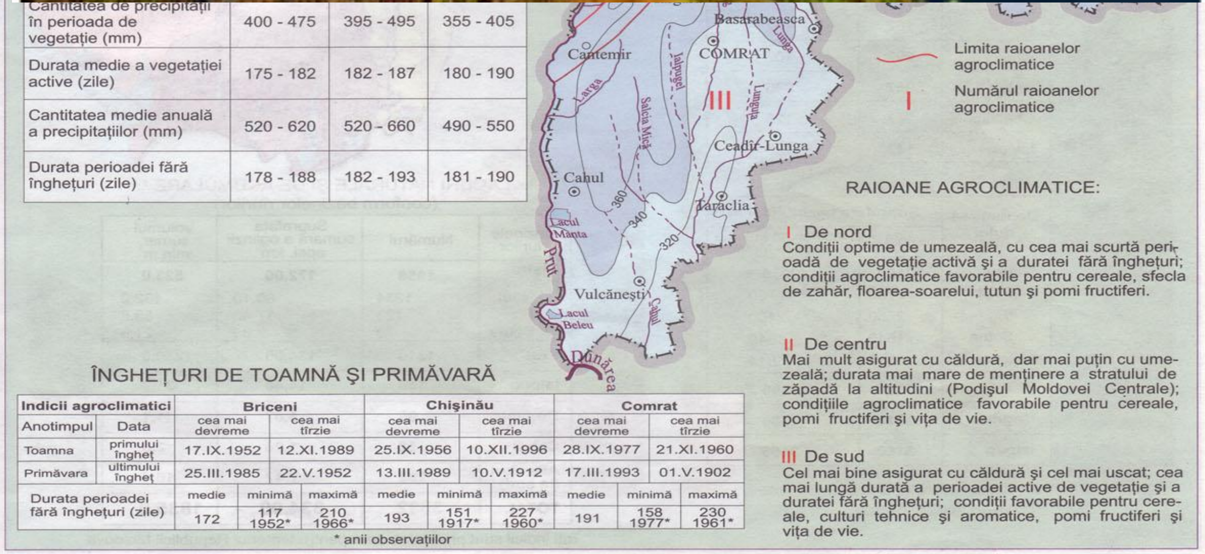
ISBN 978-9975-9774-9-4

Capital	Chisinau
Government	republic
Currency	Moldovan leu (MDL)
Area	33,843 sq km
Population	4,455,421 (July 2006 est.)
Time Zone	UTC+2

4. Drought climatology in the Republic of Moldova

- RM is situated in the South-East part of Europe, between 45°28' – 48°28' northern latitude (**350km**) and between 26°40' - 30°06' eastern longitude (**150km**).
- **The geographical position** of the territory of the RM gives its climate a marked continental character, with frequent occurrences of drought.
- Short mild winters, lengthy hot summers, modest precipitation, and long dry periods in the south.
- The average annual precipitation diminishes from north-west to south-east from **680mm** to **420mm**.
- The average annual temperature increases southward from around **8-9°C** in the north to around **10-11°C** in the south.
- The territory is hilly with hills and plains, the plateaux being located mostly in the central part (Codrii woods).
- The relief altitudes vary from **5m** (Giurgiulesti) to **429m** (Balanesti).





Cantitatea de precipitații în perioada de vegetație (mm)	400 - 475	395 - 495	355 - 405
Durata medie a vegetației active (zile)	175 - 182	182 - 187	180 - 190
Cantitatea medie anuală a precipitațiilor (mm)	520 - 620	520 - 660	490 - 550
Durata perioadei fără înghețuri (zile)	178 - 188	182 - 193	181 - 190

ÎNGHEȚURI DE TOAMNĂ ŞI PRIMĂVARĂ

Indicii agroclimatici		Briceni			Chişinău			Comrat		
Anotimpul	Data	cea mai devreme		cea mai tîrzie	cea mai devreme		cea mai tîrzie	cea mai devreme		cea mai tîrzie
Toamna	primului îngheț	17.IX.1952		12.XI.1989	25.IX.1956		10.XII.1996	28.IX.1977		21.XI.1960
Primăvara	ultimului îngheț	25.III.1985		22.V.1952	13.III.1989		10.V.1912	17.III.1993		01.V.1902
Durata perioadei fără înghețuri (zile)		medie	minimă	maximă	medie	minimă	maximă	medie	minimă	maximă
		172	117 1952*	210 1966*	193	151 1917*	227 1960*	191	158 1977*	230 1961*

* anii observațiilor

Limita raioanelor agroclimatice

I Numărul raioanelor agroclimatice

RAIOANE AGROCLIMATICE:

I De nord
Condiții optime de umezeală, cu cea mai scurtă perioadă de vegetație activă şi a duratei fără înghețuri; condiții agroclimatice favorabile pentru cereale, sfecla de zahăr, floarea-soarelui, tutun şi pomi fructiferi.

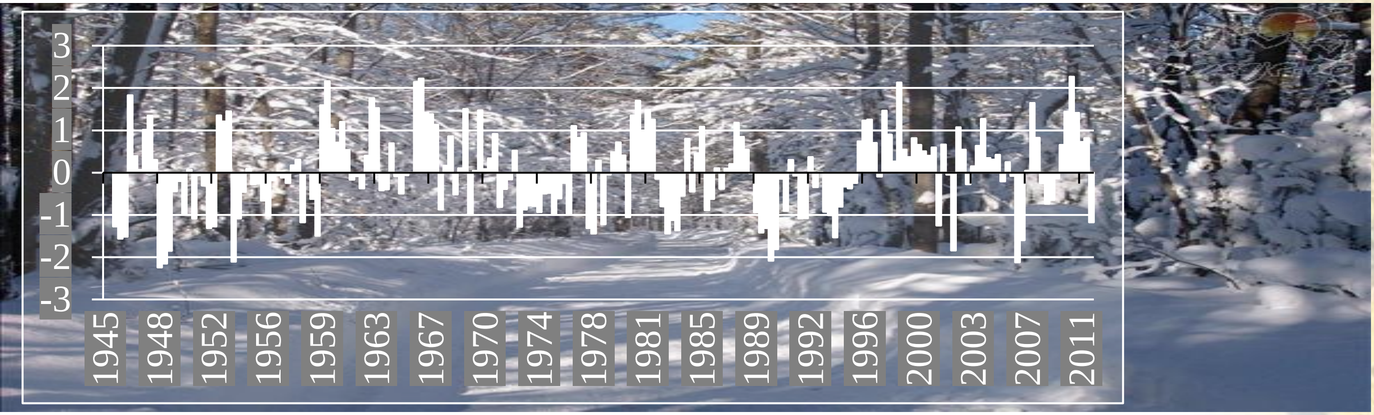
II De centru
Mai mult asigurat cu căldură, dar mai puțin cu umezeală; durata mai mare de menținere a stratului de zăpadă la altitudini (Podişul Moldovei Centrale); condițiile agroclimatice favorabile pentru cereale, pomi fructiferi şi vița de vie.

III De sud
Cel mai bine asigurat cu căldură şi cel mai uscat; cea mai lungă durată a perioadei active de vegetație şi a duratei fără înghețuri; condiții favorabile pentru cereale, culturi tehnice şi aromatice, pomi fructiferi şi vița de vie.

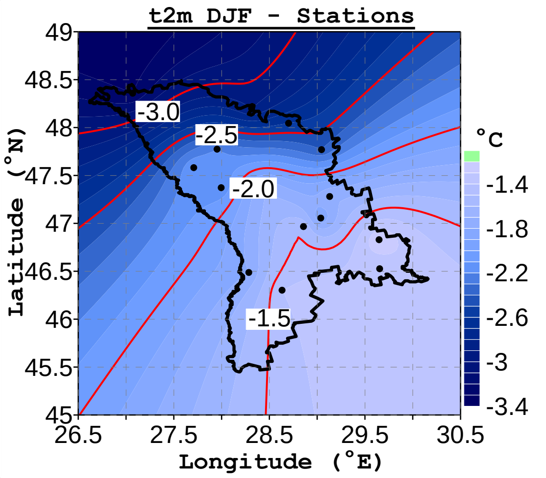
4. Drought climatology in the Republic of Moldova

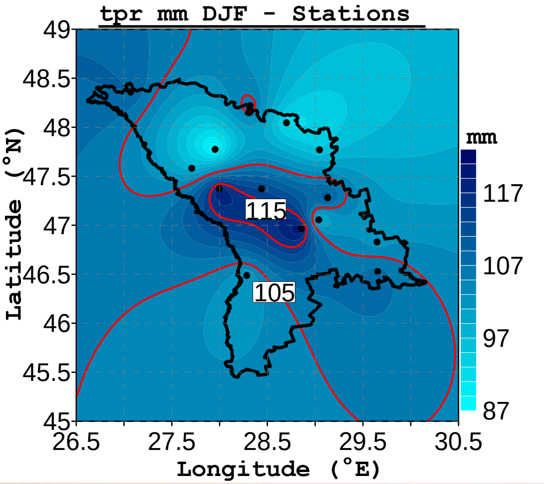
Winter (DJF)

- The winter air temperature mean ranges between -1.4 and -3.4ºC
- **The coldest winter**: 1953/1954, with *Tmean* ranging -8.0 to -9.0ºC (6.0-7.0ºC lower than the norm according to *Moldova's State Hydrometeorological Service*)
- **The warmest winter**: 2006/2007, with *Tmean* ranging +1.0ºC to +3.0ºC (exceeded the norm with 4.0-5.0ºC)
  - **Absolut minimum:** –35.5ºC (on 20 January 1963; Brătuşeni village, Edineț district)
  - **Absolut maximum:** + 23.3ºC (on 26 February 1990, Tiraspol)
- The coldest winter month: January (*Tmean* constitutes **3-5ºC below zero**)
- The high variability of the air temperature during winter season is one of the climatic particularities of Moldova
- **Precipitation**: on average 87-117 mm or 16-20% of the average annual amount
  - the precipitations are mainly in a mixed phase – rain and snow
  - the maximal daily value was 50-70 mm
- The hierarchy of the driest winters according to the SPEI: 1948, 1949, 2006, 1953, 1990, 1949, 2002, 1990, 2007, 1946, 1994 and 1959



Evolution of the SPEI at 3-month lag during winter from December of 1946 to February of 2011 at Chisinau climatological station.

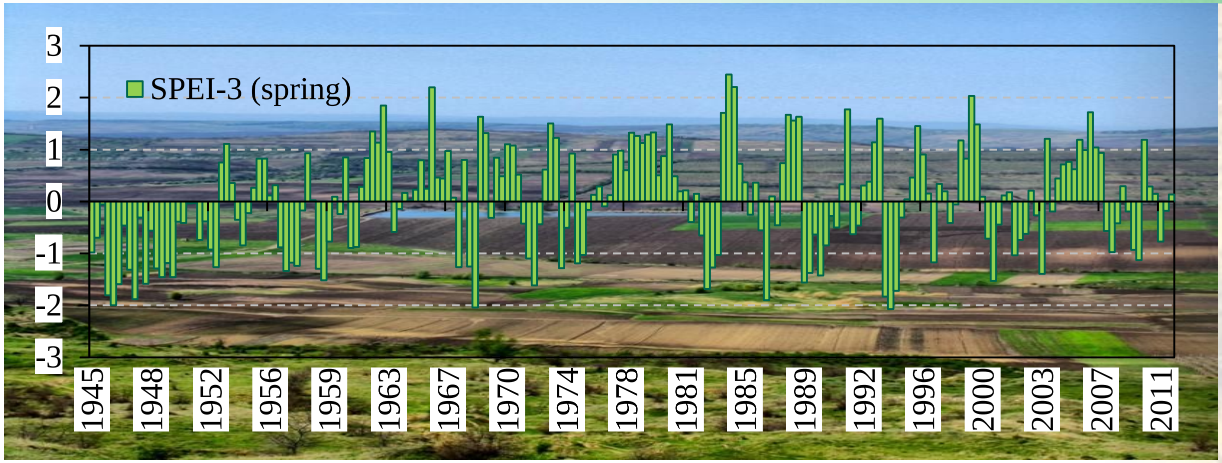


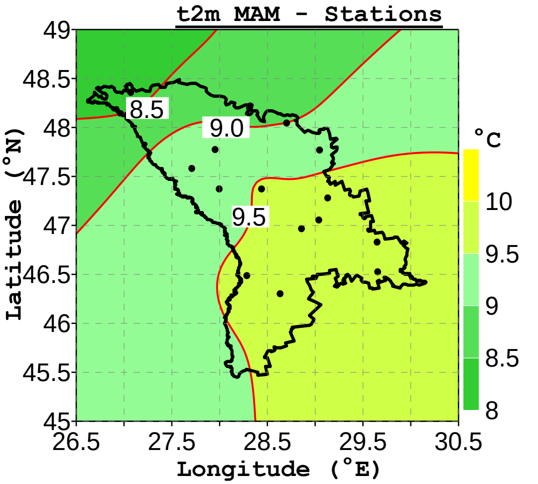


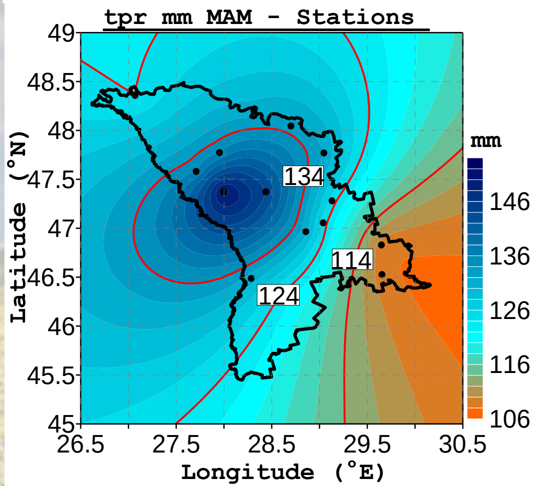
4. Drought climatology in the Republic of Moldova

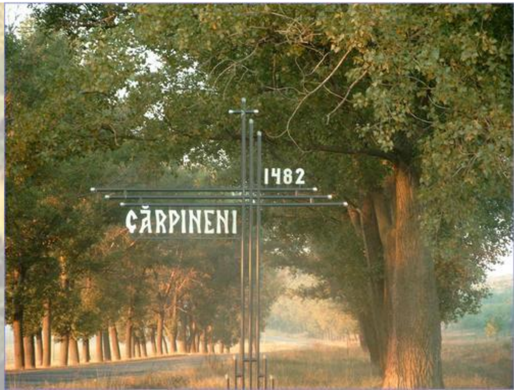
Spring (MAM)

- **The average air temperature:** ranges between +8ºC and +10ºC
- **The coldest spring:** 1987 with *Tmean* of +5 to +6ºC (3-4ºC lower than the norm)
- **The warmest springs:** 1983 and 2007 with *Tmean* ranging 11 to 13°C (above the norm with 2-3ºC)
  - **Absolut minimum:** –26ºC (on 4 March 1955 at Bravicea)
  - **Absolut maximum:** +37ºC (on 17 May 1969 and 20 May 1996, at Cahul and Stefan Voda, respectively)
- **Precipitation total:** on average 105-150mm or 24% of the mean annual total
  - **The driest** spring: 2003 - precipitations was twice lower than the norm and constituted 30-60 mm
  - **The wetness** spring: 1991, on contrary, the total fallen precipitations (200-280 mm) exceeded twice the norm
- **Daily maximum precipitation total:** was 30-100 mm
- The hierarchy of the driest springs according to the SPEI: 1994, 1968, 1946, 1947, 1986 and 1983
- The longest dry period: 1945-1950





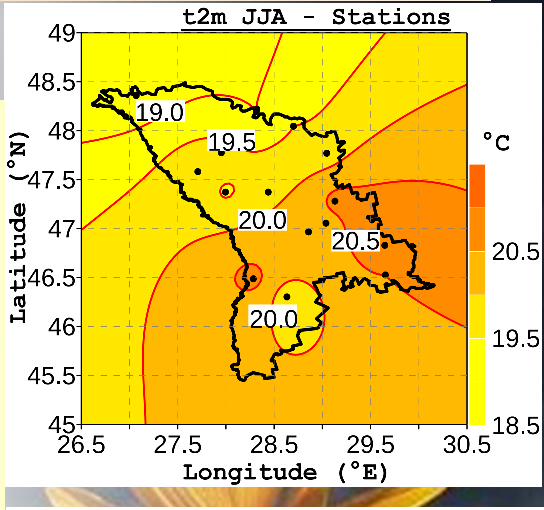


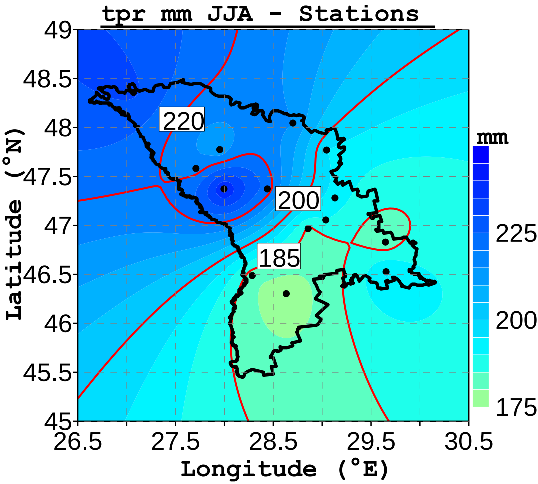


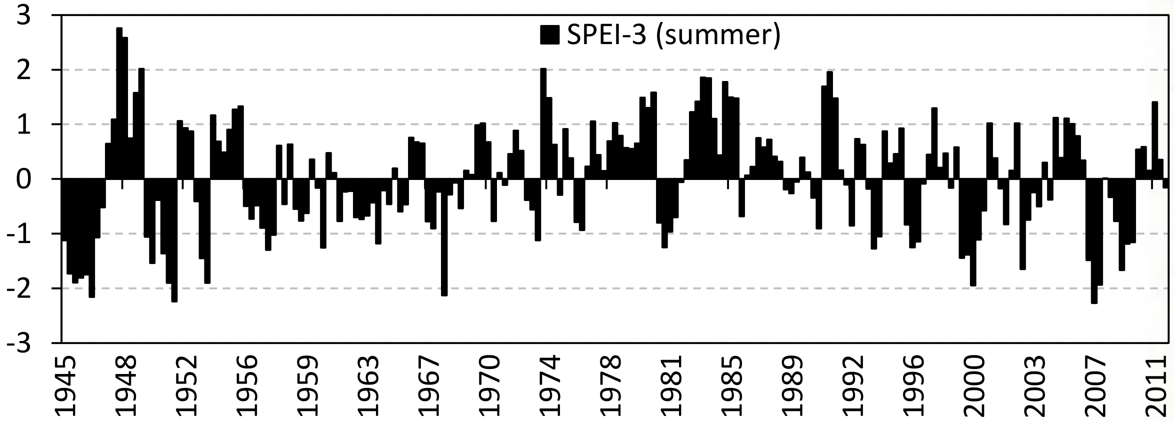
4. Drought climatology in the Republic of Moldova

Summer (JJA)

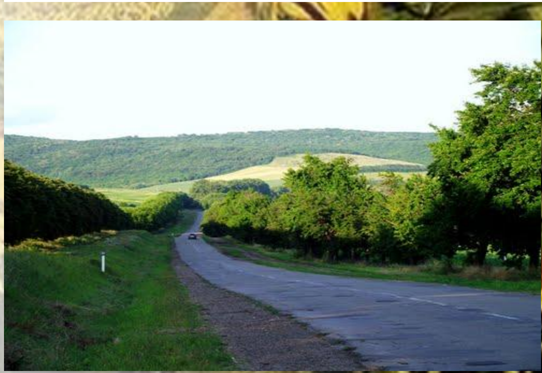
- The summer mean air temperature ranges between +18.5ºC and +21.0ºC
- **The hottest summer:** 2007 with *Tmean* ranging 22.0 to 25.0ºC (above the norm with 3.0-4.0ºC)
  - **Absolut maximum:** +41.5ºC (on 21 July 2007 at Kamenka: *Moldova's State Hydrometeorological Service source*)
- **The coldest summers:** 1976 and 1984 with *Tmean* ranging +16 to +19ºC (2ºC lower than the norm)
- **Precipitation:** on average 175-235 mm
  - **The lowest**: 37 mm (Cahul, 1924)
  - **The highest**: 531mm (Chisinau, 1948)
  - **Daily maximum rainfall:** ranges from 70 mm
- The hierarchy of the driest summers according to the SPEI: 2007, 1946, 1951, 1968, 2000, 1953, 1945, 2003 and 2009.
- The longest dry periods: 1945-1947, 1950-1951 and 1999-2000.





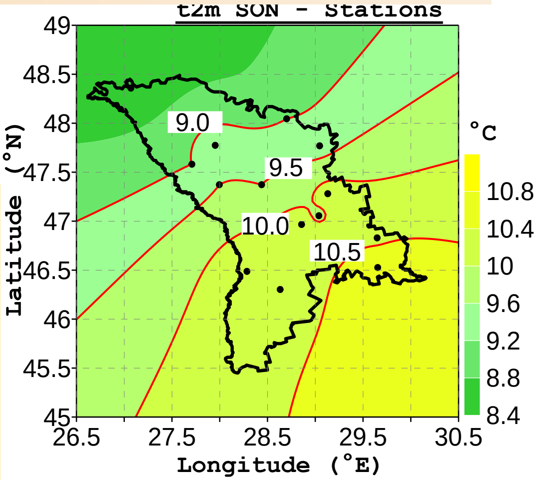


Evolution of the SPEI at 3-month lag during summer (JJA) from June of 1945 to August of 2011 at Chisinau climatological station

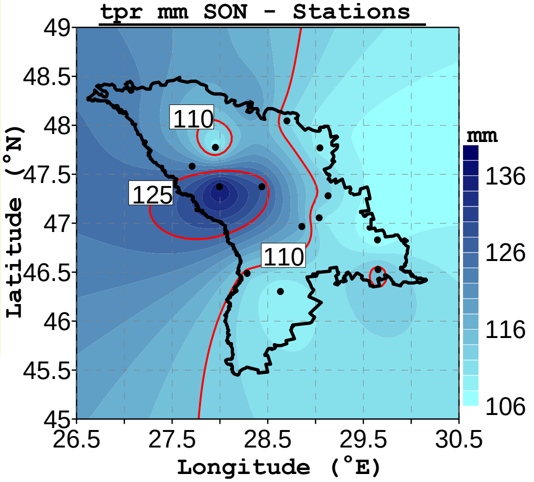


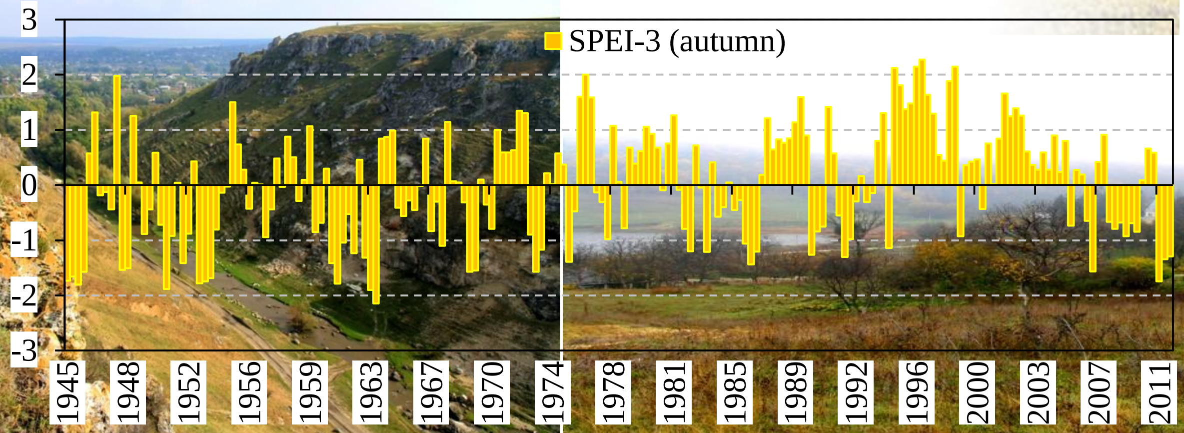
4. Drought climatology in the Republic of Moldova

Autumn (SON)



- The autumn air temperature mean ranges between +8.3ºC and +10.6ºC
- **The coldest autumn:** 1988 with *Tmean* of +6 to +8ºC (2ºC lower than the norm)
- **The warmest autumn:** 1923 with *Tmean* of 13 to 14°C (above the norm with 3°C)
    - **Absolut minimum:** -21.7°C (29 November 1892, at Chisinau)
    - **Absolut maximum:** + 37.3ºC (9 September 1946, at Chisinau)
- **Precipitation total:** on average 106-136mm, or 20% of the mean annual total
- **The driest**: 1963 with 8-36mm (7-27% of the norm)
- **The wetness:** 1996 with 240-345mm (exceeded the norm 2-3 times)
- **Daily maximum rainfall:** reached 153mm (September, 2001, at Leova)
- The hierarchy of the driest autumn according to the SPEI: 1963, 1951, 1945, 1961, 1953 and 2011
- The longest dry periods: 1951-1963 and 2006-2011





4. Drought climatology in the Republic of Moldova

1928 – The smallest amount of annual precipitations – 222 mm (Comrat).

1948 – The largest amount of precipitations during a day was recorded on 8 July – 218 mm (Chișinău).

1980 – The largest amount of annual precipitations – 934 mm (Cornești)

2004 – The highest rainfall intensity was recorded on 23 August – 149 mm of precipitations fell during an hour that is a 3 monthly norm (Soroca).

Wind

2000 – The strongest wind was recorded on 8 July – 44 m/s (158 km/h) at Codrii station.

Atmospheric phenomena

1969 – The hail with the biggest diameter (70 mm) and weight (250 g) fell on 29 August (Briceni).

1994 – On 22 May over the northern rayons of Moldova (from Văratic village, Rîșcani district, to Tătărăuca Veche village, Soroca district) there occurred a severe whirlwind with a width of 10-25 km and a length of 80 km.

2000 – The glazed frost with the biggest weight occurred in the period of 26-28 November – 720 g/m (Rîbnița).

4. Drought climatology in the Republic of Moldova

Moldova's Meteorological Records

Air temperature

1955– The lowest air temperature during the summer season for the entire period of observations was recorded on 1 June – +1,6°C (Briceni).

1963 – The lowest air temperature for the entire period of observations was recorded on 20 January – -35,5°C (Brătușeni, Edineți rayon).

1990 – The highest temperature during the winter season for the entire period of observations was recorded on 26 February – +23,3°C (Tiraspol).

2006-2007 – The warmest winter for the entire period of observations (4,0-4,5°C above the norm).

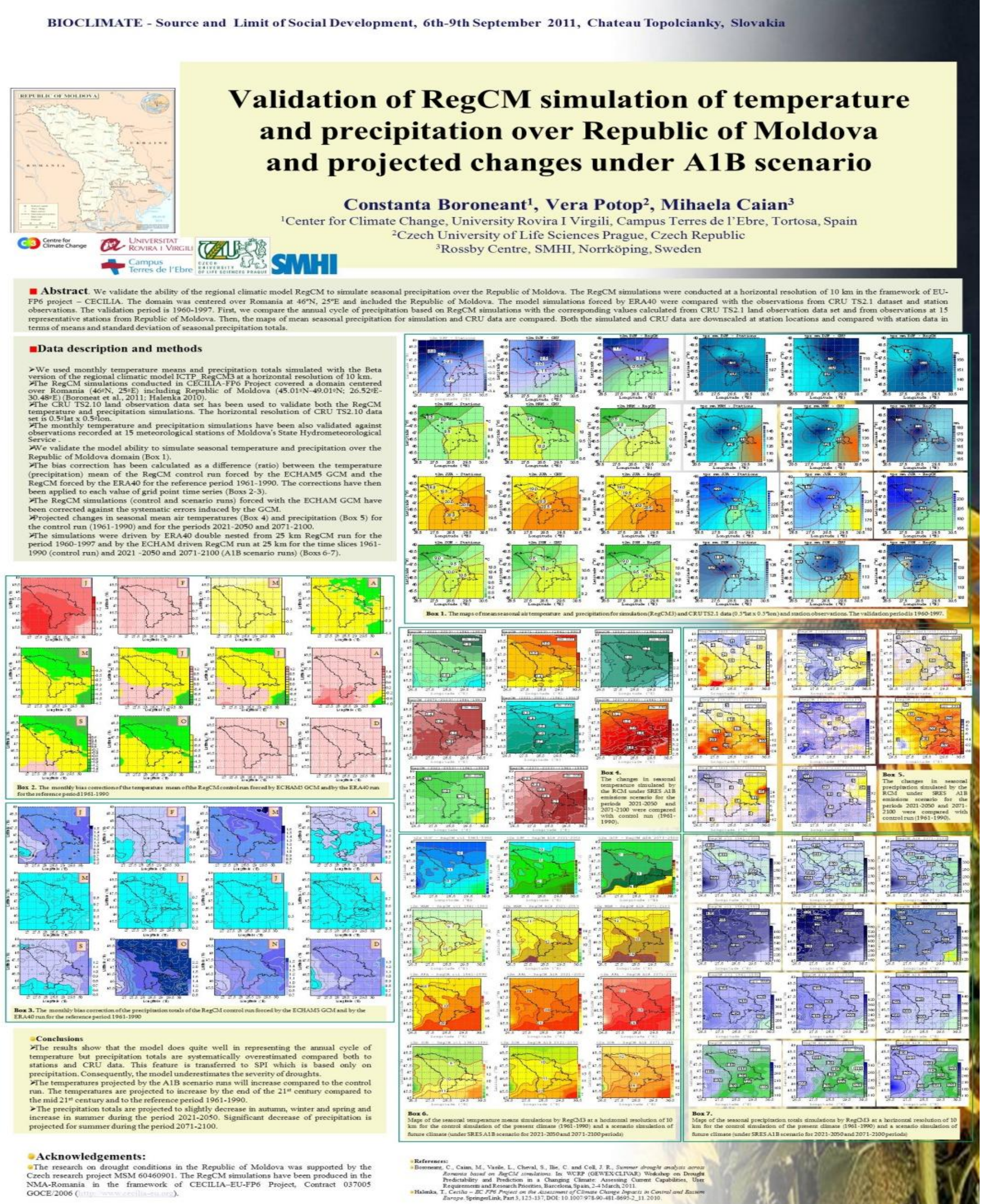
2007 – The highest air temperature was recorded on 21 July – +41,5°C (Camenca).

2007 – The warmest spring for the entire period of observations (2-3°C above the norm).

2007 – The warmest summer for the entire period of observations (2,5-4,0°C above the norm).

2007 – The warmest year for the entire period of observations (2,0-2,5°C above the norm).

4. Drought climatology in the Republic of Moldova



BIOCLIMATE - Source and Limit of Social Development, 6th-9th September 2011, Chateau Topolcianky, Slovakia

Validation of RegCM simulation of temperature and precipitation over Republic of Moldova and projected changes under A1B scenario

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[2]Czech University of Life Sciences Prague, Czech Republic
[3]Rossby Centre, SMHI, Norrköping, Sweden

Abstract. We validate the ability of the regional climatic model RegCM to simulate seasonal precipitation over the Republic of Moldova. The RegCM simulations were conducted at a horizontal resolution of 10 km in the framework of EU-FP6 project – CECILIA. The domain was centered over Romania at 46°N, 25°E and included the Republic of Moldova. The model simulations forced by ERA40 were compared with the observations from CRU TS2.1 dataset and station observations. The validation period is 1960-1997. First, we compare the annual cycle of precipitation based on RegCM simulations with the corresponding values calculated from CRU TS2.1 land observation data set and from observations at 15 representative stations from Republic of Moldova. Then, the maps of mean seasonal precipitation for simulation and CRU data are compared. Both the simulated and CRU data are downscaled at station locations and compared with station data in terms of means and standard deviation of seasonal precipitation totals.

Data description and methods

- We used monthly temperature means and precipitation totals simulated with the Beta version of the regional climatic model ICTP_RegCM3 at a horizontal resolution of 10 km.
- The RegCM simulations conducted in CECILIA-FP6 Project covered a domain centered over Romania (46ºN, 25ºE) including Republic of Moldova (45.01ºN-49.01ºN; 26.52ºE-30.48ºE) (Boroneat et al., 2011; Halenka 2010).
- The CRU TS2.10 land observation data set has been used to validate both the RegCM temperature and precipitation simulations. The horizontal resolution of CRU TS2.10 data set is 0.5ºlat x 0.5ºlon.
- The monthly temperature and precipitation simulations have been also validated against observations recorded at 15 meteorological stations of Moldova's State Hydrometeorological Service .
- We validate the model ability to simulate seasonal temperature and precipitation over the Republic of Moldova domain (Box 1).
- The bias correction has been calculated as a difference (ratio) between the temperature (precipitation) mean of the RegCM control run forced by the ECHAM5 GCM and the RegCM forced by the ERA40 for the reference period 1961-1990. The corrections have then been applied to each value of grid point time series (Boxs 2-3).
- The RegCM simulations (control and scenario runs) forced with the ECHAM GCM have been corrected against the systematic errors induced by the GCM.
- Projected changes in seasonal mean air temperatures (Box 4) and precipitation (Box 5) for the control run (1961-1990) and for the periods 2021-2050 and 2071-2100.
- The simulations were driven by ERA40 double nested from 25 km RegCM run for the period 1960-1997 and by the ECHAM driven RegCM run at 25 km for the time slices 1961-1990 (control run) and 2021 -2050 and 2071-2100 (A1B scenario runs) (Boxs 6-7).

Box 1. The maps of mean seasonal air temperature and precipitation for simulation (RegCM3) and CRU TS2.1 data (0.5°lat x 0.5°lon) and station observations. The validation period is 1960-1997.

Box 2. The monthly bias correction of the temperature mean of the RegCM control run forced by ECHAM5 GCM and by the ERA40 run for the reference period 1961-1990

Box 3. The monthly bias correction of the precipitation totals of the RegCM control run forced by the ECHAM5 GCM and by the ERA40 run for the reference period 1961-1990

Box 4. The changes in seasonal temperature simulated by the RCM under SRES A1B emissions scenario for the periods 2021-2050 and 2071-2100 were compared with control run (1961-1990).

Box 5. The changes in seasonal precipitation simulated by the RCM under SRES A1B emissions scenario for the periods 2021-2050 and 2071-2100 were compared with control run (1961-1990).

Box 6. Maps of the seasonal temperature means simulations by RegCM3 at a horizontal resolution of 10 km for the control simulation of the present climate (1961-1990) and a scenario simulation of future climate (under SRES A1B scenario for 2021-2050 and 2071-2100 periods)

Box 7. Maps of the seasonal precipitation totals simulations by RegCM3 at a horizontal resolution of 10 km for the control simulation of the present climate (1961-1990) and a scenario simulation of future climate (under SRES A1B scenario for 2021-2050 and 2071-2100 periods)

Conclusions

- The results show that the model does quite well in representing the annual cycle of temperature but precipitation totals are systematically overestimated compared both to stations and CRU data. This feature is transferred to SPI which is based only on precipitation. Consequently, the model underestimates the severity of droughts.
- The temperatures projected by the A1B scenario runs will increase compared to the control run. The temperatures are projected to increase by the end of the 21st century compared to the mid 21st century and to the reference period 1961-1990.
- The precipitation totals are projected to slightly decrease in autumn, winter and spring and increase in summer during the period 2021-2050. Significant decrease of precipitation is projected for summer during the period 2071-2100.

Acknowledgements:

The research on drought conditions in the Republic of Moldova was supported by the Czech research project MSM 60460901. The RegCM simulations have been produced in the NMA-Romania in the framework of CECILIA–EU-FP6 Project, Contract 037005 GOCE/2006 (http://www.cecilia-eu.org).

References:

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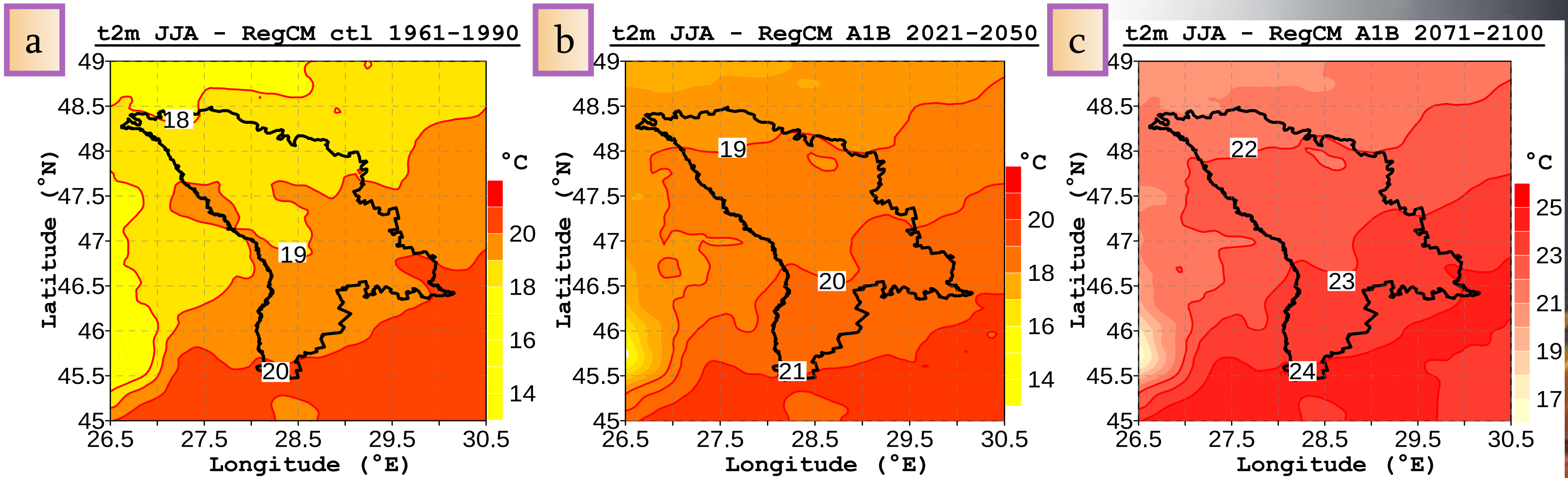
- Halenka, T., *Cecilia – EC FP6 Project on the Assessment of Climate Change Impacts in Central and Eastern Europe*. SpringerLink, Part 3, 125-137, DOI: 10.1007/978-90-481-8695-2_11. 2010.

- It is well recognized that GCMs can reproduce reasonably well climate features on large scales (global and continental), but their accuracy decreases when proceeding from continental to regional and local scales because of the lack of resolution.
- This is especially true for surface fields, such as precipitation and surface air temperature, which are critically affected by topography and land use.
- One alternative to bridge the gap between the climate information provided by GCMs and that needed in impact studies is nesting of a fine scale limited area model (or Regional Climate Model, RCM) within the GCM.
- Such an approach have been used in the framework of the EU-project CECILIA (Central and Eastern Europe Climate Change Impact and Vulnerability Assessment).

4. Drought climatology in the Republic of Moldova

Projected changes in summer mean air temperatures



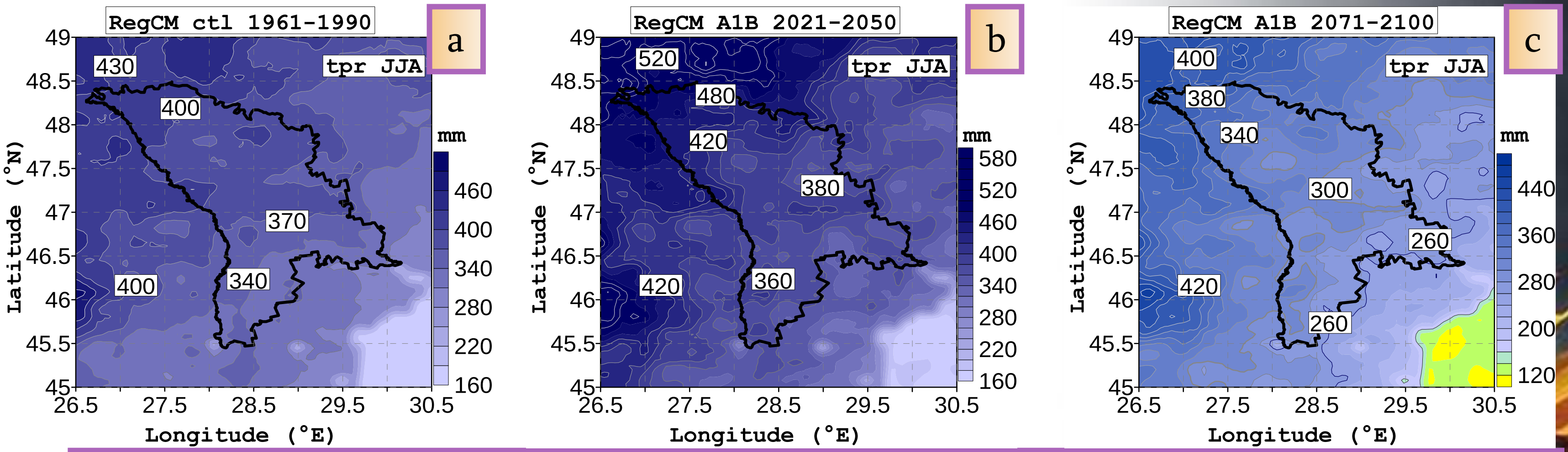
Projected changes in summer mean air temperatures (a) for the control run (b) for the period 2021-2050 and (c) for the period 2071-2100

- The regional climatic model ICTP_RegCM3 centered over Romania and including the RM was run at a horizontal resolution of 10 km, for
    - the current climate (1961-1990)
    - under SRES A1B scenario for 2021-2050 and 2071-2100 periods.

- The highest increase of monthly temperature mean is expected during summer months.
- The temperatures are projected to a higher increase by the end of the 21st century compared to the mid 21st century and reference period 1961-1990.
- The 30-year summer temperature means for Moldova domain varies between
    - 18.0°C to 20.0°C for the current climate (1961-1990),
    - between 19.0°C and 21.0°C for the A1B scenario (2021-2050),
    - 22.0°C to 24.0°C, for the A1B scenario (2071-2100).

4. Drought climatology in the Republic of Moldova

Projected changes in summer precipitation amonts



Projected changes in summer precipitation (a) for the control run (b) for the period 2021-2050 and (c) for the period 2071-2100

- ➢The monthly precipitation totals are projected to slightly decrease in late autumn (ON), winter (DJF) and spring (MA) and highly increase in summer months (JJA) during the period 2021-2050.

- ➢The A1B scenario projects significant decrease of precipitation totals in summer months (JJA) during the period 2071-2100.

4. Drought climatology in the Republic of Moldova

Drought variability and its driving factors in the Moldova

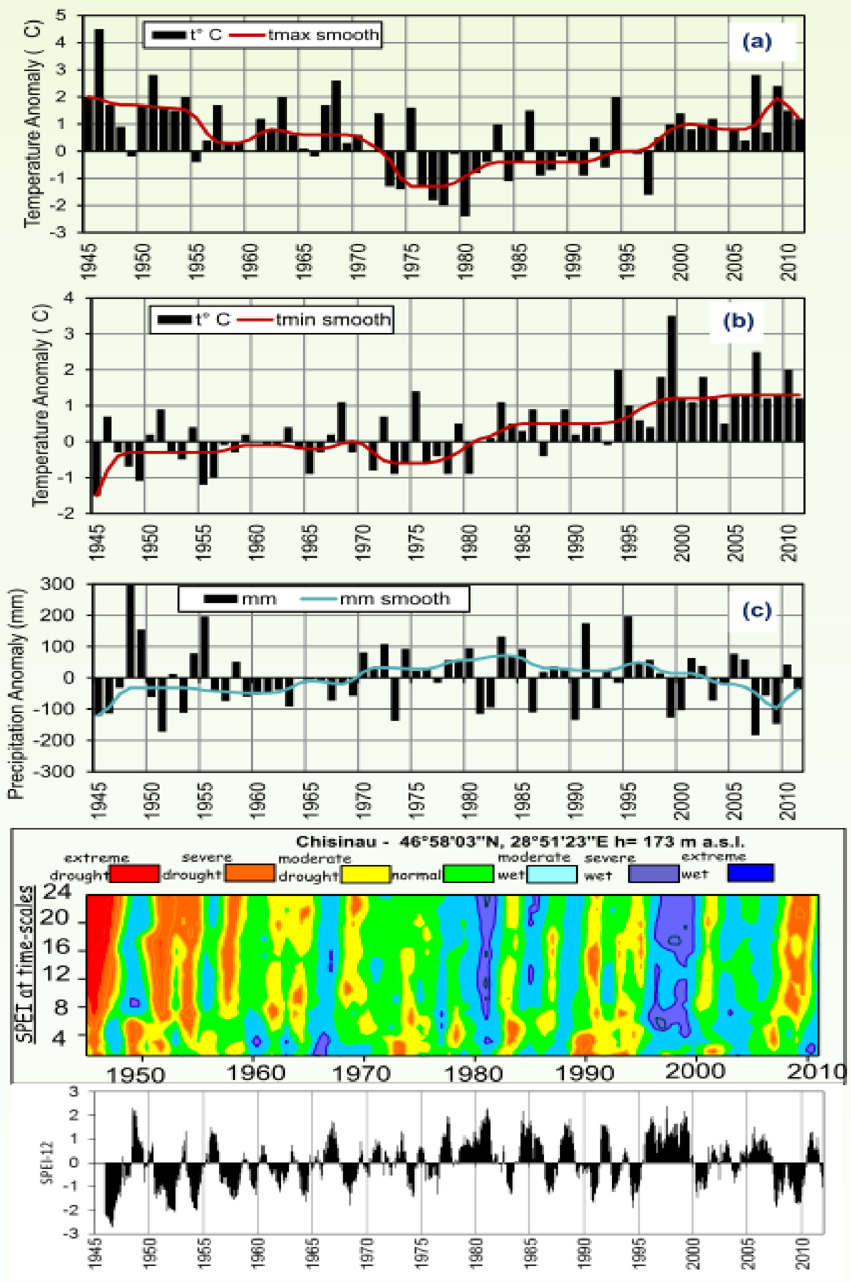
- This study presents a detailed assessment on drought variability and its driving factors in Moldova during the second half of 20th century and the first decade of the 21st century.
- Drought was identified in a multi-scalar way using the SPEI.

Data and methods

- Due to the availability of relatively long continuous series (1945-2011), we chose the Chisinau climatological st. as a representative station for testing the SPEI on various time scales in Moldova.
- The steps followed for the SPEI calculation were:
    - the parameterization of PET based on monthly minimum (Tmin) and maximum air temperature (Tmax) and extraterrestrial radiation;
    - a simple monthly water balance (D)
    - normalisation of the D into a Log-logistic PDF to obtain the SPEI series at time scales between 1 and 24 months.
- We have also analysed the trends of extreme temperatures (Tmin and Tmax) and precipitation anomalies as helpful factors to assess their influence on drought characteristics.

Source: Vera Potop, Ala Overcenco, Constanța Boroneanț, 10 – 14 September 2012 | Łódź, Poland

4. Drought climatology in the Republic of Moldova



Box 3. Temporal evolution of data series from 1945 to 2011:

Box 3. Temporal evolution of data series from 1945 to 2011:

upper panel)

air anomalies of maximum temperature (a),

minimum temperature (b),

precipitation totals (c) during the warm season of the year.

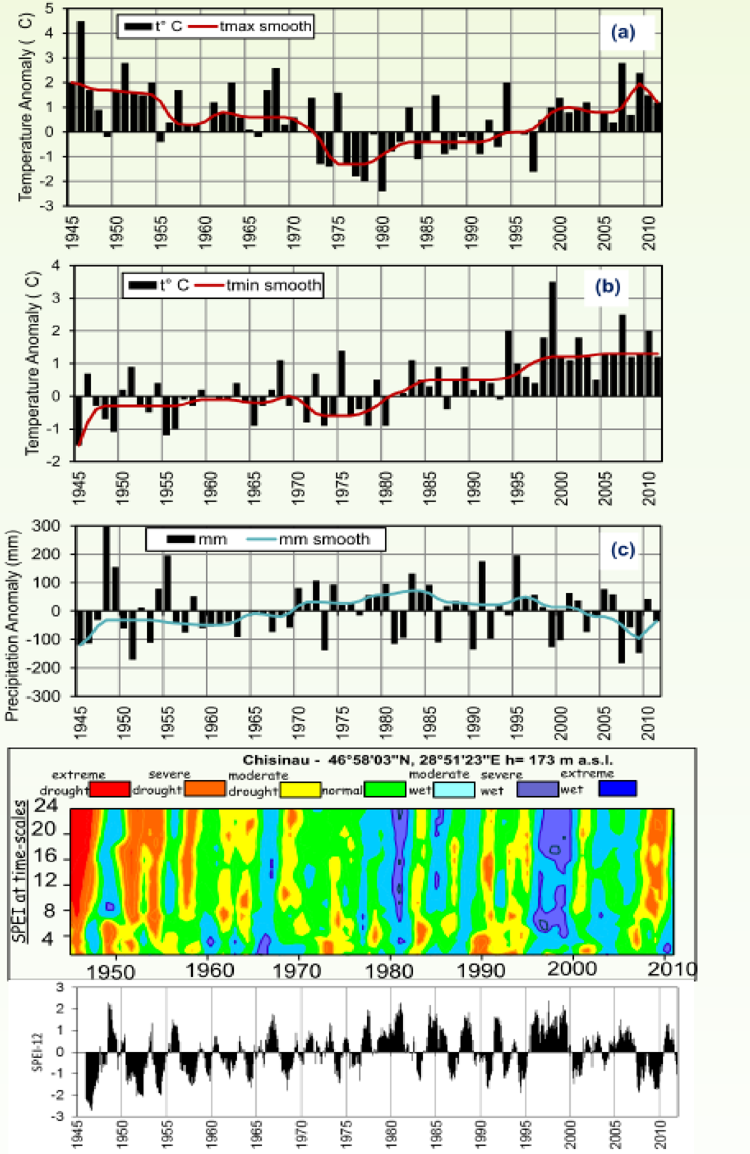
The long-term changes in both the temperature and precipitation series were represented by a smoothed filter 5-year seasonal extreme temperatures deviation and precipitation, respectively, from the baseline climate (1961-1990);

middle panel)

SPEI at time scales from 1 to 24 months,

bottom panel) the SPEI at 12-month lag.

4. Drought climatology in the Republic of Moldova



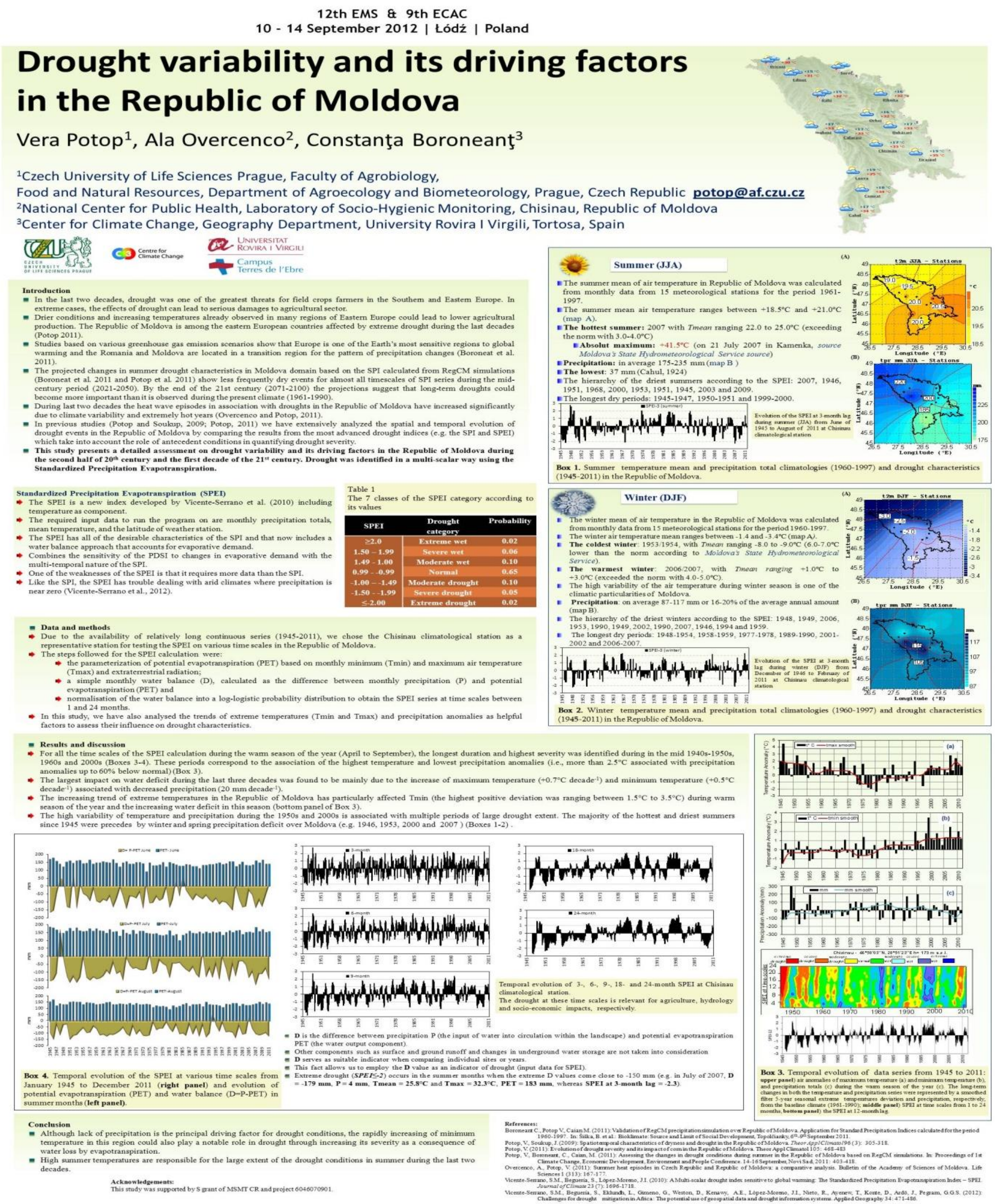
Box 3. Temporal evolution of data series from 1945 to 2011: **upper panel**) air anomalies of maximum temperature (a) and minimum temperature (b), and precipitation totals (c) during the warm season of the year (c). The long-term changes in both the temperature and precipitation series were represented by a smoothed filter 5-year seasonal extreme temperatures deviation and precipitation, respectively, from the baseline climate (1961-1990); **middle panel**) SPEI at time scales from 1 to 24 months, **bottom panel**) the SPEI at 12-month lag.

Results

- For all the time scales of the SPEI calculation during the warm season of the year (April to September), the longest duration and highest severity was identified during in the mid 1940s-1950s, 1960s and 2000s.
- These periods correspond to the association of the highest temperature and lowest precipitation anomalies (i.e., more than 2.5°C associated with precipitation anomalies up to 60% below normal).
- The largest impact on water deficit during the last three decades was found to be mainly due to the increase of maximum temperature (+0.7°C decade^{-1}) and minimum temperature (+0.5°C decade^{-1}) associated with decreased precipitation (20 mm decade^{-1}).
- The increasing trend of extreme temperatures in the Moldova has particularly affected Tmin (the highest positive deviation was ranging between 1.5°C to 3.5°C) during warm season of the year and the increasing water deficit in this season.
- The high variability of temperature and precipitation during the 1950s and 2000s is associated with multiple periods of large drought extent.
- The majority of the hottest and driest summers since 1945 were precedes by winter and spring precipitation deficit over Moldova (e.g. 1946, 1953, 2000 and 2007).

4. Drought climatology in the Republic of Moldova

- Although lack of precipitation is the principal driving factor for drought conditions, the rapidly increasing of minimum temperature in this region could also play a notable role in drought through increasing its severity as a consequence of water loss by evapotranspiration.
- High summer temperatures are responsible for the large extent of the drought conditions in summer during the last two decades.



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Drought variability and its driving factors in the Republic of Moldova

Vera Potop[1], Ala Overcenco[2], Constanţa Boroneanţ[3]

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Introduction
- In the last two decades, drought was one of the greatest threats for field crops farmers in the Southern and Eastern Europe. In extreme cases, the effects of drought can lead to serious damages to agricultural sector.
- Drier conditions and increasing temperatures already observed in many regions of Eastern Europe could lead to lower agricultural production. The Republic of Moldova is among the eastern European countries affected by extreme drought during the last decades (Potop 2011).
- Studies based on various greenhouse gas emission scenarios show that Europe is one of the Earth's most sensitive regions to global warming and the Romania and Moldova are located in a transition region for the pattern of precipitation changes (Boroneat et al. 2011).
- The projected changes in summer drought characteristics in Moldova domain based on the SPI calculated from RegCM simulations (Boroneat et al. 2011 and Potop et al. 2011) show less frequently dry events for almost all timescales of SPI series during the mid-century period (2021-2050). By the end of the 21st century (2071-2100) the projections suggest that long-term droughts could become more important than it is observed during the present climate (1961-1990).
- During last two decades the heat wave episodes in association with droughts in the Republic of Moldova have increased significantly due to climate variability and extremely hot years (Overcenco and Potop, 2011).
- In previous studies (Potop and Soukup, 2009; Potop, 2011) we have extensively analyzed the spatial and temporal evolution of drought events in the Republic of Moldova by comparing the results from the most advanced drought indices (e.g. the SPI and SPEI) which take into account the role of antecedent conditions in quantifying drought severity.
- **This study presents a detailed assessment on drought variability and its driving factors in the Republic of Moldova during the second half of 20th century and the first decade of the 21st century. Drought was identified in a multi-scalar way using the Standardized Precipitation Evapotranspiration.**

Standardized Precipitation Evapotranspiration (SPEI)
- The SPEI is a new index developed by Vicente-Serrano et al. (2010) including temperature as component.
- The required input data to run the program on are monthly precipitation totals, mean temperature, and the latitude of weather station.
- The SPEI has all of the desirable characteristics of the SPI and that now includes a water balance approach that accounts for evaporative demand.
- Combines the sensitivity of the PDSI to changes in evaporative demand with the multi-temporal nature of the SPI.
- One of the weaknesses of the SPEI is that it requires more data than the SPI.
- Like the SPI, the SPEI has trouble dealing with arid climates where precipitation is near zero (Vicente-Serrano et al., 2012).

Table 1
The 7 classes of the SPEI category according to its values

SPEI	Drought category	Probability
≥2.0	Extreme wet	0.02
1.50 – 1.99	Severe wet	0.06
1.49 - 1.00	Moderate wet	0.10
0.99 - -0.99	Normal	0.65
-1.00 – -1.49	Moderate drought	0.10
-1.50 - -1.99	Severe drought	0.05
≤-2.00	Extreme drought	0.02

- **Data and methods**
- Due to the availability of relatively long continuous series (1945-2011), we chose the Chisinau climatological station as a representative station for testing the SPEI on various time scales in the Republic of Moldova.
- The steps followed for the SPEI calculation were:
  - the parameterization of potential evapotranspiration (PET) based on monthly minimum (Tmin) and maximum air temperature (Tmax) and extraterrestrial radiation;
  - a simple monthly water balance (D), calculated as the difference between monthly precipitation (P) and potential evapotranspiration (PET) and
  - normalisation of the water balance into a log-logistic probability distribution to obtain the SPEI series at time scales between 1 and 24 months.
- In this study, we have also analysed the trends of extreme temperatures (Tmin and Tmax) and precipitation anomalies as helpful factors to assess their influence on drought characteristics.

- **Results and discussion**
- For all the time scales of the SPEI calculation during the warm season of the year (April to September), the longest duration and highest severity was identified during in the mid 1940s-1950s, 1960s and 2000s (Boxes 3-4). These periods correspond to the association of the highest temperature and lowest precipitation anomalies (i.e., more than 2.5°C associated with precipitation anomalies up to 60% below normal) (Box 3).
- The largest impact on water deficit during the last three decades was found to be mainly due to the increase of maximum temperature (+0.7°C $decade^{-1}$) and minimum temperature (+0.5°C $decade^{-1}$) associated with decreased precipitation (20 mm $decade^{-1}$).
- The increasing trend of extreme temperatures in the Republic of Moldova has particularly affected Tmin (the highest positive deviation was ranging between 1.5°C to 3.5°C) during warm season of the year and the increasing water deficit in this season (bottom panel of Box 3).
- The high variability of temperature and precipitation during the 1950s and 2000s is associated with multiple periods of large drought extent. The majority of the hottest and driest summers since 1945 were precedes by winter and spring precipitation deficit over Moldova (e.g. 1946, 1953, 2000 and 2007) (Boxes 1-2) .

Temporal evolution of 3-, 6-, 9-, 18- and 24-month SPEI at Chisinau climatological station.
The drought at these time scales is relevant for agriculture, hydrology and socio-economic impacts, respectively.

- **D** is the difference between precipitation P (the input of water into circulation within the landscape) and potential evapotranspiration PET (the water output component).
- Other components such as surface and ground runoff and changes in underground water storage are not taken into consideration
- **D** serves as suitable indicator when comparing individual sites or years.
- This fact allows us to employ the **D** value as an indicator of drought (input data for SPEI).
- Extreme drought (***SPEI≤-2***) occurs in the summer months when the extreme D values come close to -150 mm (e.g. in July of 2007, **D = -179 mm**, **P = 4 mm**, **Tmean = 25.8°C** and **Tmax = 32.3°C**, **PET = 183 mm**, whereas **SPEI at 3-month lag = -2.3**).

Box 4. Temporal evolution of the SPEI at various time scales from January 1945 to December 2011 (**right panel**) and evolution of potential evapotranspiration (PET) and water balance (D=P-PET) in summer months (**left panel**).

Summer (JJA)
- The summer mean of air temperature in Republic of Moldova was calculated from monthly data from 15 meteorological stations for the period 1961-1997.
- The summer mean air temperature ranges between +18.5°C and +21.0°C (map A).
- **The hottest summer:** 2007 with *Tmean* ranging 22.0 to 25.0°C (exceeding the norm with 3.0-4.0°C)
  - **Absolut maximum:** +41.5°C (on 21 July 2007 in Kamenka, *source Moldova's State Hydrometeorological Service source*)
- **Precipitation:** in average 175-235 mm (map B)
- **The lowest**: 37 mm (Cahul, 1924)
- The hierarchy of the driest summers according to the SPEI: 2007, 1946, 1951, 1968, 2000, 1953, 1951, 1945, 2003 and 2009.
- The longest dry periods: 1945-1947, 1950-1951 and 1999-2000.

Evolution of the SPEI at 3-month lag during summer (JJA) from June of 1945 to August of 2011 at Chisinau climatological station

Box 1. Summer temperature mean and precipitation total climatologies (1960-1997) and drought characteristics (1945-2011) in the Republic of Moldova.

Winter (DJF)
- The winter mean of air temperature in the Republic of Moldova was calculated from monthly data from 15 meteorological stations for the period 1960-1997.
- The winter air temperature mean ranges between -1.4 and -3.4°C (map A).
- **The coldest winter**: 1953/1954, with *Tmean* ranging -8.0 to -9.0°C (6.0-7.0°C lower than the norm according to *Moldova's State Hydrometeorological Service*).
- **The warmest winter**: 2006/2007, with *Tmean ranging* +1.0°C to +3.0°C (exceeded the norm with 4.0-5.0°C).
- The high variability of the air temperature during winter season is one of the climatic particularities of Moldova.
- **Precipitation**: on average 87-117 mm or 16-20% of the average annual amount (map B).
- The hierarchy of the driest winters according to the SPEI: 1948, 1949, 2006, 1953, 1990, 1949, 2002, 1990, 2007, 1946, 1994 and 1959.
- The longest dry periods: 1948-1954, 1958-1959, 1977-1978, 1989-1990, 2001-2002 and 2006-2007.

Evolution of the SPEI at 3-month lag during winter (DJF) from December of 1946 to February of 2011 at Chisinau climatological station

Box 2. Winter temperature mean and precipitation total climatologies (1960-1997) and drought characteristics (1945-2011) in the Republic of Moldova.

Box 3. Temporal evolution of data series from 1945 to 2011: **upper panel**) air anomalies of maximum temperature (a) and minimum temperature (b), and precipitation totals (c) during the warm season of the year (c). The long-term changes in both the temperature and precipitation series were represented by a smoothed filter 5-year seasonal extreme temperatures deviation and precipitation, respectively, from the baseline climate (1961-1990); **middle panel**) SPEI at time scales from 1 to 24 months, **bottom panel**) the SPEI at 12-month lag.

Conclusion
- Although lack of precipitation is the principal driving factor for drought conditions, the rapidly increasing of minimum temperature in this region could also play a notable role in drought through increasing its severity as a consequence of water loss by evapotranspiration.
- High summer temperatures are responsible for the large extent of the drought conditions in summer during the last two decades.

Acknowledgements:
This study was supported by S grant of MSMT CR and project 6046070901.

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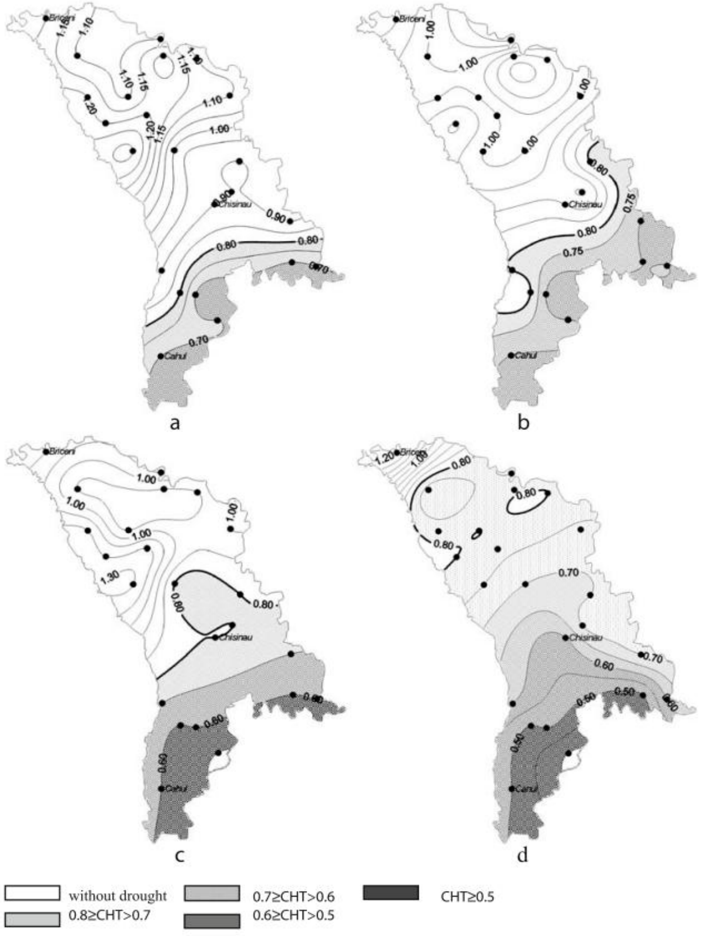
4. Drought climatology in the Republic of Moldova

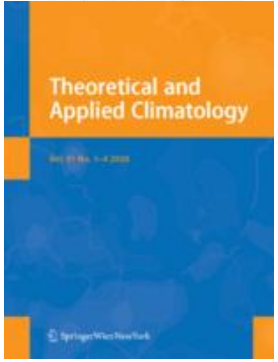
Spatiotemporal characteristics of dryness and drought in the Republic of Moldova

V. Potop · J. Soukup

Theor Appl Climatol (2009) 96:305–318 317

Fig. 2 Areas affected with local drought (**a**), widespread drought (**b**), very widespread drought (**c**) and catastrophic drought (**d**). The *points* on the maps represent meteorological stations (including 15 meteorological stations and 7 precipitation stations). The 0.80 isoline demonstrates the limit of the extent of drought by the radial basis function spatial interpolation. The *white colour* indicates the territory without drought events





Area extent of drought

- The extent of drought expressed in the percentage of the affected area is associated with a specified drought severity, which considered the total number of climatological stations as 100%.
- the drought observed on the surface of up to 10% of the territory of Moldova is classified as a local one.
- the droughts that cover 11-30% of the territory indicate widespread droughts.
- the droughts that cover a territory of 31-50% are considered very widespread
- over 50% are classified as most extensive (catastrophic)

Estimation of the territories affected by drought in the Republic of Moldova in the 1945-2006 period on the basis of data from 15 meteorological stations; “-” marks the absence of drought in that year.

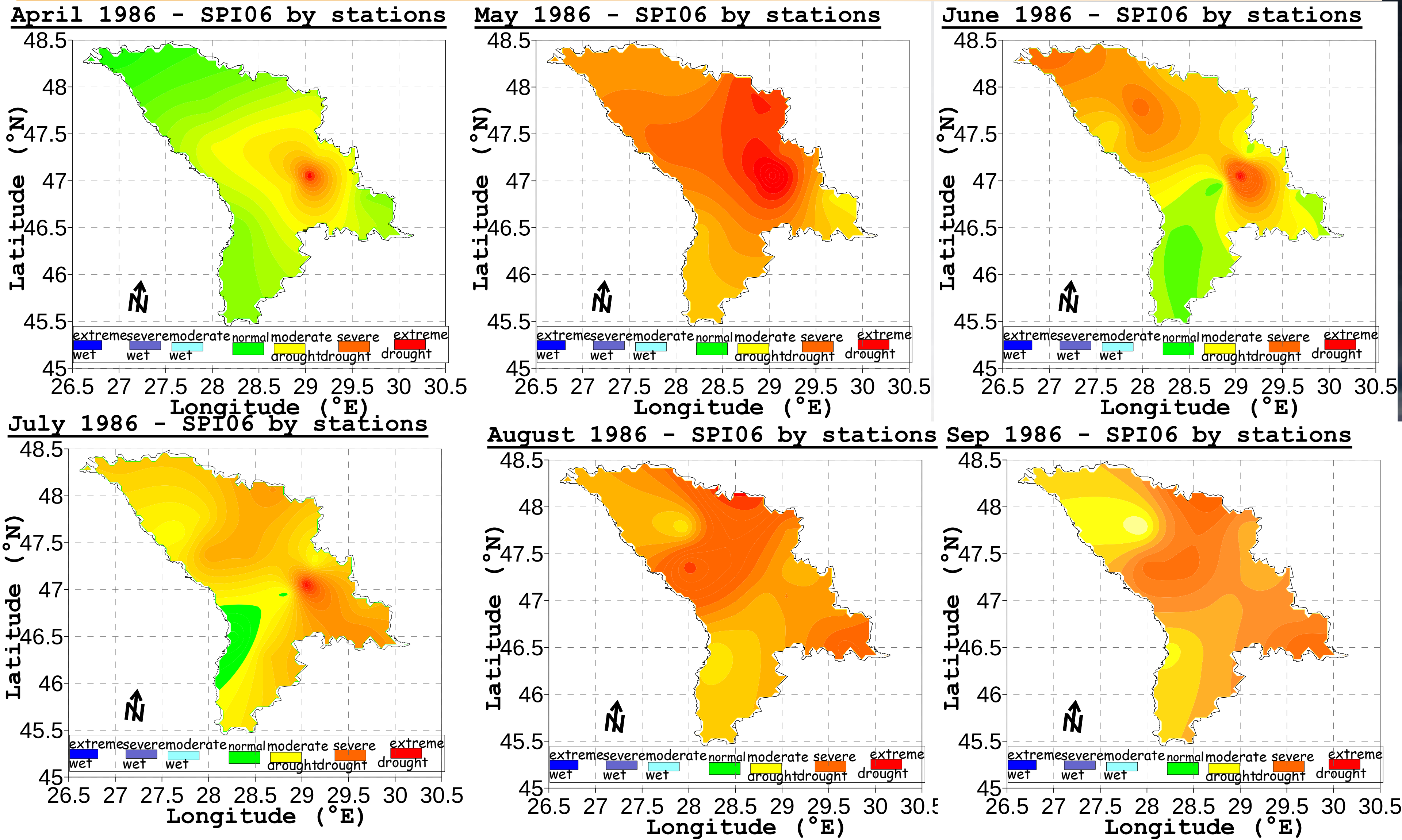
	Spring		**Summer**		**Autumn**	
Years	**Surface affected, (%)**	**Type of droughts**	**Surface affected, (%)**	**Type of droughts**	**Surface affected, (%)**	**Type of droughts**
1945	-	-	60	catastrophic	40	very widespread
1946	**100**	**catastrophic**	**33**	**very widespread**	**-**	**-**
1947	**39**	**very widespread**	**-**	**-**	**60**	**catastrophic**
1949	60	catastrophic	-	-	20	widespread
1950	33	very widespread	-	-	20	widespread
1951	60	catastrophic	40	very widespread	-	-
1952	20	widespread	20	vast widespread	-	-
1953	-	-	40	very widespread	60	catastrophic
1954	-	-	73	catastrophic	25	widespread
1956	7	local	13	widespread	20	widespread
1957	7	local	27	widespread	-	-
1958	13	widespread	-	-	-	-
1959	-	-	13	widespread	13	widespread
1960	-	-	53	catastrophic	13	widespread
1961	-	-	27	widespread	47	very widespread
1962	-	-	20	widespread	40	very widespread
1963	40	very widespread	7	local	93	catastrophic
1964	13	widespread	7	local	7	local
1965	-	-	47	very widespread	80	catastrophic
1966	47	very widespread	7	local	60	catastrophic
1967	60	catastrophic	40	very widespread	93	catastrophic
1968	93	catastrophic	7	local	-	-
1969	7	local	47	very widespread	73	catastrophic
1971	26	widespread	20	widespread	-	-
1973	20	widespread	53	catastrophic	87	catastrophic
1975	-	-	7	local	87	catastrophic
1976	27	widespread	20	widespread	7	local
1981	7	local	53	catastrophic	-	-
1982	60	catastrophic	-	-	93	catastrophic
1983	20	widespread	13	widespread	93	catastrophic
1985	27	widespread	-	-	73	catastrophic
1986	100	catastrophic	13	widespread	100	catastrophic
1987	13	widespread	7	local	40	very widespread
1989	40	very widespread	-	-	-	-
1990	7	local	67	catastrophic	60	catastrophic
1992	27	widespread	60	catastrophic	40	very widespread
1993	-	-	26	widespread	7	local
1994	**87**	**catastrophic**	**40**	**very widespread**	**100**	**catastrophic**
1995	13	widespread	26	widespread	-	-
1996	13	widespread	40	very widespread	-	-
2000	**90**	**catastrophic**	**19**	**widespread**	**70**	**catastrophic**
2003	10	local	100	catastrophic	-	-

- ❖A catastrophic drought was registered in 1994.
- ❖ During the spring of that year, the drought covered 87% of the territory of Moldova and was of a severe intensity degree and/or extreme intensity degree.
- ❖In the summer the development of the hydrothermal conditions in the area of drought affected 40% of the territory.

Spatiotemporal characteristics of dryness and drought in the Republic of Moldova

V. Potop · J. Soukup

The Standard Precipitation Indices (SPI) at time scale of 6-month during the driest growing season of 1986 (Moldova).



April 1986 - SPI06 by stations

May 1986 - SPI06 by stations

June 1986 - SPI06 by stations

July 1986 - SPI06 by stations

August 1986 - SPI06 by stations

Sep 1986 - SPI06 by stations

- ❖the most extensive and extreme drought cover the whole territory was recorded in 1986
- ❖all stations were affected by severe or extreme drought episodes during the May, August and September

4. Drought climatology in the Republic of Moldova

- presents the results of the first study on drought characteristics over Moldova based on SPI calculated for RegCM simulated data at high resolution (10 km) for the current (1961–1990) and two future climates (2021–2050 and 2071–2100).

- the results will present the RegCM performance in simulating precipitation and their influence on the SPI values which are exclusively based on precipitation.

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Assessing the changes in drought conditions during summer in the Republic of Moldova based on RegCM simulation

Vera Potop, Constanta Boroneant, Mihaela Caian

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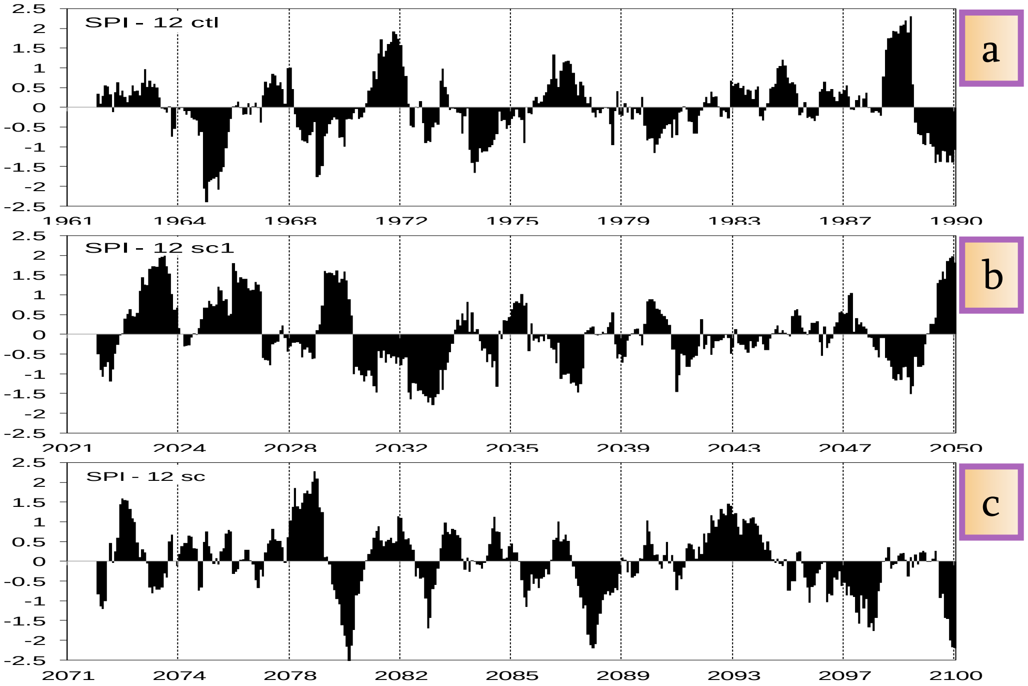
[3]Rossby Centre, SMHI, Norrköping, Sweden

4. Drought climatology in the Republic of Moldova

Projected changes in drought characteristics



SPI series at time scales of 12 months based on monthly precipitation totals simulated by the RegCM control run a) (1961-1990) and A1B scenario runs b) (2021-2050) and c) (2071-2100), averaged for all grid points of the domain.

- The results show the intensification of summer drought severity due to reduced precipitation in the context of general warming in Moldova.

- 2021-2050 - in terms of intensity and persistence of dry and wet spells, shows that the first part of the this period is charcterized by intense and persistent wet spells which are projected to be followed by some years with severe drought.

- 2071-2100 - the time series are characterized by a higher variability and longer persistence of both wet and dry periods as compared with the control run and scenario run for the period 2021-2050.

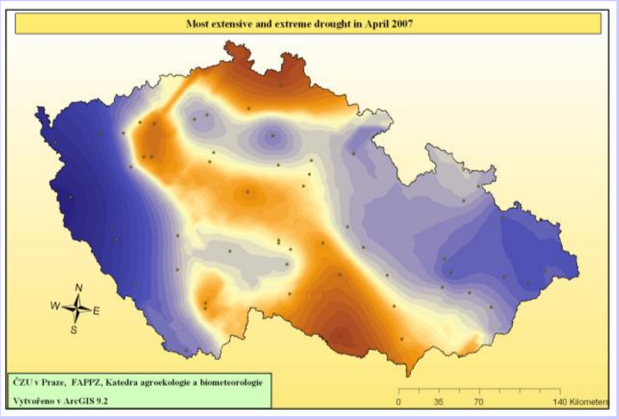
- During the mid-century period is projected to be less frequently dry events for almost all timescales of SPI series.
- By the end of the 21st century the projections suggest that long-duration droughts could thus become more important than it is observed during the present climate.
- Increases in drought severity are also projected for the end of century.

IX. Drought impacts

- Direct impacts of drought are reduced crop and forest productivity; reduced water levels; increased fire hazard …
- A reduction in crop productivity usually results in less income for farmers, increased prices for food.
- Effects of drought are dependent not only on the duration, intensity, areas affected by a drought episode and water supplies, but also on the level of economic development in a given country.
- The consequences of droughts of identical intensities and durations will have different effects in different regions.
- In the case of RM - 2007 severe drought, which presents a topical illustration of how a country can be affected by, and respond to, the dual challenge of an extreme drought events and high international cereals prices (*Potop, 2011*).
- As a result, the drought in Moldova which considerably reduced yields of winter crops (mostly wheat and barley) and summer crops (sunflower, maize, grapes, etc.), affected the overall agricultural production (*FAO 2007*).
- At the same time, a severe spring drought was registered across Czechia, which started as a consequence of poor winter snowfalls and little spring rain (*Potop et al., 2010*).
    - Firstly, due to the fact, that the drought in the CR had not occurred during the reproductive phase of the crops, the yields were not drastically affected.
    - Secondly, different effects of the drought in Moldova and Czechia are associated with different levels of development of agriculture and climate conditions in the two countries.

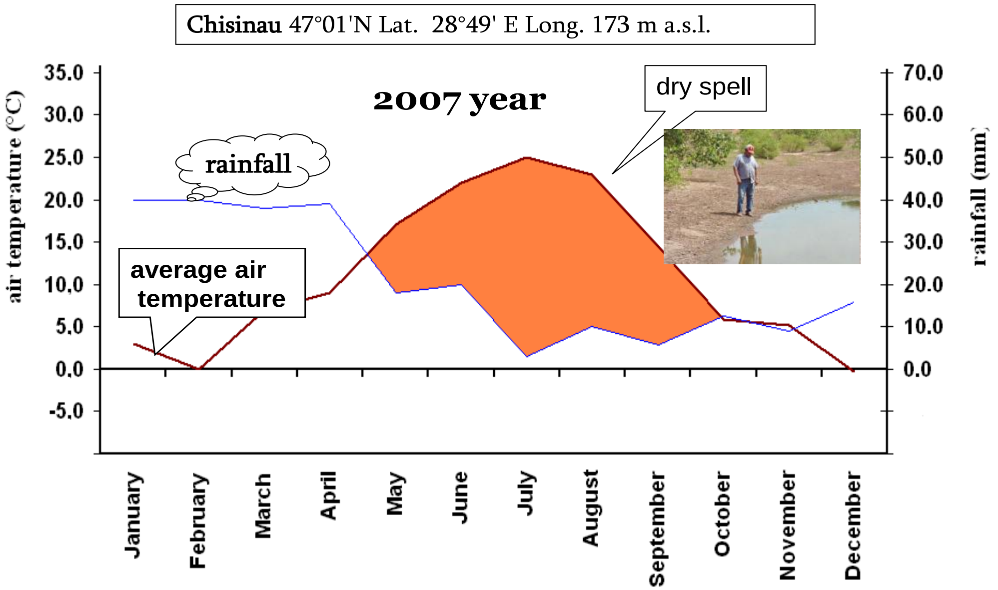
Location of the Czech Republic and the Republic of Moldova in European map

A sunflower field affected by the 2007 extreme drought (Moldova)

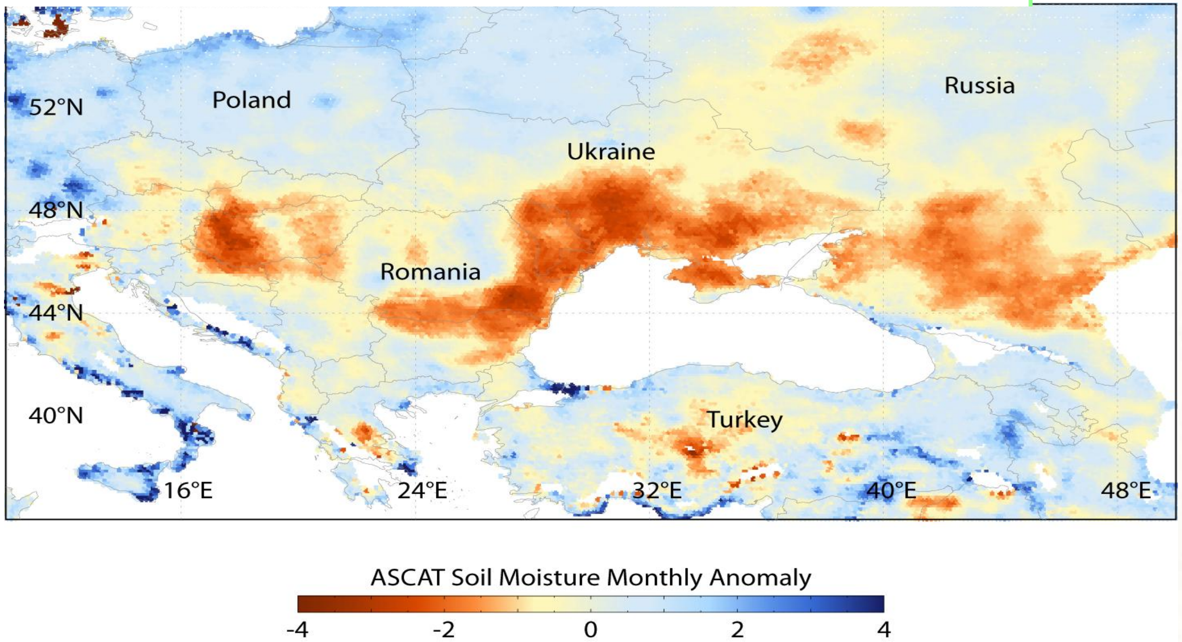


IX. Drought impacts

Republic of Moldova: Extreme Drought of 2007 year



The severity of Moldova’s 2007 drought is comparable only to the worst situation that occurred in 1946, known as the year of the famine, when many people starved to death following the loss of the spring cereal harvest.



- Map shows the extremely dry conditions in Eastern Europe during July 2007, as indicated by an ASCAT surface soil moisture anomaly.

- The anomalous area comprises parts of Hungary, Romania, Moldova and Ukraine.

IX. Drought impacts

Drought consequence on cereals production

- The indicator of agricultural drought risk may be represented by the residuals of the detrended yield.
- The fluctuations in crop yields over time were calculated on the basis of two components:
  - **the first one is** determined by the agricultural technology level and/or the climatic conditions
  - **the second one is** based on the agro-meteorological conditions during the growing season from one year to the next

- Thus, the response of yield is dependent on the meteorological conditions during the growing season as well as during the preceding periods.
- Technological progress and improvement of societal conditions are responsible for the generally increasing trend of the crop yield.
- Using the weather-yield model as a measure of the fluctuations in crop yields, it is possible to reflect the changes in the favourable and unfavourable agrometeorological conditions and their impacts on the crop production every year (Wu and Wilhite 2004).

Theoretical and Applied Climatology

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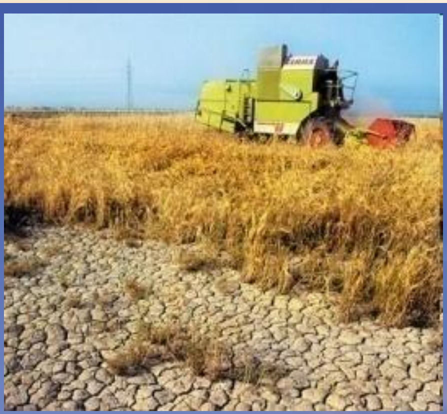
Potop (2011): Evolution of drought severity and its impact on corn in the Republic of Moldova. Theor Appl Climatol 96:305–318

IX. Drought impacts

Drought consequence on cereals production

- The year with a drought risk was identified by the cereals of detrended yield:
  - low drought risk $-0.5\sigma \geq yi(T) > -\sigma$
  - a middle drought risk $-\sigma \geq yi(T) > -1.5\sigma$
  - high drought risk $yi(T) \leq -1.5\sigma$



Crops		Three levels of departures, $y_i^{(T)}$		
		$-0.5\sigma \geq y_i^{(T)} > -\sigma$	$-\sigma \geq y_i^{(T)} > -1.5\sigma$	$y_i^{(T)} \leq -1.5\sigma$
***Triticum aestivum* L.**	**Winter wheat**	-0.06 to -0.11	-0.12 to -0.17	≤-0.18
***Triticum aestivum* L.**	**Spring wheat**	-0.06 to -0.11	-0.12 to -0.17	≤-0.18
***Hordeum vulgare* L.**	**Winter barley**	-0.09 to -0.17	-0.18 to - 0.26	≤-0.27
***Hordeum vulgare* L.**	**Spring barley**	-0.09 to -0.17	-0.18 to - 0.26	≤-0.27
***Secale cereale* L.**	**Winter rye**	-0.06 to -0.11	-0.12 to -0.17	≤-0.18
***Avena sativa* L.**	**Oats**	-0.08 to -0.15	-0.16 to -0.23	≤-0.24
***Zea mays* L.**	**Maize**	-0.09 to -0.17	-0.18 to - 0.26	≤-0.27

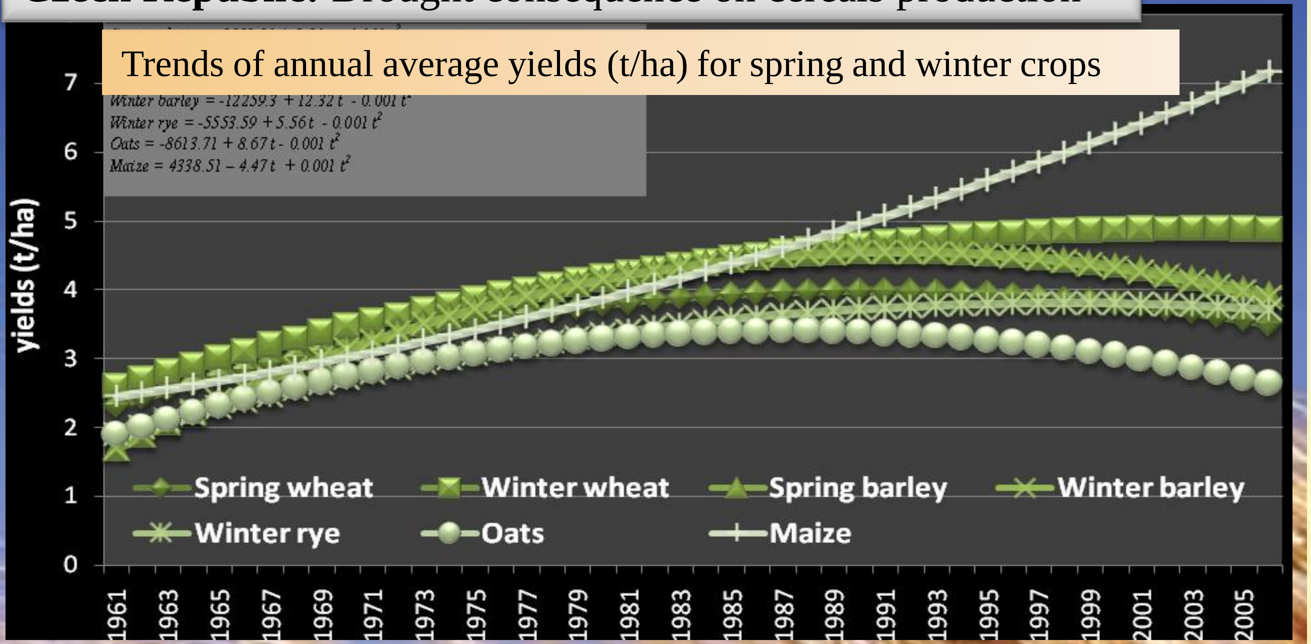

Theoretical and Applied Climatology

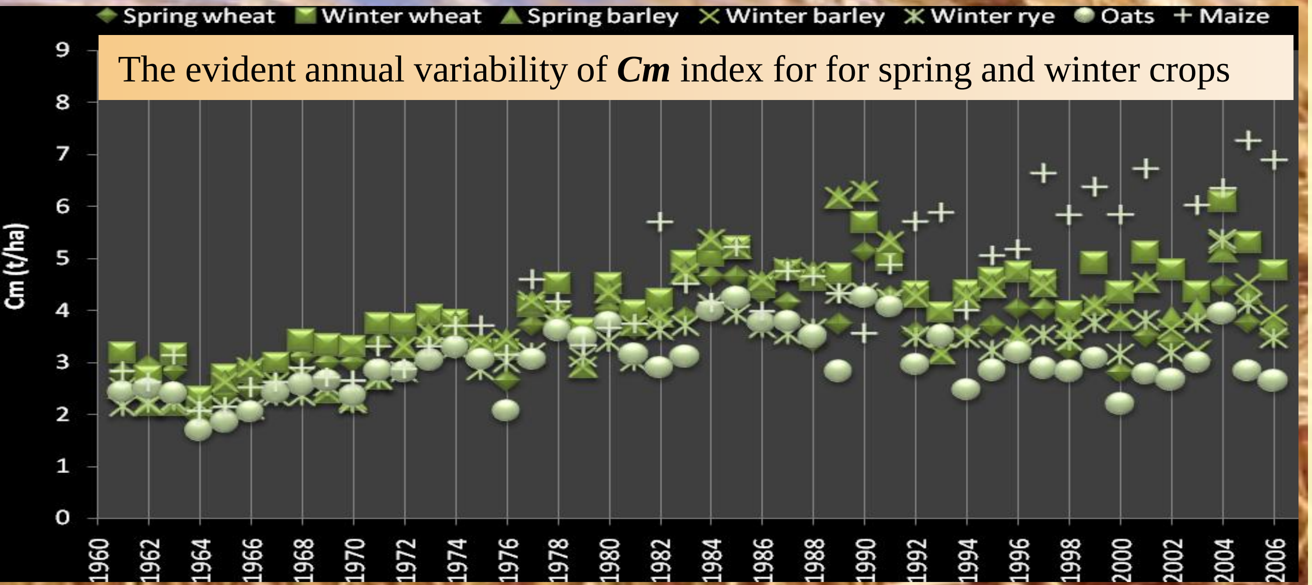
Potop V, Türkott L, Kožnarová V, Možný M (2010) Drought episodes in the Czech Republic and their potential effects in agriculture. Theor Appl Climatol 99:373–388

Potop (2011): Evolution of drought severity and its impact on corn in the Republic of Moldova. Theor Appl Climatol 96:305–318

IX. Drought impacts

Czech Republic: Drought consequence on cereals production


Trends of annual average yields (t/ha) for spring and winter crops


The evident annual variability of ***Cm*** index for for spring and winter crops

The evident annual variability of ***Cm*** index for for spring and winter crops

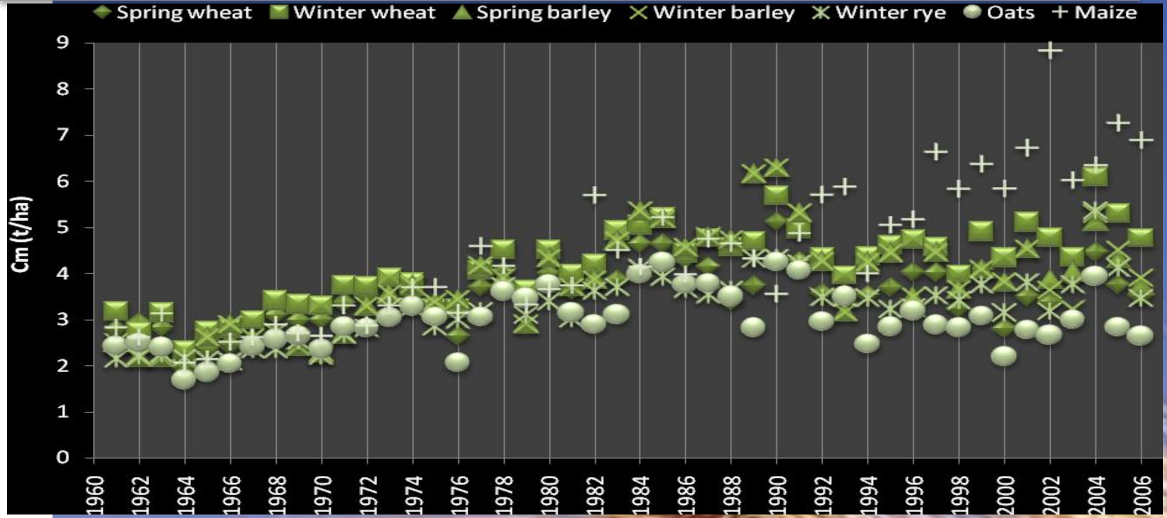
- Comparing the regional yields of crops and the national yields of crops, one can state that the yields were comparable or higher, particularly in maize and winter wheat.

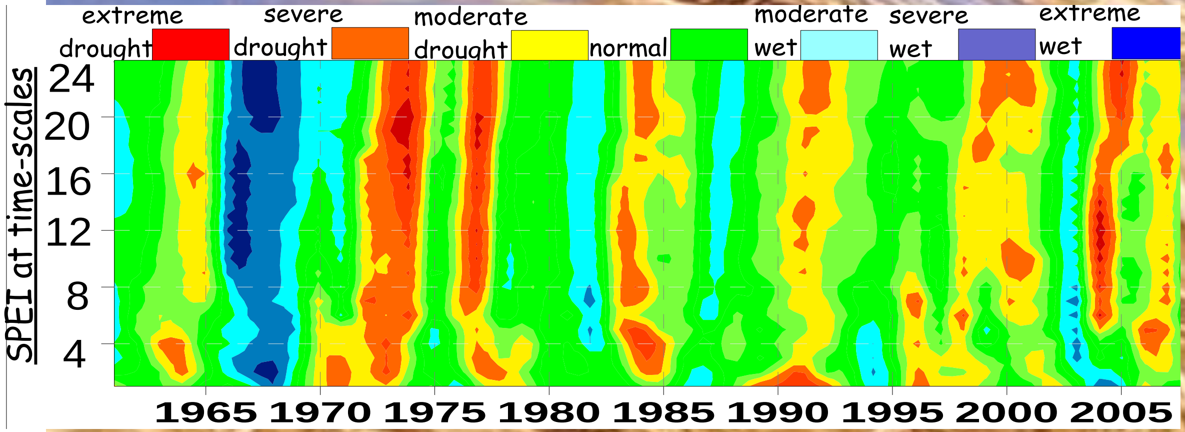
- As plots indicate, the fastest yield growth was found in maize and wheat (+4.6 and +2.3 t/ha),
  - spring barley and winter barley (+2.2 t/ha),
  - while slower growth was found for oats and winter rye (+0.7 and +1.8 t/ha).

- Winter wheat gives very high yield stability in contrast to spring wheat.

- The difference between spring and winter cereals was 23 % in favour of winter cereals.

Czech Republic: Drought consequence on cereals production





- in the year 2000 spring cereals reached the lowest yield because of the severe drought during the vegetation period.

- in 2003 winter cereals reached the lowest yield in the Czech Republic, which was around 22% lower in comparison to spring cereals due to an extensive winter kill.

- additionally, the winter cereal was badly affected by the following early spring drought.

- Maize can acquire water very well from deeper layers with its root system and is resistant to dry periods.

- It has increased demands for moisture during the flowering period (July-August). For example, a severe drought in 1992 affected all cereals with the exception of maize.

- That year's drought was widespread in Germany (crop production was reduced by 22%), Hungary, Bulgaria, Moldova and much of western Russia (Ben Lloyd-Hughes 2005).

IX. Drought impacts

Czech Republic: Drought consequence on cereals production

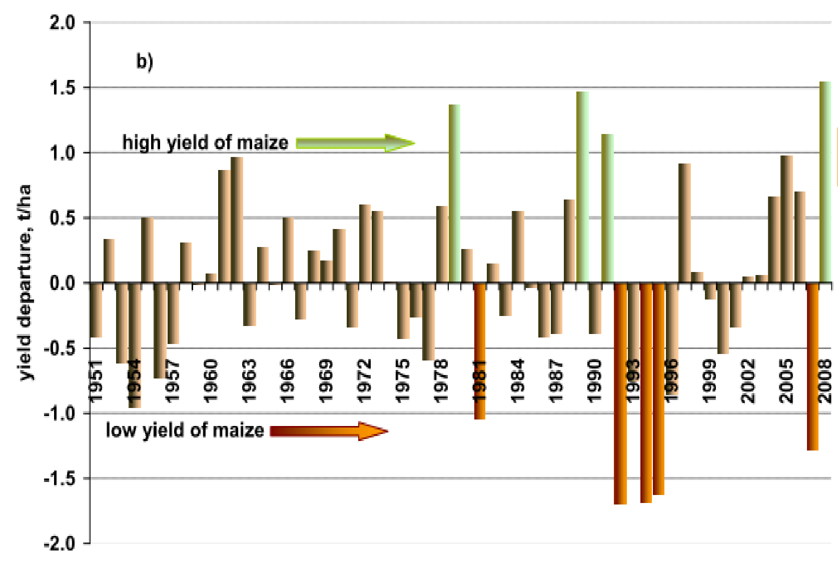
	Winter wheat	Spring wheat	Spring barley	Winter barley	Winter rye	Oats	Maize
1964	-1.5σ	-1.5σ	-0.5σ	-0.5σ		-σ	-σ
1965	-0.5σ	-σ			-0.5σ	-σ	-σ
1966	-0.5σ	-σ			-σ	-0.5σ	-0.5σ
1967	-0.5σ						-0.5σ
1968					-0.5σ		
1969			-σ	-σ			-0.5σ
1970		-0.5σ	-1.5σ	-1.5σ	-σ	-0.5σ	-0.5σ
1971			-σ	-σ			
1972							-0.5σ
1975	-σ	-0.5σ		-0.5σ	-0.5σ		
1976	-1.5σ	-1.5σ	-0.5σ	-0.5σ		-1,5σ	-0.5σ
1979	-σ		-1.5σ	-1.5σ	-0.5σ		-0.5σ
1981			-0.5σ	-0.5σ	-0.5σ		
1982			-0.5σ	-0.5σ		-0.5σ	
1988		-σ					
1989		-0.5σ				-σ	-0.5σ
1990							-1.5σ
1992	-0.5σ	-0.5σ			-0.5σ	-0.5σ	
1993	-σ		-1.5σ	-1.5σ	-0.5σ		
1994	-0.5σ	-0.5σ			-0.5σ	-1.5σ	-1.5σ
1995		-0.5σ			-σ	-0.5σ	-0.5σ
1996			-σ	-σ	-σ		-0.5σ
1997					-0.5σ	-0.5σ	
1998	-1.5σ	-σ	-σ	-0.5σ	-0.5σ	-0.5σ	
2000	-0.5σ	-1.5σ	-0.5σ	-0.5σ	-σ	-0.5σ	
2001		-0.5σ					
2002		-0.5σ				-0.5σ	
2003	-0.5σ		-0.5σ	-0.5σ	-0.5σ	-0.5σ	-0.5σ
2006	-0.5σ	-0.5σ	-0.5σ	-0.5σ	-0.5σ	-0.5σ	

The evident annual variability of yield (σ) calculated for individual crops:

- in the year 1976 summer drought occurred and, as a result, the yield was reduced in the crops with
  - -0.5σ for spring barley, winter barley and maize,
  - -1.5σ for winter wheat, spring wheat and oats.
- The summer 1976 is characterized in the literature as being exceptional drought for Europe with
  - severe droughts reaching from Scandinavia to France, affecting in particular Sweden, Denmark, the Netherlands, Northern France, England, Scotland and Ireland, later also spreading to Eastern Europe, while “the impact was worst in South-East England with supply restrictions” (Bradford 2000).

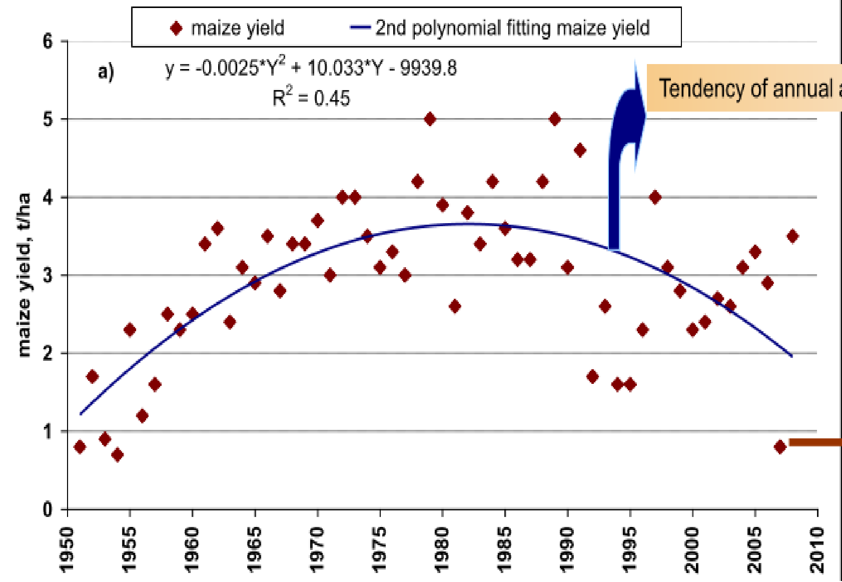
IX. Drought impacts

Republic of Moldova: Drought consequence on maize production



Departures of annual yield

Yield dynamics of national mean level (a) and annual departures from normal (b) for maize in the RM



Tendency of annual average maize yield (t/ha)

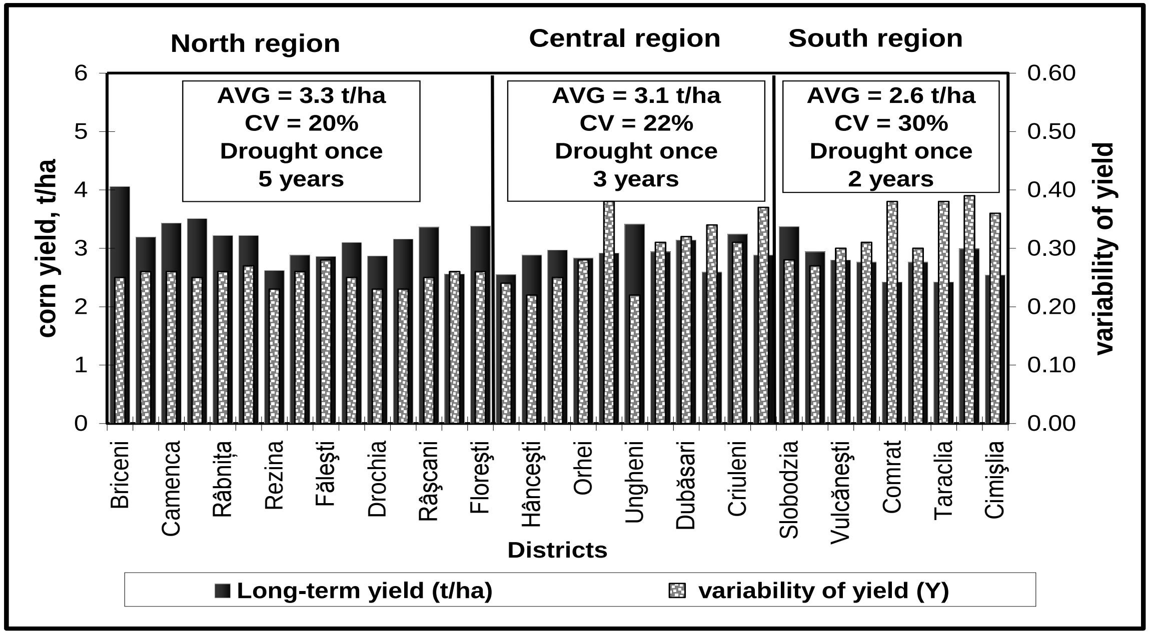
The evident annual variability of maize yield

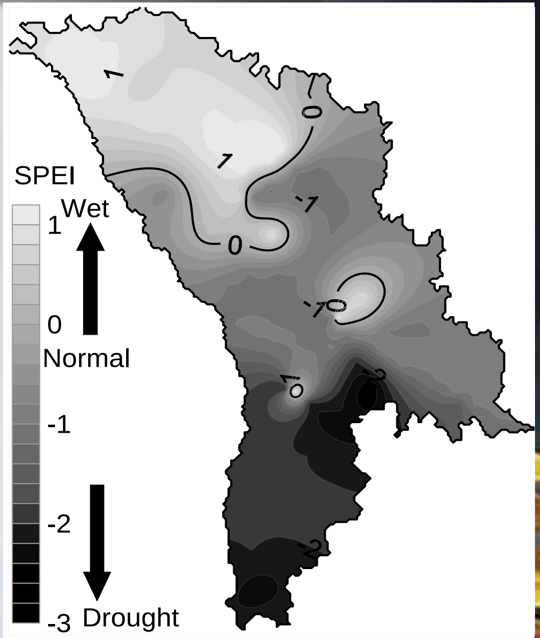
Source: Potop (2011): Evolution of drought severity and its impact on cor in the Republic of Moldova. Theor Appl Climatol 96:305–318

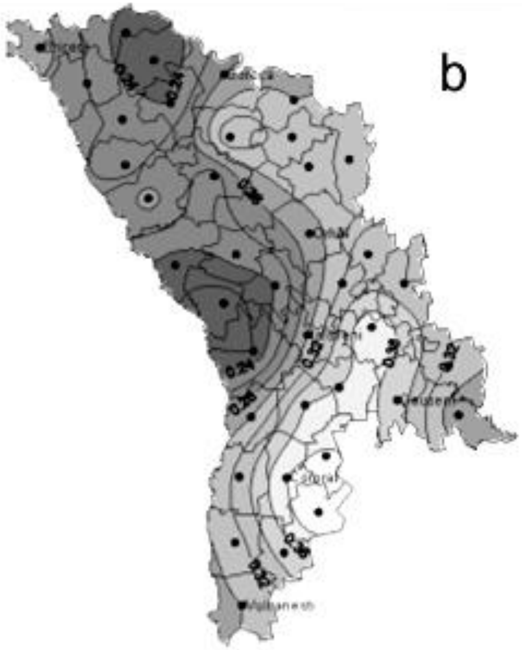
- ❖The highest maize yield was in the 70's-80's years of the 20th century, followed by a stable period, but since 1990's years harvest has stagnated, motivated by the economic reform.
- ❖The highest yield reductions due to extreme and severe drought events occurring in the flowering and grain filling stages on the whole territory were in the following years:
  - ❖1953(1.0t/ha),1992(2.5t/ha),1994(1.6t/ha),2003(2.8 t/ha) and 2007 (0.7 t/ha).
- ❖ **This fact is linked with:**
  - the increasing **drought conditions** observed for this period,
  - conditions as inappropriate **agrotechnical measures**
  - **lack of irrigation** that contribute to corn crops' decreasing drought resistance.
- ❖Economic assessment of the impact of climate vulnerability on maize in the period 1990-2008 suggests that net losses have so far exceeded net gains.

IX. Drought impacts

Long-term maize yield by district (1955-2007) and variability of maize yield in Moldova







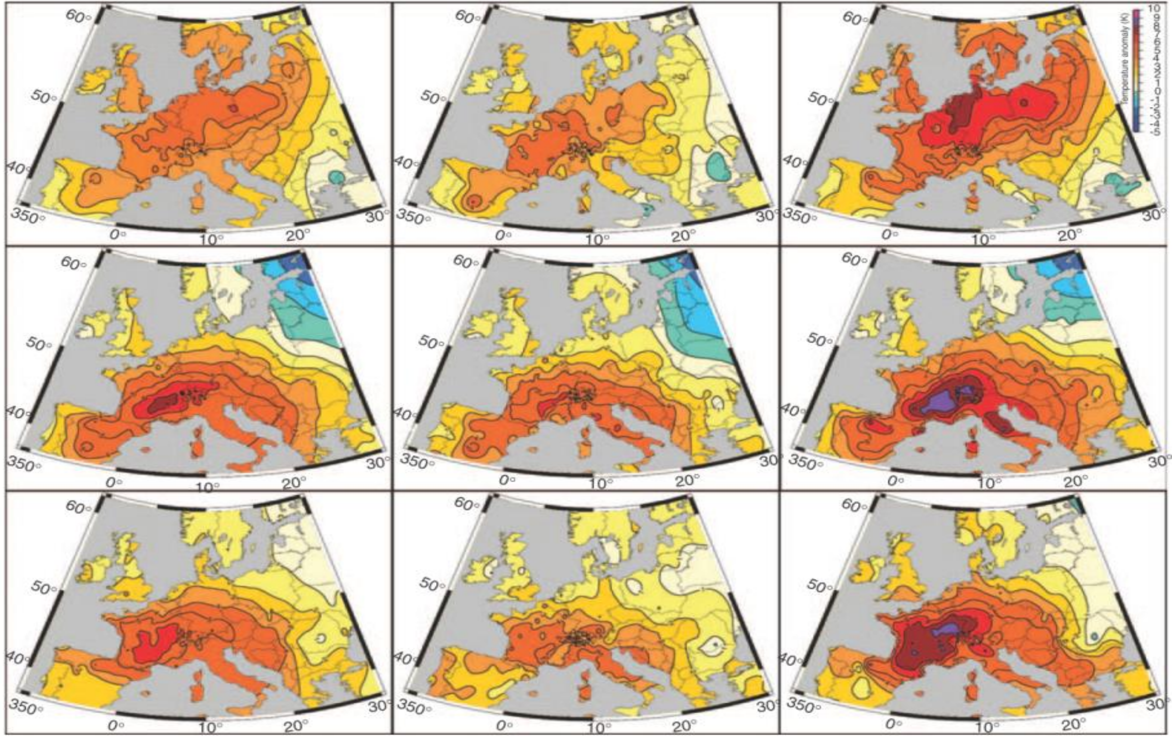
AVG – average yield per region; CV = coefficient of variation is calculated from the average and standard deviation of yield

- ❑ The regional data for variability of yield indicates that relatively favorable humidity conditions for obtaining high maize yield are in the North (CV = 20 %) and Central (CV = 22 %) regions of the country.
- ❑ Districts located in the South agro-climatic region, which receive less precipitation, tend to be more vulnerable to drought. In the South, therefore, the CV value is highest (0.30 or 30 %).
- ❑ The more extensive are the drought areas, the greater are the variability and reduction in cereal crops yields.

IX. Drought impacts

Summer heat episodes and drought in Central and Eastern Europe: Czech Republic and Republic of Moldova case

- The impact of extreme events is more serious when the extreme meteo conditions prevail over extended periods.
- The 2006 European heat wave was also a period of exceptionally hot weather that arrived at the end of June 2006 in certain European countries.
- The 2006 heat wave was clearly located more northward of Europe than in summer 2003.
- Regions such as northern France, Germany, Belgium, and the Czech Republic, which were strongly affected by the 2003 heat wave, were affected by an even more extreme heat wave in July 2006, in terms of absolute mean monthly values.



Surface air temperature anomalies in July 2006 (top), June 2003 (middle) and August 2003 (bottom): **mean (left)**, **minimum (middle) and maximum (right)** surface air temperature

Source: Rebetez et al., 2008

Differences between July 2006 and June 2003 (top), August 2003 (bottom) **average (left)**, **minimum (middle)** and **maximum (right)** surface air temperature

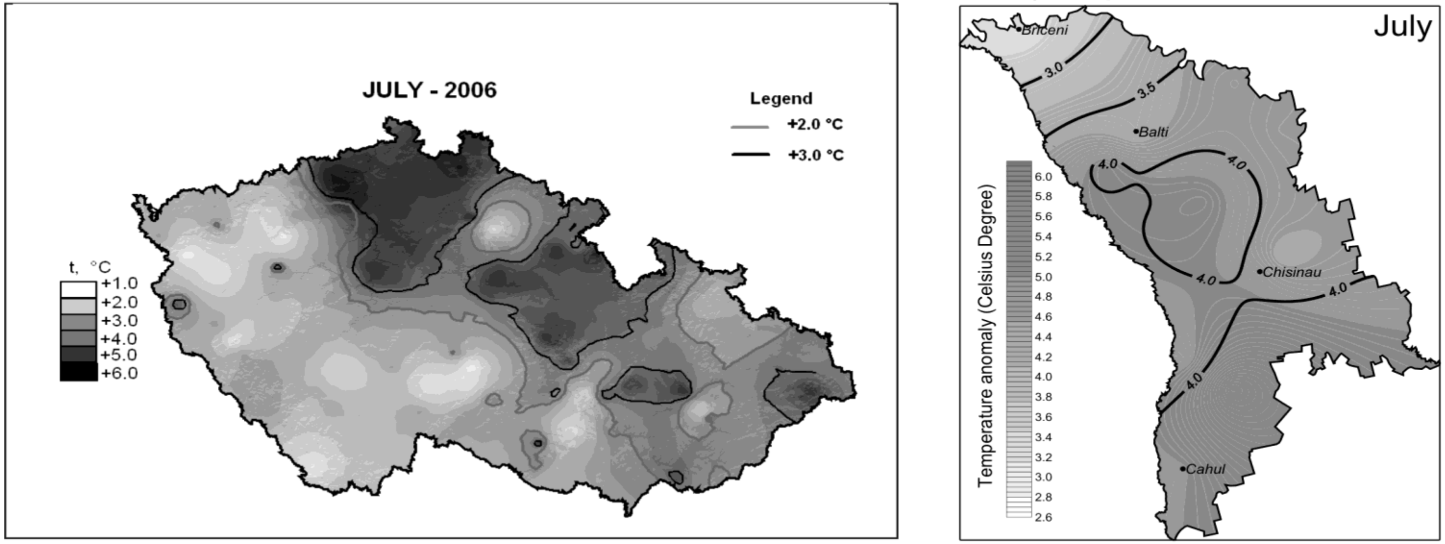
IX. Drought impacts

Summer heat episodes and drought in Central and Eastern Europe: Czech Republic and Republic of Moldova case

- We present the results of two research goals (Overcenco & Potop, 2010):
  (1) comparative assessment of the extremely hot summer of 2006 in the Czech Republic (CR) and 2007 in the Republic of Moldova (RM)
  (2) identification of heat episodes (tropical days and heat waves) in these countries during 1961-2009.

a) Czech Republic

b) Republic of Moldova



Hradec Králové weather station

Chişinău weather station

Anomalies of averaged July temperatures in the Czech Republic and Moldova (maps) and averaged summer temperatures at Hradec Králové and Chişinău weather stations (charts) in 2006 and 2007 on the background of baseline (1961-1990) temperatures approximated by a normal distribution curve.

T- the average July temperature; **σ** - standard deviation of the reference period; **δT/σ** - the normalized deviation.

IX. Drought impacts

Summer heat episodes and drought in Central and Eastern Europe: Czech Republic and Republic of Moldova case

Czechia

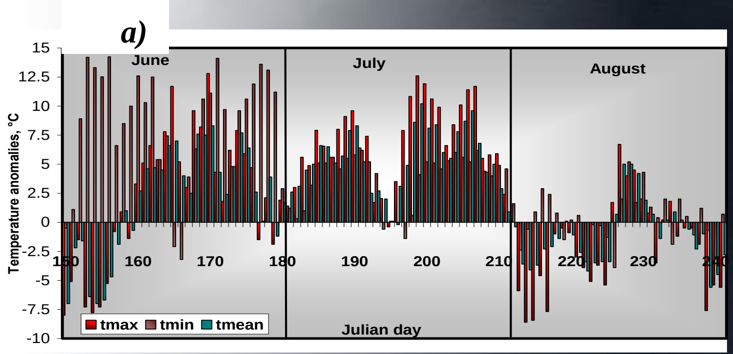
- The summer of 2006 was recorded as very hot; however, temperatures in June and July did not break record
- In July 2006, as in June and August 2003, deviation of the mean temperature from norm was more than +4.7 °C over the CR
- The chart shows that averaged temperatures were exceeded 4 standard deviations ($\delta T/\sigma = 4.2$)

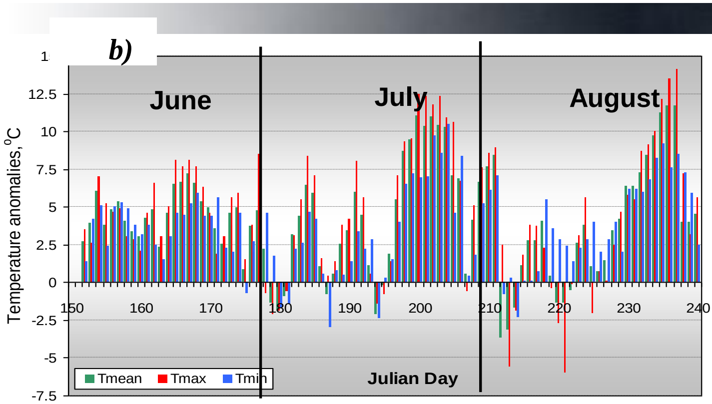
Moldova

- During summer 2007 the absolute temperature records were registered for all observation period (since 1887)
- July 2007 was the warmest month for all observation period
- Temperature anomalies have exceeded its baseline in July on $3\text{-}4\sigma$ and in summer up to 5σ
- Anomaly $\geq 2\sigma$ can occur with a probability of 5%, and $\geq 3\sigma$ ─ 0.3% (i.e. 5 times in 100 years and 3 once in 1000 years), it is easy to imagine, how rare was summer of 2007 in Moldova.

Republic of Moldova and Czech Republic

- the 2006 June and July mean, maximum and minimum temperatures in the CR were constantly above the normal temperatures with except of August
- 2007 summer temperatures in Moldova were higher not only of their mean baseline values, but also the values considered as extremes
- the IPCC Glossary (IPCC 2007b, p. 875) defines an **extreme weather event as "an event that is rare within its statistical distribution at a particular place"**
- criteria of «rarity» vary from place to place and are normally calculated as rare as (or rarer than) 90th percentile values
- by 90th and 95th quantiles – in Chişinău all three indicators of 2007 summer temperatures were significantly higher than extremely possible in the baseline climate, and for CR such exceedance in 2006 was observed only in June and July.





Deviations of summer daily air temperatures in the CR, 2006 (a) and in the RM, 2007 (b) from their baseline values *(horizontal null line)*

***a* – Hradec Králové, CR**															
Period	***Mean temperature***					***Maximal temperature***					***Minimal temperature***				
	2006	1961-1990		2000-2009		**2006**	1961-1990		2000-2009		**2006**	1961-1990		2000-2009	
		90%	95%	90%	95%		90%	95%	90%	95%		90%	95%	90%	95%
June	18.5	17.9	19.1	20.8	20.8	24.4	23.5	24.7	27.0	27.0	12.4	13.3	13.4	13.9	13.9
July	23.5	19.9	20.2	20.1	20.1	30.7	26.1	26.5	26.4	26.4	16.0	14.3	14.5	14.4	14.4
August	16.5	19.1	19.7	21.1	21.1	21.2	25.8	26.7	28.4	28.4	12.5	13.9	14.4	15.4	15.4
Summer	19.5	18.4	18.6	20.5	20.5	25.4	24.4	24.5	27.2	27.2	13.6	13.6	14.0	14.1	14.1
***b* – Chişinău, RM**															
Period	***Mean temperature***					***Maximal temperature***					***Minimal temperature***				
	2007	1961-1990		2000-2009		**2007**	1961-1990		2000-2009		**2007**	1961-1990		2000-2009	
		90%	95%	90%	95%		90%	95%	90%	95%		90%	95%	90%	95%
June	23.2	20.7	21.0	21.5	22.5	28.9	26.3	26.7	27.4	29.1	17.7	15.6	15.9	17.0	17.6
July	25.8	21.8	22.0	23.5	23.9	32.3	27.4	27.7	29.3	29.4	19.7	16.7	16.9	18.7	18.9
August	23.9	22.0	22.4	24.0	24.1	29.3	27.8	28.2	29.9	30.2	19.1	16.8	17.2	18.9	19.2
Summer	24.3	21.7	22.2	23.7	24.0	30.2	27.4	27.9	29.4	29.8	18.8	16.7	17.1	18.6	18.9

Source: Overcenco & Potop, 2010

Table: Summer 2006 (CR, ***a***) and 2007 (RM, ***b***) temperatures (°C) in comparison with 90% and 95% quantiles of their distribution in baseline and current climates

It is interesting, that as in CR, as in RM the greatest exceedance is observed for summer minimum temperatures;

In other words – the greatest contribution into the exceptionality of these summers was made by increase of Tmin.

IX. Drought impacts

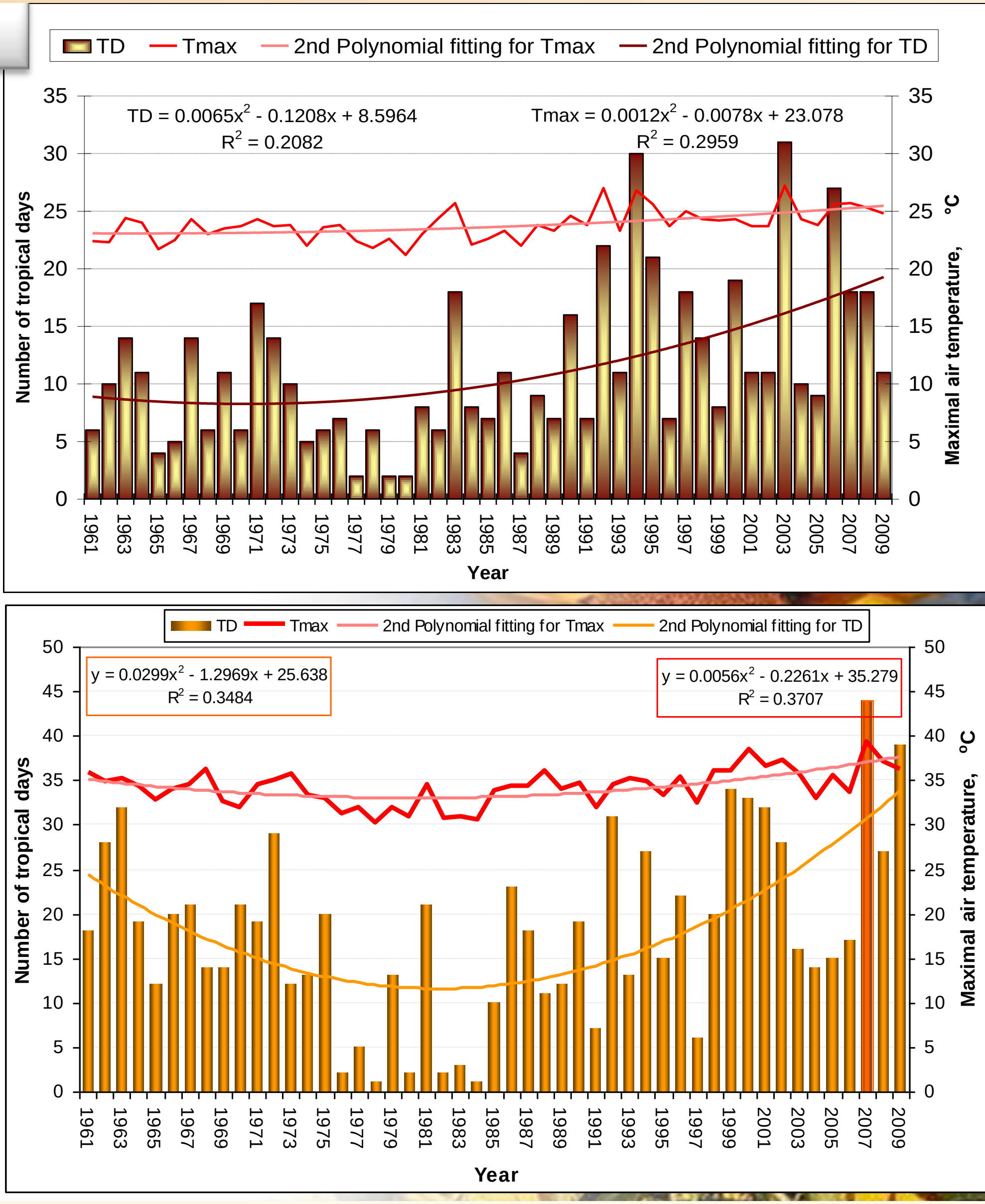
Republic of Moldova and Czech Republic

- Over past 20 years the average number of tropical days in the summer season has increased in more than 1.5 times both in Moldova and in the middle part of Elbe River Basin (CR)

- The growing number of tropical days is accompanied by increase of maximum temperatures during the whole period

- Based on surface temperature data from 100 European stations, First European Climate Assessment (ECSN 1995) reports an increase from the beginning of the 20th century until 1940, a period of stabilization or even cooling until around 1970, followed by a new increase extending up to the present time.

- Our results as for CR as for RM weather stations coincide with ECSN (1995).



Tendency of number of tropical days in summer during 1961-2009 in the Czech Republic (upper) and the Republic of Moldova (lower) Source: Overcenco & Potop, 2010

IX. Drought impacts

Republic of Moldova and Czech Republic

- In the CR, the last two decades were characterized by prolonged periods of severe heat waves, whereas the 1970s and 1980s were characterized by diminishing or completely missing heat waves
- The **hottest summer** as regards heat wave duration and severity have occurred in the CR in **1994** (the longest heatwave lasting 17 days and cumulative *Tmax* excess of 72.8 ºC at Hradec Králové) and in Moldova in **2007** (24 days and 127.2 ºC)
- It is evident that during last two decades the total number of heat episodes in two countries has increased significantly resulted by climate variability and extremely hot years.

❑**HWDI-** the maximum period greater than five consecutive days with maximum air temperature (*Tmax*) >5 °C above 1961–1990 daily *Tmax* normal (*IPCC, 2001*).

❑To characterize **the heat waves severity** the cumulative *Tmax* excess above 30.0°C ($\Sigma\Delta Tmax>30$) and the **peak temperature during heat waves** are used (*Kyselý, 2010*).

The most severe heat waves in Hradec Králové (middle part of Polabí, Czech Republic) and Chişinău (the Republic of Moldova) from 1961 to 2009. Source: Overcenco & Potop, 2010

Year	Tropical Days	Heat waves number	Heat wave Duration, days in total	Severity of heat waves (ΣΔTmax>30), ºC	Highest Tmax during heat waves, ºC	Highest Tmax for summer season, ºC
a – Hradec Králové, CR						
1994	**30**	**1**	**17**	**72.8**	**37.8**	**37.8**
b – Chişinău, RM						
2007	**44**	**3**	**24**	**127.2**	**39.4**	**39.4**

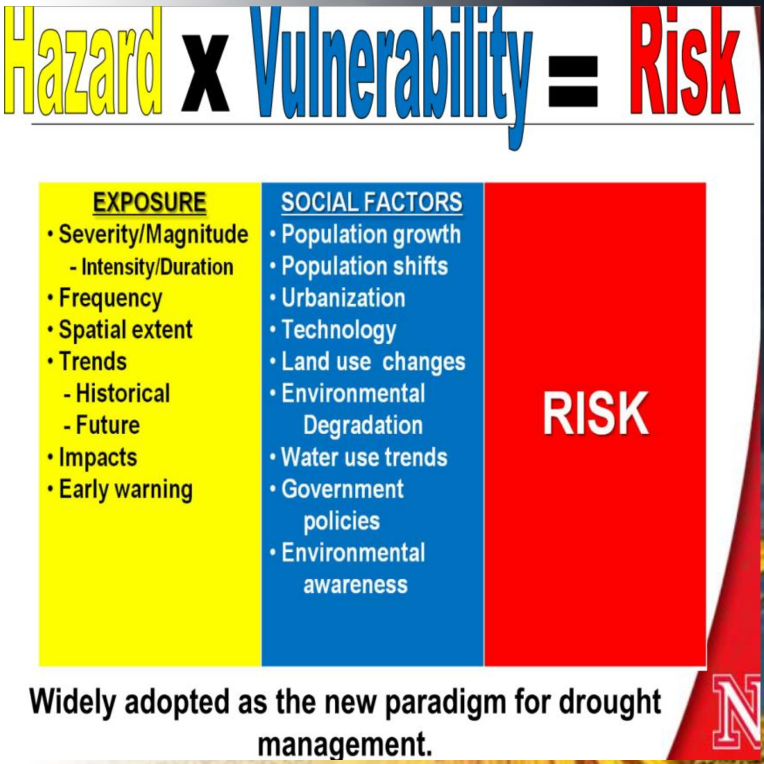
IX. Drought impacts

Republic of Moldova and Czech Republic

- Taking into account the hot summer climate of the country, the continuation of this tendency could result in very negative consequences for all biological systems, primarily affecting the most vulnerable components – agriculture and human health.
- A catastrophic drought, occurred in 2007, has led to disastrous consequences – 90% of country’s territory and 80% of rural population depending of agriculture were affected by the diminished harvest, output of cereal crops declined by 63% compared to 2006 and the wheat harvest reduced in 10 times.
- Total losses during this drought amount 1 billion USD (*UNDP 2009*).
- The oppressive weather of this summer has resulted in both direct and indirect effects on human health, reflected in increased ambulance call-outs and the increase in total mortality, especially from cardiovascular disease among the elderly population.
- As shown recent study, the direct heat effect during 2007 hot summer in Chisinau has resulted in about 200 of excess deaths (*Corobov and Opopol 2010*).
- In the CR with its quite mild summer the picture is not less depressing. Thus, the drought spell of 2006 hot summer has affected 70% of agricultural areas in the Czech Republic.
- However, the yield losses of agriculture crops due to hot and dry summer of 2006 were not as high as in summer of 2003 in the Czech Republic.

X. Top 10 Challenges to Adopting Drought Risk Management Approach

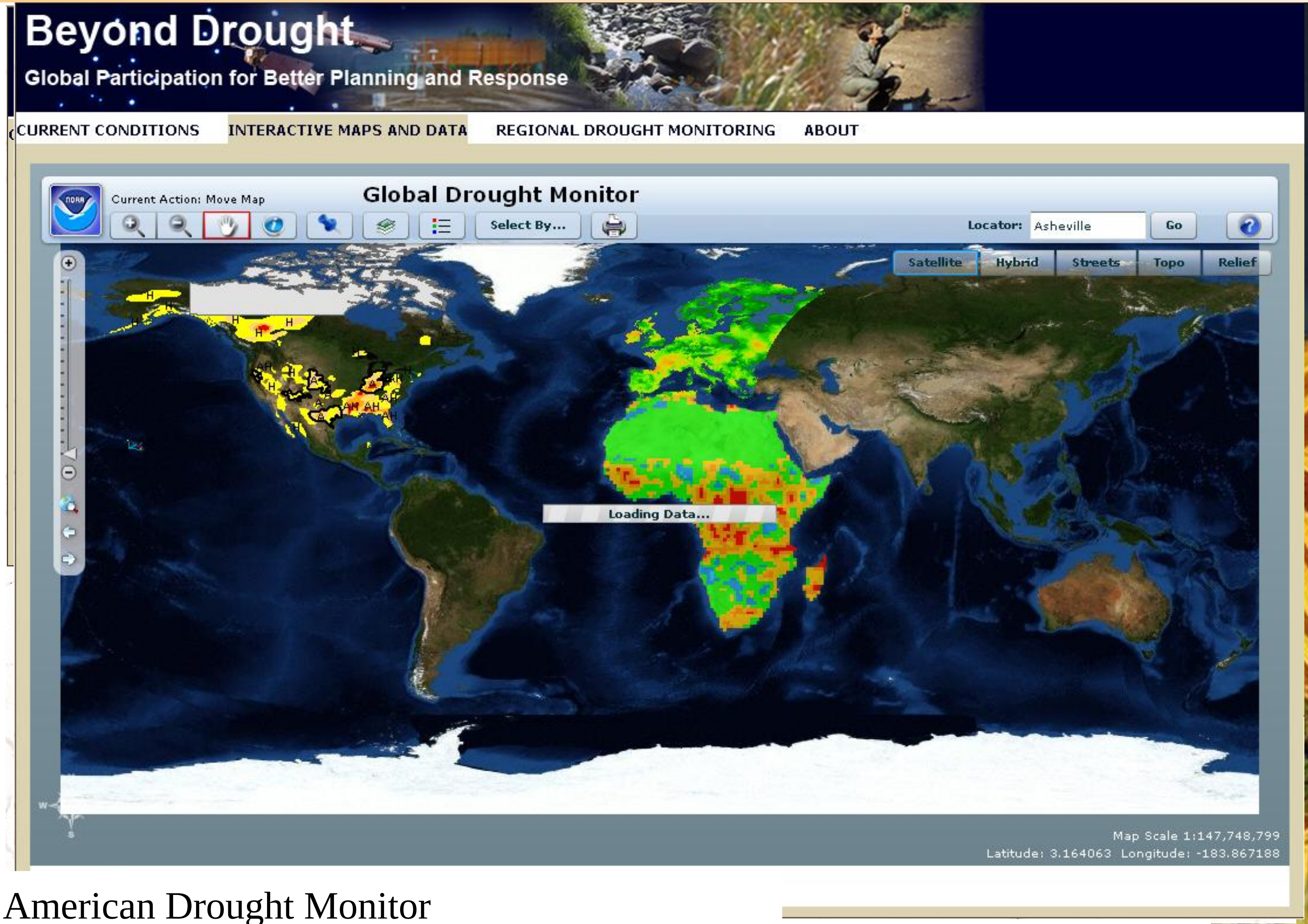
1. Drought doesn’t get the respect of other natural hazards.
2. Drought monitoring/early warning is more complex.
3. Institutional inertia constrains change from crisis to risk management.
4. Impacts are poorly understood and not well documented.
5. Drought relief discourages risk-based management approach (i.e., crisis management).
6. Poor understanding of how societal changes affect vulnerability.
7. Drought predictability is low in most cases.
8. Decision-support tools and delivery systems must be improved and tailored to the needs of users.
9. Drought mitigation actions are less obvious.
10. Political will must be present for nations to move to a more proactive, risk-based drought management approach.



Widely adopted as the new paradigm for drought management.

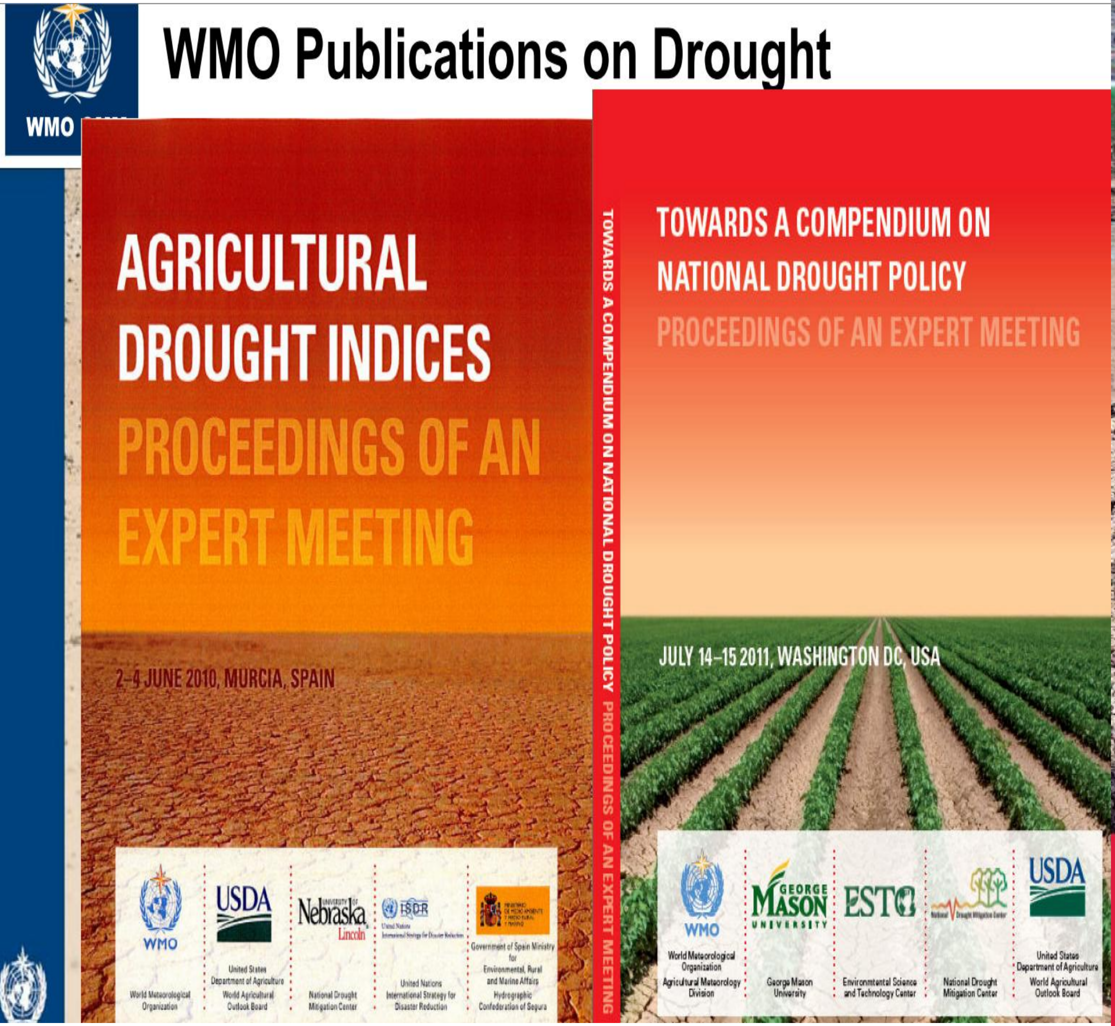
XI. The Global Drought Monitor Portal **(GDMP)**

http://www.drought.gov/portal/server.pt/community/global_drought



North American Drought Monitor
European Drought Observatory
Princeton University African Drought Monitor

llege London



WMO Publications on Drought

AGRICULTURAL DROUGHT INDICES
PROCEEDINGS OF AN EXPERT MEETING

2-4 JUNE 2010, MURCIA, SPAIN

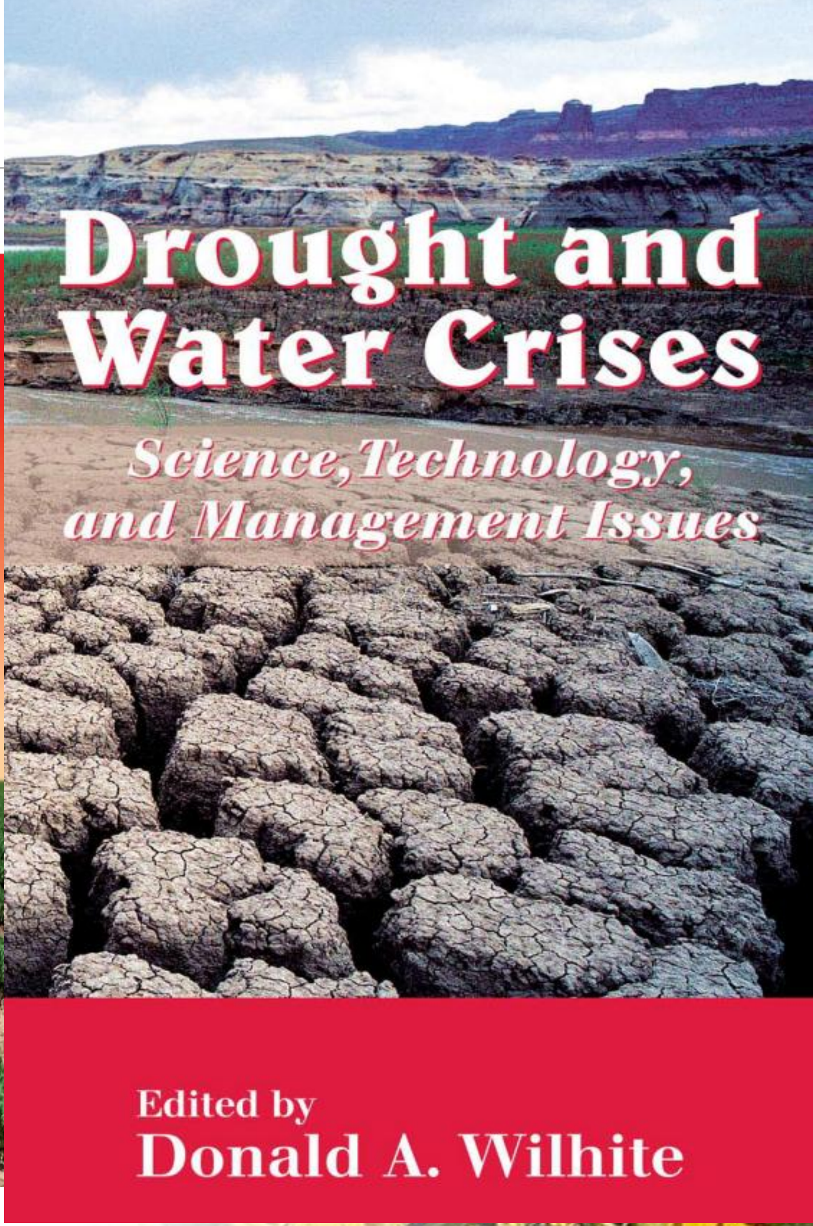
World Meteorological Organization
United States Department of Agriculture World Agricultural Outlook Board
National Drought Mitigation Center
United Nations International Strategy for Disaster Reduction
Government of Spain Ministry for Environmental, Rural and Marine Affairs Hydrographic Confederation of Segura

TOWARDS A COMPENDIUM ON NATIONAL DROUGHT POLICY
PROCEEDINGS OF AN EXPERT MEETING

JULY 14–15 2011, WASHINGTON DC, USA

TOWARDS A COMPENDIUM ON NATIONAL DROUGHT POLICY PROCEEDINGS OF AN EXPERT MEETING

World Meteorological Organization Agricultural Meteorology Division
George Mason University
Environmental Science and Technology Center
National Drought Mitigation Center
United States Department of Agriculture World Agricultural Outlook Board



Drought and Water Crises

Science, Technology, and Management Issues

Edited by
Donald A. Wilhite

ČESKÁ ZEMĚDĚLSKÁ UNIVERZITA V PRAZE

Lifelong
Learning
Programme

ERASMUS Programme
STA - TEACHING ASSIGNMENT

DRAOUGHT CLIMATOLOGY

Practical exercises: Calculation of drought indices

30 September – 13 October
Universitat Rovira I Virgili
Tarragona
Spain

Professor: Dr. Vera Potop

Department Agroecology and Biometeorology
Faculty of Agrobiology, Food and Natural Resources
Czech University of Life Sciences in Prague
potop@af.czu.cz

Objective of the seminar:

-Calculate the most advance multi-scalar drought indices for two climatological stations situated in different climatological regions from the Czech Republic.

-Describe and compare the temporal evolution of moisture conditions in lowland and mountain regions using SPI and SPEI drought indices.

-Create a time series of Standardized Precipitation-Evapotranspiration Index (SPEI) and Standardized Precipitation Index for the period 1961-2010 and five accumulated periods: 1, 3, 6, 12 and 24 months.

General information of climatological stations:

1. Doksany lowland station

Designator: U1DOKS01

Geographical position: *Elevation*: **158 m above sea level**

Latitude: **50° 27' N (50.4583 degree)**

Longitude: **14° 10' E (14.1703 degree)**

Long-term of mean annual temperature: **8.7°C**

Long-term of annual amount of precipitation: **449 mm**

Climatic classification according to Quitt (1971): **warm region**

2. Lysá hora mountain station

Designator: O1LYSA01

Geographical position: *Elevation*: **1322 m above sea level**

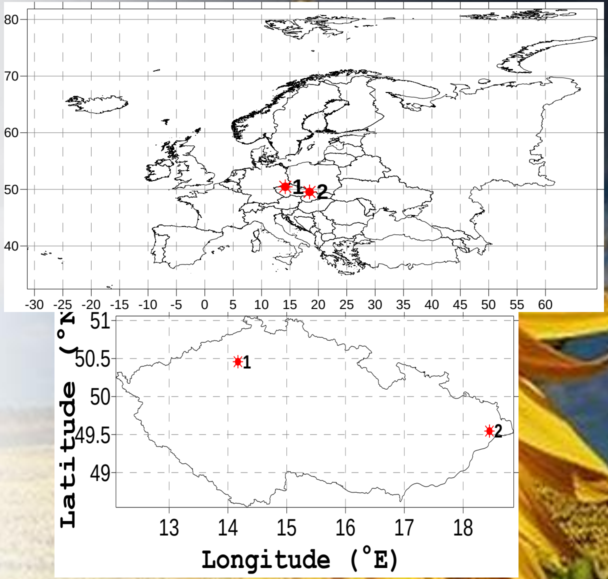
Latitude: **49° 32' N (49.5461degree)**

Longitude: **18° 26' E (18.4478 degree)**

Long-term of mean annual temperature: **2.8°C**

Long-term of annual amount of precipitation: **1407 mm**

Climatic classification according to Quitt (1971): **cold region**



Location of stations used for the calculation of the SPEI and SPI drought indices in the Czech Republic. 1-Doksany and 2-Lysá hora

"I SEE MY TIME IS UP.
THANK YOU.

"ARE THERE ANY
QUESTIONS?"