

# **Risk Estimation of Drought**

**( R E D v1.01 )**

**Tamás Szentimrey**

**Varimax Limited Partnership**

**Budapest, Hungary**

**e-mail: szentimrey.t@gmail.com**

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## **I. INTRODUCTION**

One of the aim of the DriDanube project is the drought risk assessment within WP5 and the main responsible partner of this activity is the Hungarian Meteorological Service.

However unfortunately there is no commonly accepted procedure for this purpose therefore it was necessary to review and prepare the mathematical methodology that can be applied for drought risk assessment in this project.

Varimax Limited Partnership as a subcontractor of the Hungarian Meteorological Service undertook to develop the mathematical methodology and the software.

The elaborated mathematical methodology is described in the deliverable D5.2.1: Algorithm of drought risk assessment.

This D5.2.1 is the mathematical background of this software RED (Risk Estimation of Drought) that is developed for the deliverable D5.2.2: Software of drought risk calculation.

## II. MATHEMATICAL BACKGROUND

### 1. Estimation of drought risk based on estimated yield function and SPI series

According to the formula (14) at Section 4 in D5.2.1, the estimation of the meteorological drought risk using estimated yield function  $\hat{Y}(\mathbf{X}(\mathbf{s}, t))$  and  $SPI(\mathbf{s}, t)$  series can be written as,

$$\hat{Risk}(\mathbf{s}) = \hat{P}_D \cdot \left( \left( \frac{1}{n - n_D} \sum_{SPI(\mathbf{s}, t) \geq C_p} \hat{Y}(\mathbf{X}(\mathbf{s}, t)) \right) - \left( \frac{1}{n_D} \sum_{SPI(\mathbf{s}, t) < C_p} \hat{Y}(\mathbf{X}(\mathbf{s}, t)) \right) \right) \quad (1)$$

where  $\hat{P}_D$  is the estimated probability of drought and  $C_p$  is the critical value belonging to this probability. The final result of this methodology can be summarized such as the estimated drought risk is the product of the probability of drought and the estimated conditional expectation of the loss given drought. We remark that instead of SPI optional drought index or drought definition can be used!

### 2. Regression model for the relative yield function

According to the formula (16) at Section 5 in D5.2.1 the regression model is,

$$\hat{Y}_{rel}(\mathbf{X}(\mathbf{s}, t)) = \alpha_1 \cdot (\ln X_1(\mathbf{s}, t) - E_{ln,1}(\mathbf{s})) + \alpha_2 \cdot (X_2(\mathbf{s}, t) - E_2(\mathbf{s})) \quad (2)$$

where  $\hat{Y}_{rel}(\mathbf{X}(\mathbf{s}, t))$  is the relative yield function in percent (D5.2.1,(15)),  $X_1(\mathbf{s}, t)$  is precipitation sum and  $X_2(\mathbf{s}, t)$  is temperature mean for a given 3 or 6 months period. Furthermore there are the appropriate expected values  $E_{ln,1}(\mathbf{s})$ ,  $E_2(\mathbf{s})$  varying in space.

The common coefficients  $\alpha_1, \alpha_2$  can be estimated by the method of least squares.

At this software the variables are, YieldPercent= $\hat{Y}_{rel}(\mathbf{X}(\mathbf{s}, t))$ , precipitation index PI= $\ln X_1(\mathbf{s}, t) - E_{ln,1}(\mathbf{s})$ , temperature index TI= $X_2(\mathbf{s}, t) - E_2(\mathbf{s})$  and standardized precipitation index SPI= $SPI(X_1(\mathbf{s}, t))$ . At the risk estimation formula (1) this  $SPI(X_1(\mathbf{s}, t))$  can be applied in accordance with Remark1 at Section 5 in D5.2.1. Then we can evaluate the connection and signification of the different type SPI series with the real drought loss.

At this software there is possibility to examine several SPI series with various periods. These examinations can be implemented for several 3 or 6 months periods and the estimated regression coefficients  $\alpha_1, \alpha_2$  are included by the parameter files Reg{.}.par in the subdirectory RED\RiskCalculation\RegPar. These parameter files are given for four plants: maize, wheat, rape and barley. Detailed information can be found at Section VI.

### III. THE STRUCTURE OF PROGRAM SYSTEM

Main Directory: **RED**

- Subdirectory **IndexCalculation**
  - Subdirectory **SPI** (for Standard Precipitation Index SPI)
    - Subdirectory **SPicalc**
      - Main Program Files
      - Subdirectory sub (do not use it including subroutines)
      - Subdirectory work (do not use it)
    - Subdirectory **SPiselect**
      - Main Program Files
      - Subdirectory sub (do not use it including subroutines)
  - Subdirectory **RegressionIndeces**
    - Subdirectory **PI** (for Precipitation Index PI)
      - Subdirectory **Picalc**
        - Main Program Files
        - Subdirectory sub (do not use it including subroutines)
        - Subdirectory work (do not use it)
      - Subdirectory **Piselect**
        - Main Program Files
        - Subdirectory sub (do not use it including subroutines)
    - Subdirectory **TI** (for Temperature Index TI)
      - Subdirectory **Ticalc**
        - Main Program Files
        - Subdirectory sub (do not use it including subroutines)
        - Subdirectory work (do not use it)
      - Subdirectory **Tiselect**
        - Main Program Files
        - Subdirectory sub (do not use it including subroutines)
  - Subdirectory **IndexReCalibration**(for SPI, PI, TI together)
    - Main program files
    - Subdirectory sub (do not use it including subroutines)
  - Subdirectory **RiskCalculation**
    - Main Program Files
    - Subdirectory **RegPar**
    - Subdirectory **RiskYD**

Directory **Example**

- Example for the main Input/Output files

## **IV. THE MAIN STEPS OF RISK ESTIMATION**

### **1. INDEX CALCULATION**

#### **1.1.1 SPI calculation for 12 months**

Input: PrecMonthly.ser  
(station or gridded) monthly precipitation series for 12 months in one file,  
max: 200 year, max: 10000 stations or grid points;  
Calibration period; Run lengths (3 and 6 are suggested)

Output: series SPI{J}.ser (J run length) for 12 months; SPI.par

Run1: IndexCalculation\SPI\SPICALC\StartSPI.bat

Run2: IndexCalculation\SPI\SPICALC\MonthlySPI.bat  
(by using SPI\_monthly\_CP.exe from DMCSEE for one location)

Run3: IndexCalculation\SPI\SPICALC\CopyCalcSelect.bat

#### **1.1.2 Selection of SPI for given month**

Input: SPI{J}.ser, SPI.par (copied from 1.1.1 automatically); M (index of month)

Output: series SPI.ser for run length J and month M; LastSPI.txt

Run: IndexCalculation\SPI\SPiselect\SelectSPI.bat

#### **1.2.1 PI calculation for 12 months**

Input: PrecMonthly.ser (same as at 1.1.1); SPI.par (copied from 1.1.1 automatically)  
Calibration period, Run lengths (automatic 1.1.1 SPI parametrization is suggested)

Output: series PI{J}.ser (J run length) for 12 months, PI.par

Run1: IndexCalculation\RegressionIndeces\PI\PIcalc\MonthlyPI.bat

Run2: IndexCalculation\RegressionIndeces\PI\PIcalc\CopyCalcSelect.bat

#### **1.2.2 Selection of PI for given month**

Input: PI{J}.ser, PI.par (copied from 1.2.1 automatically); M (index of month)

Output: series PI.ser for run length J and month M; LastPI.txt

Run: IndexCalculation\RegressionIndeces\PI\PIselect\SelectPI.bat

#### **1.3.1 TI calculation for 12 months**

Input: TempMonthly.ser  
Monthly temperature series for 12 months in one file, for the same locations and time as  
PrecMonthly.ser at 1.1.1.; SPI.par (copied from 1.1.1 automatically)  
Calibration period, Run lengths (automatic 1.1.1 SPI parametrization is suggested)

Output: series TI{J}.ser (J run length) for 12 months, TI.par

Run1: IndexCalculation\RegressionIndeces\TI\TIcalc\MonthlyTI.bat

Run2: IndexCalculation\RegressionIndeces\TI\TIcalc\CopyCalcSelect.bat

### 1.3.2 Selection of TI for given month

Input: TI{J}.ser, TI.par (copied from 1.3.1 automatically); M (index of month)

Output: series TI.ser for run length J and month M; LastTI.txt

Run: IndexCalculation\RegressionIndeces\TI\TIselect\SelectTI.bat

### 1.4 Recalibration of indeces SPI, PI, TI

Input: SPI.ser, PI.ser, TI.ser with same parametrization (run length, month);  
new calibration period; SPI.par (copied from 1.1.1 automatically)

Output: SPI.ser, PI.ser, TI.ser with the new calibration period;  
Calibration.stat (some control statistics)

Run: IndexCalculation\IndexReCalibration\Calibration.bat

## 2. RISK CALCULATION

### 2.1 Regression of relative crop yield

Input: SPI.ser, PI.ser, TI.ser (copied from 1.1.2, 1.2.2, 1.3.2 automatically);  
SPI.par (copied from 1.1.1 automatically); Reg.par (to be copied from subdir RegPar);  
Index of regression on Reg.par; time interval of estimation

Output: YieldPercent.ser (series of estimated relative crop yield (%));  
Risk.par, work.ser

Run: RiskCalculation\YieldRegression.exe

### 2.2 Definition of drought by SPI

Input: SPI.ser, Risk.par; probability of drought (0.3, 0.25, 0.2, 0.15, 0.1, 0.05)

Output: DroughtSPI.ser (indicator series of drought defined by SPI and probability:  
drought: 1, no drought: 0), Risk.par

Run: RiskCalculation\DroughtSPI.exe

### 2.3 Estimation of risk on the basis of regression (2.1) and drought (2.2)

Input: YieldPercent.ser, DroughtSPI.ser, Risk.par

Output: Risk.res (estimated expected loss (%) and risk values)

Run: RiskCalculation\RiskCalc.exe

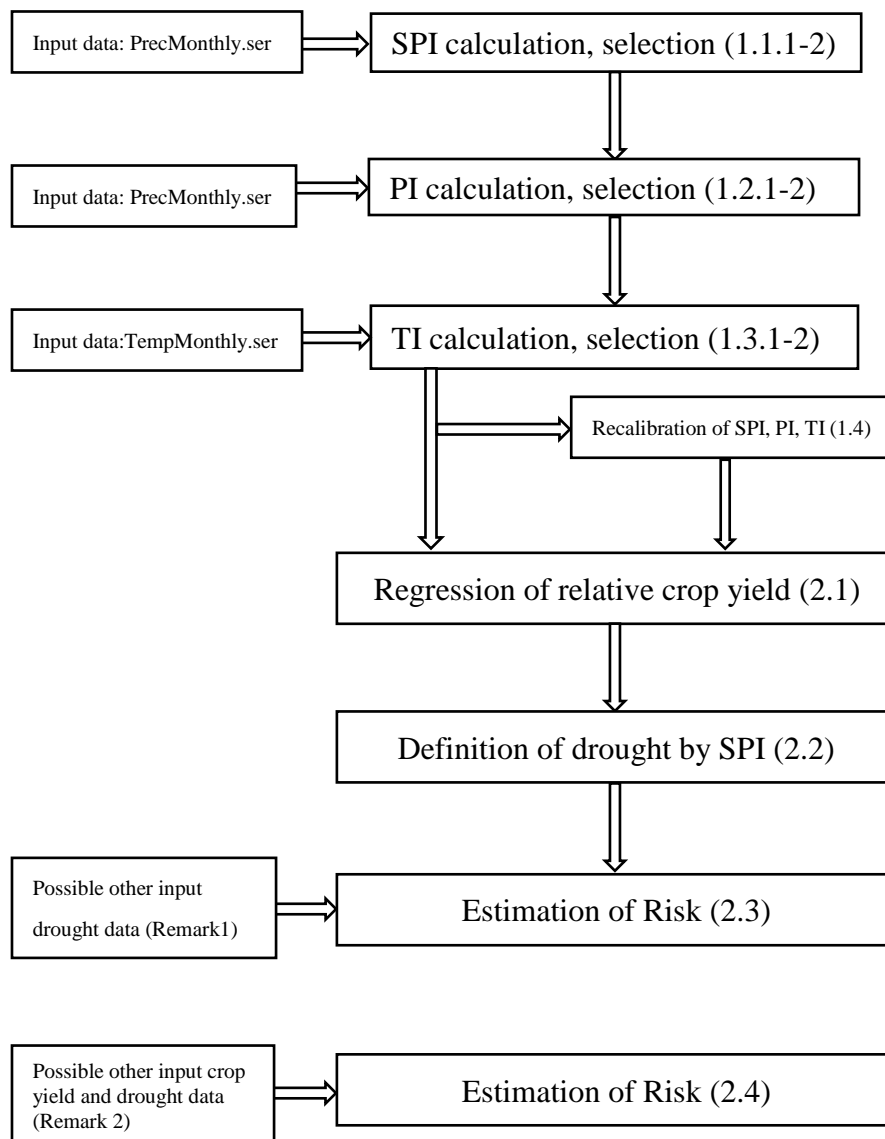
### Remark 1

We had the remark at Section II.1 that instead of SPI optional drought index or drought definition can be used! In this case at step 2.3 the input file DroughtSPI.ser has to be replaced with other indicator series (0-1) of drought. The format of this input file can be seen on Fig.7 at Section V. The probability of drought must be given on the parameter file Risk.par whose format in the first row: value 1, number of locations (I6); value 2, first year (i6); value 3, last year (i6); value 3, probability of drought (f6.2).

Another possibility is to run: RiskCalculation\RiskDP.exe

Input: YieldPercent.ser, Drought.ser (same as 2.4);

Output: RiskDP.res (similar as RiskYDP.res at 2.4)



**Figure 1. Flow diagram for steps 1.1-2.3 or 2.4**

### **Remark 2**

We did not intend to develop a general crop-weather model for the project region that would have been beyond our possibilities of course. Our intention was to estimate an expected value only i.e. the risk instead of a more precise crop yield estimation. Therefore a not too complicated regression model was acceptable for our aim. However in case of having crop-weather model and identification of drought with good quality then these values can be used according to the formula (10) at Section 3 in D5.2.1 by the following program.

### **2.4 Estimation of risk on the basis of given yield and drought**

Input: Yield.ser (crop yield series), Drought.ser (indicator series of drought)

Output: RiskYDP.res

(estimated expected loss and risk values with probabilities of drought (PD))

Run: RiskCalculation\RiskYD\RiskYDP.exe

## V. THE MAIN INPUT/OUTPUT FILES

**Input Files:** PrecMonthly.ser, TempMonthly.ser, Reg.par (see Section V.)

### Output Files:

SPI.ser, PI.ser, TI.ser: index series

YieldPercent.ser: series of estimated relative crop yield (%)

DroughtSPI.ser: indicator series of drought defined by SPI and probability

Risk.res: estimated expected loss (%) and risk values

### Format of PrecMonthly.ser, TempMonthly.ser:

Many years' monthly data series without missing values (max. number of series: 10000, max. number of years: 200)

row 1: station number or index, or grid index (obligatory!), Format: I8

column 1: date of year (I4)

column 2: month (I3)

column i+2: series i.

Data Format: F8.2 (See the Data Files of EXAMPLE)

### Example: monthly data series (1961-2010) for 10 locations

		1	2	3	4	5	6	7	8	9	10
1961	1	29.67	27.39	24.43	22.51	22.33	19.49	20.14	20.47	20.08	18.07
1961	2	25.64	22.19	21.51	23.08	22.71	19.45	18.16	20.03	17.98	16.28
1961	3	9.64	9.21	11.01	14.75	15.31	14.88	13.31	10.11	10.16	9.62
.....											
2010	9	144.19	131.40	123.81	104.35	94.68	91.29	86.79	96.30	89.50	81.86
2010	10	25.65	18.82	20.80	21.14	22.78	25.82	24.03	20.57	21.40	18.84
2010	11	89.75	81.23	77.79	71.30	68.30	64.54	61.42	73.56	76.09	70.87
2010	12	91.66	87.52	78.19	74.91	73.52	69.04	75.50	89.41	87.48	79.60

**Figure 1. Format of input file PrecMonthly.ser**

		1	2	3	4	5	6	7	8	9	10
1961	1	-3.34	-3.95	-4.15	-3.92	-3.72	-3.60	-2.98	-3.04	-4.44	-4.76
1961	2	-0.62	-0.95	-1.24	-0.86	-0.77	-0.49	0.08	-0.08	-1.27	-1.39
1961	3	5.95	6.17	5.71	6.02	5.99	6.24	6.77	6.37	5.56	5.28
.....											
2010	9	13.20	12.90	13.26	13.69	13.64	14.26	13.92	13.08	12.74	13.78
2010	10	6.78	6.31	6.49	6.89	6.91	7.37	7.31	6.85	6.03	6.79
2010	11	6.72	6.79	6.52	6.82	6.78	7.08	7.40	7.22	6.53	6.50
2010	12	-3.64	-3.93	-4.13	-3.65	-3.35	-2.90	-2.26	-2.45	-3.74	-3.74

**Figure 2. Format of input file TempMonthly.ser**

Calibration period: 1961-1990					Month: 8	spi6.ser				
	1	2	3	4	5	6	7	8	9	10
1961	-1.66	-1.60	-1.88	-1.73	-1.76	-1.86	-2.00	-2.57	-1.94	-2.10
1962	-1.28	-1.15	-1.13	-1.06	-0.92	-1.26	-1.34	-1.12	-1.23	-1.21
1963	-0.06	-0.32	-0.41	-0.50	-0.66	-1.04	-1.20	-1.20	-1.42	-1.27
.....										
2008	-0.04	-0.29	-0.43	-0.32	-0.48	0.13	0.28	0.65	0.95	1.00
2009	-0.58	-0.51	-0.45	-0.35	-0.33	-0.42	-0.58	-0.45	-1.26	-1.14
2010	2.58	3.10	2.83	2.78	2.50	2.52	2.62	2.47	2.87	3.27

**Figure 3. Format of output file SPI.ser**



```

Calibration period: 1961-1990   Month: 8   pi6.ser
      1      2      3      4      5      6      7      8      9      10
1961 -0.44 -0.41 -0.50 -0.46 -0.47 -0.51 -0.55 -0.81 -0.50 -0.54
1962 -0.33 -0.29 -0.28 -0.27 -0.23 -0.33 -0.36 -0.32 -0.30 -0.29
1963  0.00 -0.07 -0.09 -0.12 -0.16 -0.27 -0.31 -0.34 -0.35 -0.31
.....
2008  0.00 -0.06 -0.10 -0.07 -0.11  0.04  0.08  0.19  0.23  0.24
2009 -0.14 -0.12 -0.10 -0.08 -0.07 -0.10 -0.14 -0.12 -0.31 -0.27
2010  0.59  0.69  0.64  0.64  0.58  0.59  0.62  0.64  0.63  0.70

```

**Figure 4. Format of output file PI.ser**

```

Calibration period: 1961-1990   Month: 8   ti6.ser
      1      2      3      4      5      6      7      8      9      10
1961  0.81  0.81  0.80  0.75  0.71  0.71  0.67  0.71  0.67  0.66
1962 -0.56 -0.54 -0.55 -0.59 -0.62 -0.65 -0.66 -0.64 -0.70 -0.71
1963  0.42  0.42  0.42  0.38  0.38  0.35  0.34  0.32  0.33  0.33
.....
2008  1.03  0.99  1.02  0.98  1.00  0.98  0.99  0.99  0.97  0.96
2009  1.44  1.47  1.50  1.51  1.53  1.55  1.57  1.59  1.58  1.58
2010  0.87  0.84  0.89  0.93  0.93  1.00  1.02  0.99  1.02  1.03

```

**Figure 5. Format of output file TI.ser**

```

MAIZE          Period of Months: 3 - 8          Yield(%)
      1      2      3      4      5      6      7      8      9      10
1961 -17.85 -17.19 -19.46 -17.30 -16.99 -18.74 -19.46 -27.04 -17.62 -18.66
1962  -0.02   0.72   1.35   2.54   4.19   1.02   0.26   1.61   2.82   3.23
1963  -0.90  -3.15  -3.49  -3.47  -4.46  -7.92  -8.97  -9.22  -9.63  -8.46
.....
2008  -7.42  -8.94 -10.19  -8.43  -9.64  -5.65  -4.58  -0.99   0.37   0.78
2009 -15.86 -15.81 -15.32 -14.38 -14.14 -15.81 -17.17 -16.40 -21.83 -20.65
2010  11.43  14.44  12.69  12.73  11.15  10.11  10.78  12.08  11.46  13.40

```

**Figure 6. Format of output file YieldPercent.ser**

```

Calibration period: 1961-1990   Month: 8   spi6.ser          Probability of Drought: 0.10
      1      2      3      4      5      6      7      8      9      10
1961   1      1      1      1      1      1      1      1      1      1
1962   1      0      0      0      0      0      1      0      0      0
1963   0      0      0      0      0      0      0      0      1      0
.....
2008   0      0      0      0      0      0      0      0      0      0
2009   0      0      0      0      0      0      0      0      0      0
2010   0      0      0      0      0      0      0      0      0      0

```

**Figure 7. Format of output file DroughtSPI.ser (drought: 1, no drought: 0)**

```

MAIZE          Period of Months: 3 - 8
Time Interval: 1961-2010
Probability of Drought: 0.10
Location   Loss(%)   Risk
      1      13.40   1.340
      2      17.36   1.736
      3      20.15   2.015
      4      24.67   2.467
      5      25.96   2.596
      6      22.29   2.229
      7      16.46   1.646
      8      26.73   2.673
      9      22.30   2.230
     10      24.13   2.413

```

**Figure 8. Format of output file Risk.res**

(Remark: Loss(%) is the estimated conditional expectation of the loss given drought.)

## VI. REGRESSION PARAMETER FILES (REG.PAR)

One of the key issues of the developed risk estimation methodology is the regression of the relative crop yield on the meteorological variables according to the formula I.(1). The type of the regression formula seems acceptable so we intended to estimate the unknown parameters  $\alpha_1, \alpha_2$  by the method of least squares.

Then the first step is collecting sample for the crop yield  $Yield(s, t)$  and the meteorological variables  $X_1(s, t), X_2(s, t)$ . Data requirements from project partners were impact data (crop yield) and meteorological data for sample of regression. For this purpose we used also detailed yield database (2001-2016) on about 1900 pilot sites in the Farm Accountancy Data Network (FADN) for the four main plants in Hungary: maize, wheat, rape and barley. As regards the reliable meteorological variables the precipitation and temperature series homogenized by method MASH (Szentimrey) were interpolated by method MISH (Szentimrey and Bihari) for the pilot sites.

The regression on the sample were implemented for the most important 3 or 6 months periods and the estimated regression coefficients  $\alpha_1, \alpha_2$  are included by the parameter files in the subdirectory RED\RiskCalculation\RegPar. These parameter files are given for four plants: maize, wheat, rape and barley. For example the RegMaize.par is the following.

MAIZE					
ind	nv	period	PI	TI	corr
1	2	9 - 2	32.275	0.030	0.285
2	2	10 - 3	25.697	0.949	0.246
3	2	11 - 4	32.281	3.209	0.298
4	2	12 - 5	14.468	0.486	0.136
5	2	1 - 6	23.351	-0.691	0.251
6	2	2 - 7	45.632	-0.864	0.429
7	2	3 - 8	29.044	-10.683	0.488
8	2	4 - 9	20.211	-12.006	0.427
9	2	9 -11	21.537	-5.143	0.374
10	2	10 -12	25.736	0.082	0.305
11	2	11 - 1	13.115	-1.469	0.162
12	2	12 - 2	0.004	1.284	0.067
13	2	1 - 3	7.177	0.766	0.114
14	2	2 - 4	18.144	3.139	0.303
15	2	3 - 5	11.509	-4.227	0.227
16	2	4 - 6	10.632	-14.004	0.399
17	2	5 - 7	28.579	-15.428	0.572
18	2	6 - 8	18.590	-14.386	0.578
19	2	7 - 9	15.508	-7.286	0.359

**Figure 1. Regression parameter file RegMaize.par**

### Notations of the parameter file:

ind: index of regression (input of RiskCalculation\YieldRegression.exe)

nv: number of independent variables

period: period of months (with length 3 or 6)

PI: coefficient  $\alpha_1$  of  $PI = \ln X_1(s, t) - E_{\ln,1}(s)$  at regression formula I.(2)

TI: coefficient  $\alpha_2$  of  $TI = X_2(s, t) - E_2(s)$  at regression formula I.(2)

corr: multiple correlation of the regression

Four parameter files (RegMaize.par, RegWheat.par, RegRape.par, RegBarley.par) can be found in the subdirectory RiskCalculation\RegPar. Before application please to copy and rename the actual parameter file into the directory RiskCalculation as Reg.par and during running of RiskCalculation\YieldRegression.exe choose the index of regression.

WHEAT					
ind	nv	period	PI	TI	corr
1	2	9 - 2	23.417	3.895	0.311
2	2	10 - 3	22.189	3.660	0.315
3	2	11 - 4	18.230	5.015	0.284
4	2	12 - 5	12.447	3.512	0.191
5	2	1 - 6	16.513	2.597	0.221
6	2	2 - 7	20.626	1.603	0.239
7	2	3 - 8	6.941	-7.539	0.290
8	2	4 - 9	-5.554	-12.447	0.285
9	2	9 -11	16.329	-1.430	0.330
10	2	10 -12	15.496	1.372	0.237
11	2	11 - 1	0.440	1.827	0.087
12	2	12 - 2	2.827	3.760	0.248
13	2	1 - 3	9.491	2.673	0.269
14	2	2 - 4	11.944	3.789	0.320
15	2	3 - 5	9.135	-2.852	0.218
16	2	4 - 6	-7.854	-15.451	0.369
17	2	5 - 7	-1.828	-12.801	0.409
18	2	6 - 8	-5.774	-10.448	0.316
19	2	7 - 9	4.262	-3.066	0.160

**Figure 2. Regression parameter file RegWheat.par**

RAPE					
ind	nv	period	PI	TI	corr
1	2	9 - 2	9.692	6.461	0.275
2	2	10 - 3	15.843	6.143	0.326
3	2	11 - 4	11.889	7.756	0.330
4	2	12 - 5	14.089	7.465	0.307
5	2	1 - 6	16.934	6.272	0.273
6	2	2 - 7	19.139	6.093	0.244
7	2	3 - 8	9.821	0.049	0.100
8	2	4 - 9	1.675	-4.271	0.110
9	2	9 -11	7.129	1.430	0.122
10	2	10 -12	6.400	4.107	0.176
11	2	11 - 1	-3.255	4.928	0.242
12	2	12 - 2	7.422	5.840	0.351
13	2	1 - 3	11.678	4.036	0.349
14	2	2 - 4	11.842	5.782	0.347
15	2	3 - 5	10.116	4.041	0.135
16	2	4 - 6	-8.130	-7.027	0.135
17	2	5 - 7	1.992	-6.853	0.195
18	2	6 - 8	-4.410	-6.811	0.168
19	2	7 - 9	6.560	-0.826	0.114

**Figure 3. Regression parameter file RegRape.par**

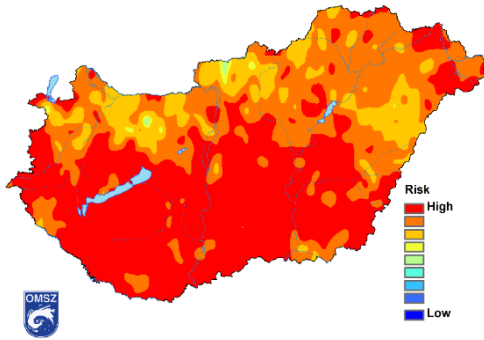
BARLEY					
ind	nv	period	PI	TI	corr
1	2	9 - 2	15.432	4.227	0.243
2	2	10 - 3	12.461	4.394	0.247
3	2	11 - 4	6.710	5.150	0.223
4	2	12 - 5	5.280	4.829	0.196
5	2	1 - 6	8.072	4.370	0.182
6	2	2 - 7	10.642	3.859	0.153
7	2	3 - 8	4.410	-2.322	0.110
8	2	4 - 9	-2.641	-5.558	0.120
9	2	9 -11	13.108	-1.447	0.252
10	2	10 -12	9.004	0.884	0.133
11	2	11 - 1	-3.471	2.485	0.137
12	2	12 - 2	-0.488	4.280	0.271
13	2	1 - 3	4.996	3.506	0.263
14	2	2 - 4	4.856	4.116	0.243
15	2	3 - 5	5.086	-0.021	0.081
16	2	4 - 6	-11.084	-10.521	0.220
17	2	5 - 7	-2.452	-7.090	0.206
18	2	6 - 8	-3.060	-4.797	0.134
19	2	7 - 9	7.214	0.937	0.104

**Figure 4. Regression parameter file RegBarley.par**

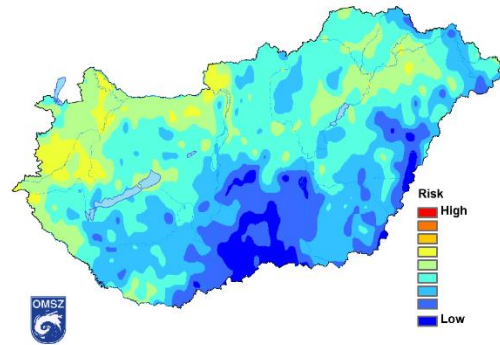
## VII. EXAMPLE: MAPPING OF RISK FOR HUNGARY

Some figures are presented below for illustration of mapping risk.

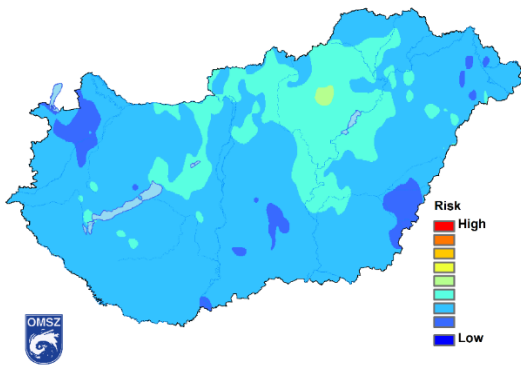
These risk maps were based on gridded data series. The risk calculation was implemented for a grid with spatial resolution  $0.1^\circ$  for Hungary and the output risk.res values are presented using the coordinates of the grid.



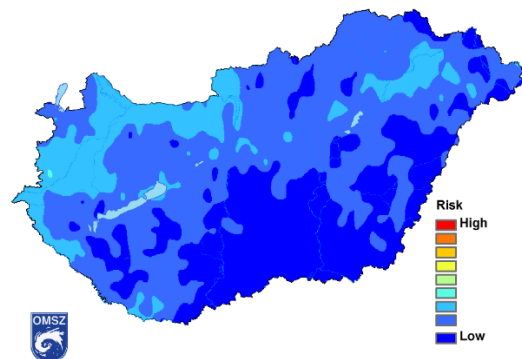
**Figure 1. Risk Map for Maize**  
(period: 5-7, drought probability: 0.2)



**Figure 2. Risk Map for Wheat**  
(period: 1-6, drought probability: 0.2)



**Figure 3. Risk Map for Rape**  
(period: 2-4, drought probability: 0.2)



**Figure 4. Risk Map for Barley**  
(period: 2-4, drought probability: 0.2)

## References

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