PROPOSED SET OF INDICATORS

A structured network for integration of climate knowledge into policy and territorial planning

DELIVERABLE INFORMATION	
WP:	WP3 Mapping and Harmonising Data & Downscaling
Activity:	3.2 Proposal for the cross-harmonized set of indicators and guidance documents for their calculation and potential use
WP Leader:	RHMSS
Activity leader:	RHMSS
Participating part-ners:	RHMSS, NIMH, OMSZ, NMA, DHMZ, RHMZ RS, HMSM, OSENU, BMLFUW, CMCC, PAT, Attica Region
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I Introduction

The ORIENTGATE project aims to implement concerted and coordinated climate adaptation actions across South Eastern Europe (SEE). The partnership comprises 22 financing partners, nine associates and three observers, covering 13 countries, that together will explore climate risks faced by coastal, rural and urban communities, contributing to a better understanding of the impacts of climate variability and climate change on water regimes, forests and agroecosystems. The main objective of the project is to communicate up-to-date climate knowledge for the benefit of policy makers, including urban planners, nature protection authorities, regional and local development agencies, and territorial and public works authorities. *Retrieved from http://orientgate.rec.org/.*

Republic Hydrometeorological Service of Serbia (RHMSS) is the leader of the Work Package 3 (WP3)-*Mapping and Harmonizing data and Downscaling*. WP3 maps the variety of the methodologies, tools and indicators used across the SEE countries within the field of work related to climate variability and climate change issues. All information was collected from a number of Hydrometeorological services by using a custom made template by WP leader. Collected data served as a starting point to create a proposal for the new cross-harmonized set of climate data based parameters and indices which will serve as indicators of effects of climate change.

The purpose of the present document is to propose a set of indicators which will be tested in different pilot areas of 3 Thematic centres (TC):
TC1- Forestry and Agriculture (pilot studies in Austria and Romania);
TC2- Drought, Water and Coasts (pilot studies in Italy and Greece);
TC2- Urban Adaptation and Health (pilot study in Hungary).

The calculation of indicators will be executed side by side using the observed meteorological data and data time series generated on the basis of climate projections.

II Proposed set of indicators

A variety of indicators are used to analyze the effects of climate change. In order for end users to better understand the use of these indicators, the ones **based on the temperature and precipitation** as the basic meteorological elements have been chosen. Moreover, these meteorological elements were most accessible.

According to the indicators recommended by the ETCCDI Expert's Group within the WMO necessary meteorological data for the calculation are:

TN - daily minimum temperature (°C)
TG - daily mean temperature (°C)
TX - daily maximum temperature (°C)
RR - daily precipitation amount (mm)

In addition to aforementioned indicators, analysis was performed for the indicators recommended by the ECA&D as well as the other indicators used in the partner countries which were obtained through '*ORIENTGATE QUESTIONNAIRE - Review of the currently used indicators of climate risks'.* The set of proposed indicators also includes indicators that are not based solely on the above data, but can still be used in case the designated pilot area has the required data.

In accordance with the project documentation and the focus of some pilot areas, sets of indicators are grouped by sector.

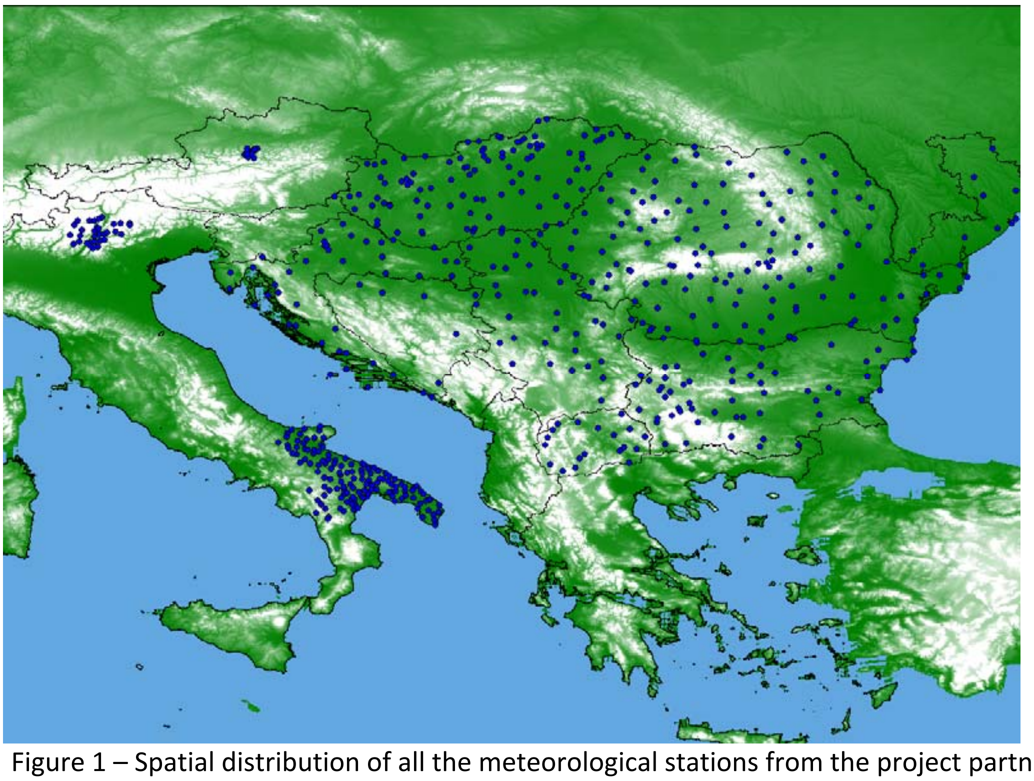

Figure 1 – Spatial distribution of all the meteorological stations from the project partners involved in WP3 activities

1. Agriculture

Index	Name	Index	Name
FD	Frost Days	**SDII**	Simple Daily Intensity Index
TD	Tropical Days	**R5mm**	n° of days with RR ≥ 5mm
CTD	Consecutive Tropical Days	**CDD**	Consecutive Dry Days
GSL	Growing Season Length	**CWD**	Consecutive Wet Days
GDD	Growing Degree Days	**R99pTOT**	Precipitation due to extremely wet days (> 99th percentile)
WSDI	Warm Spell Duration Index	**PRCPTOT**	Total precipitation in wet days
CSDI	Cold Spell Duration Index	**WD**	Warm/Dry
PaDI	Palfai Drought Index	**SPI3**	Standardized Precipitation Index
PET-Th	Thornthwaite Potential EvapoTranspiration	**SPEI3**	Standardized Precipitation-Evapotranspiration Index
PET-Ha	Hargreaves Potential EvapoTranspiration	**AI**	Aridity Index

1. **FD** - frost days: count the number of days in chosen period where TN < 0°C

2. **TD** - tropical days: count the number of days in chosen period where TX > 30°C

3. **CTD** – consecutive tropical days: maximum number of consecutive tropical days

   Count the largest number of consecutive days in chosen period where TX > 30°C

4. **GSL** - growing season length: annual count of days between first span of at least six days where TG > 5°C and first span in second half of the year of at least six days where TG < 5°C

   Let TG_{ij} be the daily mean temperature on day i in period j. Count the annual (1 Jan to 31 Dec in Northern Hemisphere) number of days between the first occurrence of at least six consecutive days where $TG_{ij} > 5°C$ and the first occurrence after 1 July of at least six consecutive days where $TG_{ij} < 5°C$.

5. **GDD** – growing degree days: the number of temperature degrees above a threshold base temperature (10°C) in a chosen period.

$$T_b = 10°C$$
$$GDD_i = TG_i - T_b \quad \text{if } T_b < TG_i$$
$$GDD_i = 0 \quad \text{if } T_b \geq TG_i$$

$$GDD = \sum_{i=1,I} GDD_i$$

6. **WSDI** - warm spell duration index: count of days in a span of at least six days where TX > 90th percentile. Choose the maximum spell duration in a chosen period.

   Let TX_{ij} be the daily maximum temperature on day i in period j and let $TX_{in}90$ be the calendar day 90th percentile of daily maximum temperature calculated for a five-day window centred on each calendar day in the base period n (1961-1990). Count the number of days where, in intervals of at least six consecutive days $TX_{ij} > TX_{in}90$.

7. **CSDI** - cold spell duration index: count of days in a span of at least six days where TN > 10th percentile. Choose the maximum spell duration in a chosen period.

Let TN_{ij} be the daily minimum temperature on day i in period j and let $TN_{in}10$ be the calendar day 10th percentile of daily minimum temperature calculated for a five-day window centred on each calendar day in the base period n (1961-1990). Count the number of days where, in intervals of at least six consecutive days $TN_{ij} < TN_{in}10$.

8. **SDII** - simple daily intensity index: mean precipitation amount on a wet day

Let RR_{ij} be the daily precipitation amount on wet day w (RR ≥ 1 mm) in period j. If W represents the number of wet days in j then the simple precipitation intensity index

$$SDII_j = \text{sum}(RR_{wj}) / W.$$

9. **R5mm**: count the number of days in chosen period where RR ≥ 5mm

10. **CDD** - consecutive dry days: maximum length of dry spell

Count the largest number of consecutive days in chosen period where RR < 1 mm.

11. **CWD** - consecutive wet days: maximum length of wet spell

Count the largest number of consecutive days in chosen period where RR ≥ 1 mm.

12. **R99pTOT**: total precipitation due to extremely wet days (> 99th percentile)

Let RR_{wj} be the daily precipitation amount on a wet day w (RR ≥ 1 mm) in period j and let $RR_{wn}99$ be the 99th percentile of precipitation on wet days in the base period n (1961-1990). Then:

$$R99pTOT_j = \text{sum}(RR_{wj}), \text{ where } RR_{wj} > RR_{wn}99$$

13. **PRCPTOT**: total precipitation in wet days

Let RR_{wj} be the daily precipitation amount on a wet day w (RR ≥ 1 mm) in chosen period j. Then:

$$PRCPTOT_j = \text{sum}(RR_{wj})$$

14. **WD** - warm/dry: number of days with TG > 75th percentile and RR < 25th percentile

Let TG_{ij} be the daily mean temperature at day i of period j and let $TG_{in}75$ be the calendar day 75th percentile calculated for a 5-day window centred on each calendar day in the 1961–1990 period. Let RR_{wj} be the daily precipitation amount at wet day w (RR ≥ 1.0 mm) of period j and let $RR_{wn}25$ be the 25th percentile of precipitation at wet days in the 1961–1990 period. Then counted is the number of days in chosen period where:

$$TG_{ij} > TG_{in}75 \text{ and } RR_{wj} < RR_{wn}25$$

15. **SPI3** - Standardized Precipitation Index

Computation of the SPI involves fitting a Gamma probability density function to a given frequency distribution of precipitation totals for a station. The alpha and beta parameters of the Gamma probability density function are estimated for each station, for time scale of 3 months and for each month of the year based on the referent period 1961-1990. The distribution is defined by its probability density function:

$$g(P) = (1/\beta^{\alpha}\,\Gamma(\alpha))\;\; P^{(\alpha -1)}\, \exp(-P/\beta) \;\; \text{for} \;\; P > 0$$

α, β - the shape and scale parameters respectively,
P - the precipitation amount and
$\Gamma(\alpha)$ - the gamma function.

α and β can be estimate from climatology using maximum likelihood method:

$$\alpha = 1 / (4A) \{1+ \surd (1+4A / 3)\} \;\; ; \;\; A = \ln (P_{mean}) - \textstyle\sum_i \ln(P_i) / n$$

$$\beta = P_{mean} / \alpha$$

P_{mean} – mean precipitation amount,
P_i – precipitation amount for time scale 3 months and for each month of the year in climatological period (1961-1990), and
n - number of observations.

The resulting parameters are then used to find the cumulative probability of an observed precipitation event for the given month and time scale for the station in question. Since g(P) is undefined for P=0 and a precipitation distribution may contain zeros, the cumulative probability becomes:

$$H(P) = q + (1-q)G(P)$$

q - the probability of a zero, and
G(P) - the cumulative density function of Gamma distribution.
If m is the number of zeros in a precipitation time series, then q can be estimated by:

$$q = m/n$$

Then SPI can be obtained by:

$$SPI = - \{t - (c_0 + c_1 t + c_2 t^2) / (1 + d_1 t + d_2 t^2 + d_3 t^3)\} \quad \text{for } 0 < H(P) \le 0.5$$

$$SPI = + \{t - (c_0 + c_1 t + c_2 t^2) / (1 + d_1 t + d_2 t^2 + d_3 t^3)\} \quad \text{for } 0.5 < H(P) < 1$$

$$t = \surd\{\ln [\, 1 / (H(P)^2) \,]\, \} \quad \text{for } 0 < H(P) \le 0.5$$

$$t = \surd\{\ln [\, 1 / (1 - H(P))^2 \,]\, \} \quad \text{for } 0.5 < H(P) < 1$$

$c0 = 2.515517 \quad d_1 = 1.432788$
$c1 = 0.802853 \quad d2 = 0.189269$
$c2 = 0.010328 \quad d3 = 0.001308$

Table 1. Classification by SPI values

SPI value	*Category*
> 2.0	Extremely wet
1.5 – 2.0	Severely wet
1.0 – 1.5	Moderately wet
-1.0 – 1.0	Near normal
-1.5 - -1.0	Moderately dry
-2.0 - -1.5	Severely dry
< -2.0	Extremely dry

Definition and method of calculation can be found in e.g. McKee (1993) and Loukas (2004).

16. **SPEI3** - Standardized Precipitation-Evapotranspiration Index

Computation of the SPEI involves fitting a three parameter Log-logistic probability density function to a given frequency distribution of difference between precipitation and Thornthwaites' potential evapotranspiration for a station. The parameters of the Log-logistic probability density function are estimated for each station, for time scale of 3 months and for each month of the year based on the referent period 1961-1990. The distribution is defined by its probability density function:

$$g(D) = \beta/\alpha \, [(D - \gamma) / \alpha]^{\beta-1} \{1 + [(D-\gamma) / \alpha]^{\beta}\}^{-2}$$

α, β, γ - scale, shape and origin parameters.

$$D_n = \sum_{i=0,k-1}(P_{n-i} - PET_{n-i})$$

k – timescale of the aggregation (3 months)
n - calculation month

The resulting parameters are then used to find the cumulative probability of an observed precipitation event for the given month and time scale for the station in question.

$$G(D) = \{1 + [\alpha / (D- \gamma)^{\beta}]\}^{-1}$$

G(D) - the cumulative density function of the Log-logistic function.

$$SPEI = W - (c_0 + c_1W + c_2W^2) / (1 + d_1W + d_2W^2 + d_3W^3) \quad \text{for } p \le 0.5$$

$$SPEI = - \{W - (c_0 + c_1W + c_2W^2) / (1 + d_1W + d_2W^2 + d_3W^3)\} \quad \text{for } p > 0.5$$

$$W = \sqrt{[-2 \ln(p)]}$$

$$p = 1 - G(D) \quad ; \quad \text{if } p > 0.5 \Rightarrow p = 1-p$$

p - probability of exceeding a determined *D* value,

$c0 = 2.515517 \quad d_1 = 1.432788$
$c1 = 0.802853 \quad d2 = 0.189269$
$c2 = 0.010328 \quad d3 = 0.001308$

Table 2. Classification by SPEI values

SPEI value	***Category***
> 2.0	Extremely wet
1.5 – 2.0	Severely wet
1.0 – 1.5	Moderately wet
-1.0 – 1.0	Near normal
-1.5 - -1.0	Moderately dry
-2.0 - -1.5	Severely dry
< -2.0	Extremely dry

Definition and method of calculation for SPEI can be found in Vicente-Serrano (2009).

17. **PaDI** - Palfai drought Index

The formula of the base-value is:

$$PaDI_0 = \{\sum_{i=apr,aug} T_i / 5*100\} / \{c + \sum_{i=oct,sept} (P_i*w_i)\}$$

$PaDI_0$ – base-value of drought index (°C/100 mm),
T_i – monthly mean temperature from April to August (°C),
P_i – monthly sum of precipitation from October to September (mm)
w_i – weighting factor,
c – constant value (10 mm).

The weight factors (w_i, Table 2) of precipitation express the difference between the moisture accumulation in soil and the water demand of plants.

Table 3. Weight factors

Month	***w_i weight factors***
October	0.1
November, December	0.4
January-April	0.5
May	0.8
June	1.2
July	1.6
August	0.9
September	0.1

Then, PaDI can be obtained by:

$$PaDI = PaDI_0 * k_1 * k_2 * k_3$$

PaDI – Palfai Drought Index (°C/100 mm)
k_1 – temperature correction factor,
k_2 – precipitation correction factor,
k_3 – correction factor, which characterizes the precipitation circumstances of the previous 36 month.

From the correction factors the temperature factor k_1 represent the relation between examined and average summer mean temperature, the precipitation factor k_2 represent the relation between examined and average summer precipitation sum and k_3 represent the effect of precipitation circumstances of previous 36 month.

Table 4. Drought categories

PaDI, ºC/100 mm	***Description***
< 4	droughtless year
4 – 6	mild drought
6 – 8	moderate drought
8 – 10	heavy drought
10 – 15	serious drought
15 – 30	very serious drought
> 30	extreme drought

18. **PET-Th** – Thornthwaite potential evapotranspiration
PET based on Thornthwaite method (Willmott et al. 1985):

$$PET_0 = 0 \quad \text{for } T<0°C$$

$$PET_0 = 16(10T / I)^a \quad \text{for } 0 \leq T < 26.5°C$$

$$PET_0 = -415.85 + 32.24T – 0.43T^2 \quad \text{for } T \geq 26.5°C$$

$$I = \sum_{i=1,12}(Ti/5)^{1.514}$$

$$a = 6.75*10^{-7}\, I^3 - 7.71*10^{-5}\, I^2 + 1.79*10^{-2}\, I + 0.49$$

$$PET\text{-}Th = PET_0\, [(\theta/30)\, (h/12)]$$

T – mean monthly temperature (°C)
θ – length of the month (in days)
h – duration of daylight (in hours) on the fifteenth of the month.

19. **PET-Ha** – Hargreaves potential evapotranspiration
PET based on Hargreaves method (Hargreaves et al. 1994):

$$PET\text{-}Ha = 0.0023 \cdot RA \cdot (TG + 17.8) \cdot TD^{0.5}$$

TD – mean daily temperature range (TX-TN)
RA – extraterrestrial radiation, radiation on top of atmosphere, calculated as function of latitude and day of the year

20. **AI** – aridity index: a numerical indicator of the degree of dryness of the climate at a given location

Let P be accumulated precipitation and PET Thornthwaites' potential evapotranspiration in the chosen period. Then aridity index for the period is given by:

$$AI = P/PET$$

Indices that require other parameters as input:

1. **PET-PMFAO** – Penman Monteith potential evapotranspiration

PET based on Penman Monteith method simplified for reference crop by FAO (Allen et al. 1998):

$$ET = \{0.408\ \Delta\ (R_n - G) + \gamma\ [900/(T + 273)]\ u_2\ (e_s - e_a)\} / \{\ \Delta\ + \gamma(1+0.34u_2)\}$$

R_n- net radiation at the crop surface (MJ m^{-2} day^{-1}),
G - soil heat flux density (MJ m^{-2} day^{-1}),
T - mean daily air temperature at 2 m height (°C),
u_2 - wind speed at 2 m height (m s^{-1}),
e_s - saturation vapour pressure (kPa),
e_a - actual vapour pressure (kPa),
e_s - e_a - saturation vapour pressure deficit (kPa),
Δ - slope vapour pressure curve (kPa $°C^{-1}$),
g - psychrometric constant (kPa $°C^{-1}$).

2. **PSMD** – Potential soil moisture deficit

The potential Soil Moisture Deficit is the cumulated soil water shortage during the growing season. To estimate PSMD, a water balance model is used:

$$PSMD_i = PSMD_{i-1} + ET_{0i} – P_i$$

$PSMD_i$ - the potential soil moisture deficit at the end of day i, mm
$PSMD_{i-1}$ - the potential soil moisture deficit at the end of day i–1, mm
ET_{0i} - the potential evapotranspiration in day i, mm
P_i - the precipitation in day i, mm

From beginning of the year, PSMD is assumed to be zero as long as the monthly precipitation exceeds the monthly PET, namely as long as soil moisture is fulfilled. Thereafter, while monthly ET_0 exceeds monthly precipitation, PSMD is cumulated month by month until a maximum PSMD is reached. The maximum PSMD is used as agro-climatic indicator.

2. Forests

Index	Name	Index	Name
MAT	Mean Annual Temperature	**GDD**	Growing Degree Days
APA	Annual Precipitation Amount	**CDD**	Consecutive Dry Days
ATR	Annual Temperature Range	**WD**	Warm/Dry
APR	Annual Precipitation Range	**EQ**	Ellenberg's Climate Quotient
GSL	Growing Seasonal Length	**FAI**	Forest Aridity Index

1. **MAT** - mean annual temperature: mean temperature for the year

    Let TG_{ij} be the mean temperature at day i of year j. Then mean values in period j are given by:

$$TG_j = \sum_{i=1,I} TG_{ij} / I$$

2. **APA** - annual precipitation amount: total precipitation in a year

    Let RR_{ij} be the daily precipitation amount on a day i in year j. Then:

$$APA = sum\ (RR_{ij})$$

3. **ATR** - annual temperature range: difference between annual absolute maximum and annual absolute minimum temperature

    Let TX_i be the daily maximum and TN_i minimum temperature at day i of the year. Then the annual temperature range is:

$$ATR = max\ (TX_i) - min\ (TN_i)$$

4. **APR** - annual precipitation range: difference between maximum monthly and minimum monthly precipitation

    Let P_j be the precipitation amount for month j:

$$P_j = \sum_{i=1,I} RR_i$$

    Then the annual precipitation range is:

$$APR = max\ (P_j) - min\ (P_j)$$

5. **GSL** - growing season length: annual count of days between first span of at least six days where TG > 5°C and first span in second half of the year of at least six days where TG < 5°C

    Let TG_{ij} be the daily mean temperature on day i in period j. Count the annual (1 Jan to 31 Dec) number of days between the first occurrence of at least six consecutive days where $TG_{ij} > 5°C$ and the first occurrence after 1 July of at least six consecutive days where $TG_{ij} < 5°C$.

6. **GDD** – growing degree days: the number of temperature degrees above a threshold base temperature (10°C) in a chosen period.

$$T_b = 10°C$$
$$GDD_i = TG_i - T_b \quad \text{if } T_b < TG_i$$
$$GDD_i = 0 \quad \text{if } T_b \geq TG_i$$

$$GDD = \sum_{i=1,I} GDD_i$$

7. **CDD** – consecutive dry days: maximum length of dry spell

    Count the largest number of consecutive days in chosen period where RR < 1 mm.

8. **WD** - warm/dry: number of days with TG > 75th percentile and RR < 25th percentile

    Let TG_{ij} be the daily mean temperature at day i of period j and let $TG_{in}75$ be the calendar day 75th percentile calculated for a 5-day window centred on each calendar day in the 1961–1990 period. Let RR_{wj} be the daily precipitation amount at wet day w (RR ≥ 1.0 mm) of period j and let $RR_{wn}25$ be the 25th percentile of precipitation at wet days in the 1961–1990 period. Then counted is the number of days in the chosen period where:

$$TG_{ij} > TG_{in}75 \text{ and } RR_{wj} < RR_{wn}25$$

9. **EQ** - Ellenberg's climate quotient: explains the connection between the distribution of beech and soil humidity.

    EQ is defined by a simple equation in which the mean temperature of the warmest month (in °C) is divided by the annual precipitation amount (in mm) and multiplied by 1000

$$EQ = (T_{vii} / P_{annual}) * 1000$$

10. **FAI** - forest aridity index:

    The ratio of the average temperature of the critical months (July and August) and the precipitation sums in main growth cycle (May to July) plus the precipitation sums in the critical months (from July to August)

$$FAI = 100 * T_{vii-viii} / (P_{v-vii} + P_{vii-viii})$$

Index that require other parameters as input:

1. **KBDI** – Keetch-Byram drought index:

    KBDI is a soil/duff drought index that ranges from 0 (no drought) to 200 (extreme drought) and is based on soil capacity of 200 mm of water (Keetch and Byram, 1968). Factors in the index are maximum daily temperature, daily precipitation, antecedent precipitation, and annual precipitation.

$$A = [203.2 – Q] [0.968 \exp (0.0875TX + 1.5552) – 8.30] d\tau$$
$$B = 1+ 10.88 \exp (-0.001736 R)$$
$$dQ = 10^{-3} A / B$$

dQ – drought factor (mm)
Q – moisture deficiency (mm)
R – mean annual precipitation (mm)
d τ – time increment (days)

Q is equal to drought factor of previous day reduced by the daily net precipitation.

2. **FFWI** - Canadian forest fire weather index

3. Hydrology

Index	Name	Index	Name
CID	Consecutive Ice Days	**CDD**	Consecutive Dry Days
PRCPTOT	Total precipitation in wet days	**SPI12**	Standardized Precipitation Index
R50mm	n° of days with RR ≥ 50mm	**SPEI12**	Standardized Precipitation-Evapotranspiration Index
R100mm	n° of days with RR ≥ 100mm		

1. **CID** – consecutive ice days: maximum number of consecutive ice days
   Count the largest number of consecutive days in chosen period where TX < 0°C

2. **PRCPTOT**: total precipitation in wet days
   Let RR_{wj} be the daily precipitation amount on a wet day (RR ≥ 1 mm) in chosen period j. Then:

$$PRCPTOT_j = \text{sum}\,(RR_{wj})$$

3. **R50mm:** precipitation days with RR ≥ 50 mm
   Count the number of days in chosen period where $RR_{ij} \geq 50$ mm

4. **R100mm:** precipitation days with RR ≥ 100 mm
   Count the number of days in chosen period where $RR_{ij} \geq 100$ mm

5. **CDD** – consecutive dry days: maximum length of dry spell
   Count the largest number of consecutive days in chosen period where RR < 1 mm.

6. **SPI12** - Standardized Precipitation Index
   Computation of the SPI involves fitting a Gamma probability density function to a given frequency distribution of precipitation totals for a station. The alpha and beta parameters of the Gamma probability density function are estimated for each station, for time scale of 3 months and for each month of the year based on the referent period 1961-1990. The distribution is defined by its probability density function:

$$g(P) = (1/\beta^{\alpha}\,\Gamma(\alpha))\ \ P^{(\alpha-1)}\,\exp(-P/\beta)\ \ \text{for}\ \ P > 0$$

   α, β - the shape and scale parameters respectively,
   P - precipitation amount and
   $\Gamma(\alpha)$ - the gamma function.

   α and β can be estimate from climatology using maximum likelihood method:

$$\alpha = 1 / (4A)\ \{1 + \sqrt{(1+4A/3)}\}\ ;\ A = \ln(P_{mean}) - \sum_i \ln(P_i) / n$$

$$\beta = P_{mean} / \alpha$$

   P_{mean} – mean precipitation amount,

P_i – precipitation amount for time scale 12 months and for each month of the year in climatological period (1961-1990), and
n - number of observations.

The resulting parameters are then used to find the cumulative probability of an observed precipitation event for the given month and time scale for the station in question. Since g(P) is undefined for P=0 and a precipitation distribution may contain zeros, the cumulative probability becomes:

$$H(P) = q + (1-q)G(P)$$

q - the probability of a zero, and
G(P) - the cumulative density function of Gamma distribution.
If m is the number of zeros in a precipitation time series, then q can be estimated by:

$$q = m/n$$

Then SPI can be obtained by:

$$SPI = - \{t - (c_0 + c_1 t + c_2 t^2) / (1 + d_1 t + d_2 t^2 + d_3 t^3)\} \quad \text{for } 0 < H(P) \leq 0.5$$

$$SPI = + \{t - (c_0 + c_1 t + c_2 t^2) / (1 + d_1 t + d_2 t^2 + d_3 t^3)\} \quad \text{for } 0.5 < H(P) < 1$$

$$t = \sqrt{\ln [1 / (H(P)^2)]} \quad \text{for } 0 < H(P) \leq 0.5$$

$$t = \sqrt{\ln [1 / (1 - H(P))^2]} \quad \text{for } 0.5 < H(P) < 1$$

c0 =2.515517 d_1 =1.432788
c1 =0.802853 d2 =0.189269
c2 =0.010328 d3 =0.001308

Table 5. Classification by SPI values

SPI value	***Category***
> 2.0	Extremely wet
1.5 – 2.0	Severely wet
1.0 – 1.5	Moderately wet
-1.0 – 1.0	Near normal
-1.5 - -1.0	Moderately dry
-2.0 - -1.5	Severely dry
< -2.0	Extremely dry

Definition and method of calculation can be found in e.g. McKee (1993) and Loukas (2004).

7. **SPEI12** - Standardized Precipitation-Evapotranspiration Index
Computation of the SPEI involves fitting a three parameter Log-logistic probability density function to a given frequency distribution of difference between precipitation

and Thornthwaites' potential evapotranspiration for a station. The parameters of the Log-logistic probability density function are estimated for each station, for time scale of 3 months and for each month of the year based on the referent period 1961-1990. The distribution is defined by its probability density function:

$$g(D) = \beta/\alpha\ [(D - \gamma) / \alpha]^{\beta-1} \{1 + [(D-\gamma) / \alpha]^{\beta}\}^{-2}$$

α, β, γ - scale, shape and origin parameters.

$$D_n = \sum_{i=0,k-1}(P_{n-i} - PET_{n-i})$$

k – timescale of the aggregation (12 months)
n - calculation month

The resulting parameters are then used to find the cumulative probability of an observed precipitation event for the given month and time scale for the station in question.

$$G(D) = \{1 + [\alpha / (D- \gamma)^{\beta}]\}^{-1}$$

G(D) - the cumulative density function of the Log-logistic function.

$$SPEI = W - (c_0 + c_1W + c_2W^2) / (1 + d_1W + d_2W^2 + d_3W^3) \quad \text{for } p \leq 0.5$$

$$SPEI = - \{W - (c_0 + c_1W + c_2W^2) / (1 + d_1W + d_2W^2 + d_3W^3)\} \quad \text{for } p > 0.5$$

$$W = \sqrt{[-2 \ln(p)]}$$

$$p = 1 - G(D) \quad ; \quad \text{if } p > 0.5 \Rightarrow p = 1-p$$

p - probability of exceeding a determined *D* value,

$c0 = 2.515517$ $d_1 = 1.432788$
$c1 = 0.802853$ $d2 = 0.189269$
$c2 = 0.010328$ $d3 = 0.001308$

Table 6. Classification by SPEI values

SPEI value	***Category***
> 2.0	Extremely wet
1.5 – 2.0	Severely wet
1.0 – 1.5	Moderately wet
-1.0 – 1.0	Near normal
-1.5 - -1.0	Moderately dry
-2.0 - -1.5	Severely dry
< -2.0	Extremely dry

Definition and method of calculation for SPEI can be found in Vicente-Serrano (2009).

Indices that require other parameters as input:

1. **SC** - snow cover: count the number of days in chosen period where snow depth is ≥ 1cm

2. **SWE** - Snow water equivalent

   It is a measurement of the amount of water contained in snow pack. It can be considered as the depth of water that would theoretically result if the whole snow pack instantaneously melts. Snow Water Equivalent (SWE) is the product of snow depth and snow density:

   SWE (kg/m2) = snow depth (m) x snow density (kg/m3)

3. **Pct-RO** - runoff anomalies and percentiles

   The percentiles indicate a ranking of runoff anomalies in the normal distribution fit of runoff events

4. **GRI** - Groundwater resource index

   The GRI (Mendicino et al, 2008) is derived from a simple distributed water balance model: if the sum of precipitation P plus snow melt is greater than the sum of evapotranspiration (ET) plus precipitation transformed in snow accumulation, then the water comes to fill the root zone reservoir. If this reservoir is completely filled, then the water surplus S is subdivided in surface runoff αS and groundwater recharge (1 − α)S. The groundwater detention reservoir (D) generates a monthly groundwater runoff equal to D times β (groundwater reservoir constant).

   GRI is calculated as:

$$GRI_{y,m} = [D_{y,m} - \mu_{D,m}] / \sigma_{D,m}$$

   $GRI_{y,m}$ - the values of the index for the year y and month m

   $D_{y,m}$ - the values of the groundwater detention for the year y and month m

   $\mu_{D,m}$ - the mean of groundwater detention for the month m in a defined number of years

   $\sigma_{D,m}$ - standard deviation of groundwater detention for the month m in a defined number of years.

5. **SDI** - Streamflow drought index

   The SDI (Nalbantis and Tsakiris, 2009) is defined for each reference period k of the i-th hydrological year as:

$$SDI_{i,k} = (V_{i,k} – V_{mk}) / s_k$$

   $V_{i,k}$ - the cumulative streamflow volume for the i-th hydrological year and the k-th reference period, k = 1 for October_December, k = 2 for October-March, K = 3 for October –June and k = 4 for October-September

   V_{mk} - the mean of cumulative streamflow volumes

   s_k - the standard deviation of cumulative streamflow volumes

Table 7. Definition of states of hydrological drought with the aid of SDI

Criterion	*Description*	*State*
≥ 0.0	Non-drought	0
-1.0 – 0.0	Mild drought	1
-1.5 - -1.0	Moderate drought	2
-2.0 - -1.5	Severe drought	3
< -2.0	Extreme drought	4

6. **BFI** - Base Flow index

   The BFI (Institute of Hydrology, 1980) is the ratio of the base flow to the total flow. It is achieved considering observed daily runoff values, subdivided in contiguous groups with dimension n = 5 day.

7. **SYC** - Storage yield curves

   Monthly inflows series from the hydrological analysis at sub-basin level allow calculation of storage yield curves (SYCs) for each sub-basin, indicating the storage capacity needed to provide a given basin yield or, alternatively, the firm basin yield produced from a given level of water storage. SYCs can be built with reference to Sequent Peak Algorithm (SPA; Thomas & Burden 1963). SYCs are useful to consider the combined effect of annual flow amount and inter-annual variability for a hypothetic reservoir put at the outlet of each sub-basin. Unlike runoff, reservoir yield provides information on the variability or accessibility for water supply needs rather than annual availability alone (e.g. Strzepek et al. 2010).

4. Health

Index	Name	Index	Name
HW	Heat Waves	**WW**	Warm/Wet
CTD	Consecutive Tropical Days	**WSDI**	Warm Spell Duration Index
CTN	Consecutive Tropical Nights	**CSDI**	Cold Spell Duration Index
CID	Consecutive Ice Days		

1. **HW** - heat waves

   Number of days in intervals of at least 6 days with TX 5°C higher then mean calculated for each calendar day (on basis of 1961-1990) using running 5 day window.

2. **CTD** - consecutive tropical days: maximum number of consecutive tropical days

   Count the largest number of consecutive days in chosen period where TX > 30°C

3. **CTN** - consecutive tropical nights: maximum number of consecutive tropical nights

   Count the largest number of consecutive days in chosen period where TN > 20°C

4. **CID** - consecutive ice days: maximum number of consecutive ice days

   Count the largest number of consecutive days in chosen period where TX < 0°C

5. **WW** - warm/wet: number of days with TG > 75th percentile and RR > 75th percentile

   Let TG_{ij} be the daily mean temperature at day i of period j and let $TG_{in}75$ be the calendar day 75th percentile calculated for a 5-day window centred on each calendar day in the 1961–1990 period. Let RR_{wj} be the daily precipitation amount at wet day w (RR ≥ 1.0 mm) of period j and let $RR_{wn}75$ be the 75th percentile of precipitation at wet days in the 1961–1990 period. Then counted is the number of days in the chosen period where:

   $$TG_{ij} > TG_{in}75 \text{ and } RR_{wj} > RR_{wn}75$$

6. **WSDI** - warm spell duration index: count of days in a span of at least six days where TX > 90th percentile. Choose the maximum spell duration in a chosen period.

   Let TX_{ij} be the daily maximum temperature on day i in period j and let $TX_{in}90$ be the calendar day 90th percentile of daily maximum temperature calculated for a five-day window centred on each calendar day in the base period n (1961-1990). Count the number of days where, in intervals of at least six consecutive days $TX_{ij} > TX_{in}90$.

7. **CSDI** - cold spell duration index: count of days in a span of at least six days where TN > 10th percentile. Choose the maximum spell duration in a chosen period.

   Let TN_{ij} be the daily minimum temperature on day i in period j and let $TN_{in}10$ be the calendar day 10th percentile of daily minimum temperature calculated for a five-day window centred on each calendar day in the base period n (1961-1990). Count the number of days where, in intervals of at least six consecutive days $TN_{ij} < TN_{in}10$.

Indices that require other parameters as input:

1. UTCI - universal thermal climate index
2. PhET – physiologically equivalent temperature
3. HCI - human comfort index

Conclusion

We recommend that the chosen period is one year. In that way comparison of the future and the present climate can be done by comparing the 30 year average of the indicators. In addition, for the SPI calculation it is the best to use the same referent period for the parameter calculation in order to reserve the possibility to compare present and future outputs. Same rule applies for the SPEI calculation.

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