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# Mutual information applications to estimate the solar/ geomagnetic signatures in the drought indices in the Danube basin

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**ABSTRACT**

**The climatic condition for the dry or wet situations from 15 meteorological stations in the Danube basin has been evaluated using four indices: Palmer Drought Severity Index (PDSI), Palmer Hydrological Drought Index (PHDI), Weighted PDSI (WPLM) and Palmer Z-index (ZIND).**
**The overall temporal characteristic of the four indices has been analysed by means of the principal component of the Multivariate Empirical Orthogonal Functions decomposition (PC1-MEOF). Also, a simple drought index (TPPI) calculated as the difference between PC1 of the standardized temperature and precipitation, was considered.**
**To find the simultaneous influence of both solar and geomagnetic activities on drought indices in the Danube basin, the difference between synergistic and redundant components for each season was estimated, using the mutual information between the analyzed variables. The greater this difference is, the greater the simultaneous signature of the two variables in the drought indices is more significant, than by taking each of the two variables separately.**
**The solar activity was highlighted by Wolf numbers for the period 1901-2000 and for 1948-2000 by solar radio flux. For both periods the geomagnetic activity was quantified by the aa index.**
**The most significant results were obtained for 1948-2000. For this interval the consideration of the two predictors aa and solar flux in the simultaneous action leads to a gain of information on extreme events with a delay of two and three years.**

**Target:** In the present investigation, we focused on the solar/geomagnetic impact on the drought indices, which can influence the extreme events occurrence.

Response of the terrestrial variables to external factors was tested by means of the information theory. We applied the mutual information **to find the simultaneous influence of both solar and geomagnetic activities on drought indices in the Danube basin.**

Previous results of the authors related to the topics of this study are presented in: Demetrescu and Dobrica (2008), Dobrica et al. (2017), Mares et al. (2016ab,c), Mares et al. (2019), Mares et al. (2020).

## DATA

### *Solar/geomagnetic signal*

Solar activity was represented by Wolf numbers and 10.7cm solar flux and the geomagnetic activity by the *aa* index.

For the 100 years interval 1901-2000, the solar/geomagnetic activities are quantified by the sunspot number, retrieved from ftp://ftp.ngdc.noaa.gov/STP/space-weather/solar-data/solar-indices/ sunspot-numbers/ /international and, respectively, by the *aa* index. The latter describes the geomagnetic activity at mid-latitudes; it is available at http://isgi.cetp.ipsl.fr/lesdonne.htm. For the shorter time interval 1948-2000, the solar forcing is quantified by the solar radio flux at 10.7 cm (usually called F10.7 index). Since the 10.7 cm solar radio flux is a more objective measurement, and always measured on the same instruments, this proxy for "solar activity" should have a similar behavior but smaller intrinsic scatter than the sunspot number.

### *Drought indicators*

Climate variables defined at 15 stations (FIG. 1) : precipitation, temperature, drought indices quantified by four indices of Palmer type and a simple index calculated only from precipitation and temperature were considered.

We analyse four versions of Palmer index. Three of the Palmer indices used in the present study, namely the PDSI, the Palmer hydrological drought index (PHDI) and the Palmer Z index (ZIND), appear in the initial model proposed by Palmer (1965).The fourth index used is the modified PDSI (WPLM).

To see the composed influence of all four types of Palmer indices, for both the original (or) and the self-calibrating (sc), the procedure of development in multivariate EOF (MEOF) for each season were performed. Only the first principal component (PC1_MEOF) has been considered. Details in Mares et al.(2016).

Palmer's indices quantify the dry or the wet periods, in estimating ecological, hydrological and agricultural impact. Also the Palmer indices address two important issues of droughts: their intensity, their beginning and their end.

**A simple drought index (TPPI)** calculated as the difference between PC1 of the standardized temperature and precipitation, was also considered.
The analysis was achieved for two periods : 1901-2000 and 1948-2000.

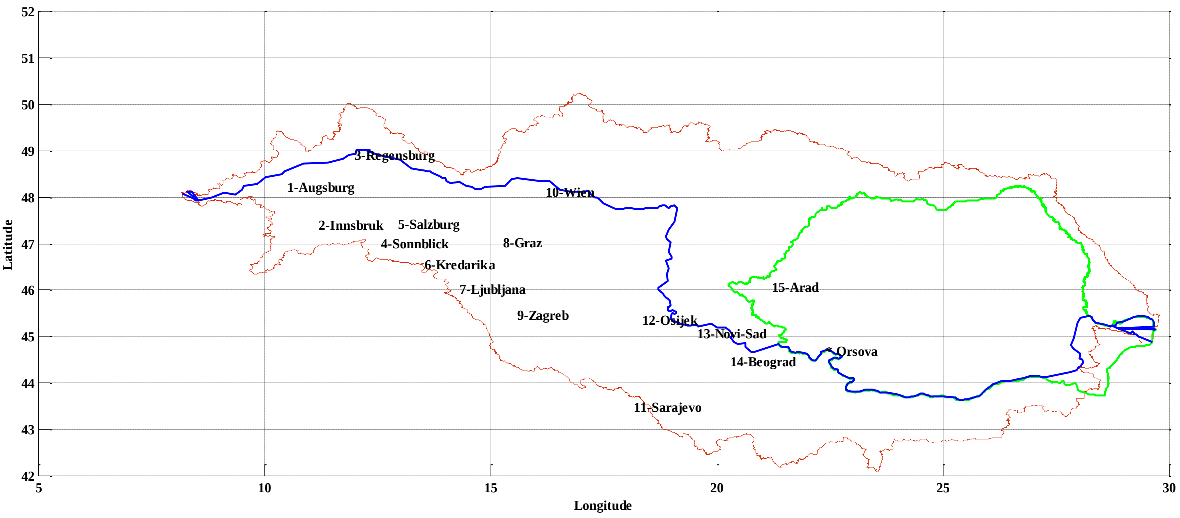


*Fig. 1. Localization of 15 stations situated in the Danube basin*

## METHODS

### *Mutual information (MI)*

$$MI(X,Y) = H(X) + H(Y) - H(X,Y) \qquad (1)$$

***H-*** information entropy (Shannon, 1948)

***S-R = Synergy (Y; $X_1$,$X_2$) – Redundancy (Y; $X_1$,$X_2$)***

$$S - R = MI\ (X_1, X_2; Y) - MI\ (X_1, Y) - MI\ (X_2, Y) \qquad (2)$$

**Total correlation (TC) in the mutual information** terms for 3  variables (Timme et al., , 2014) is:

$$TC = MI(X_1; X_2) + MI(X_1, X_2; Y) \quad (3)$$

**TC is a measure of the the total information between all variables.**

A performance analysis of predictors' contribution to predictand but also by reducing redundancy produced by predictors is achieved by simultaneous analysis of synergy and redundancy (eq.2). A negative value implies that the redundant contribution is greater in magnitude than the synergetic contribution.

## RESULTS

In Figure 2 are presented the results obtained for 3 drought indices, TPPI, original and self-calibrating Palmer drought indices, in response to the concomitant influence of two external factors, namely the geomagnetic index aa and solar activity expressed by solar flux, analysis performed for the period 1948-2000. Three variants were considered, the predictand (one of the drought indices) analyzed at the same moments (lag 0) as the predictors (aa and the solar flux), as well as the predictand considered with a delay from 1 to 3 years.

In Figure 2A, where the values of the difference between synergy (S) and redundancy (R) were presented, it is observed that the highest values are obtained in the case of TPPI for the winter season at Lag 1, for the Palmer index (or) in the winter season for Lag 1 and for Palmer (sc) in the spring season at Lag 3. These results are also confirmed by the TC values in Fig. 2B, where the highest value of TC is obtained for Palmer (sc) in the spring season at Lag 3.

Figures 3A and 3B show the values of S-R and TC corresponding to the three predictands, having as predictors aa and the Wolf number. These measures show that the combination aa and the Wolf number is less efficient than the combination aa and solar flux.

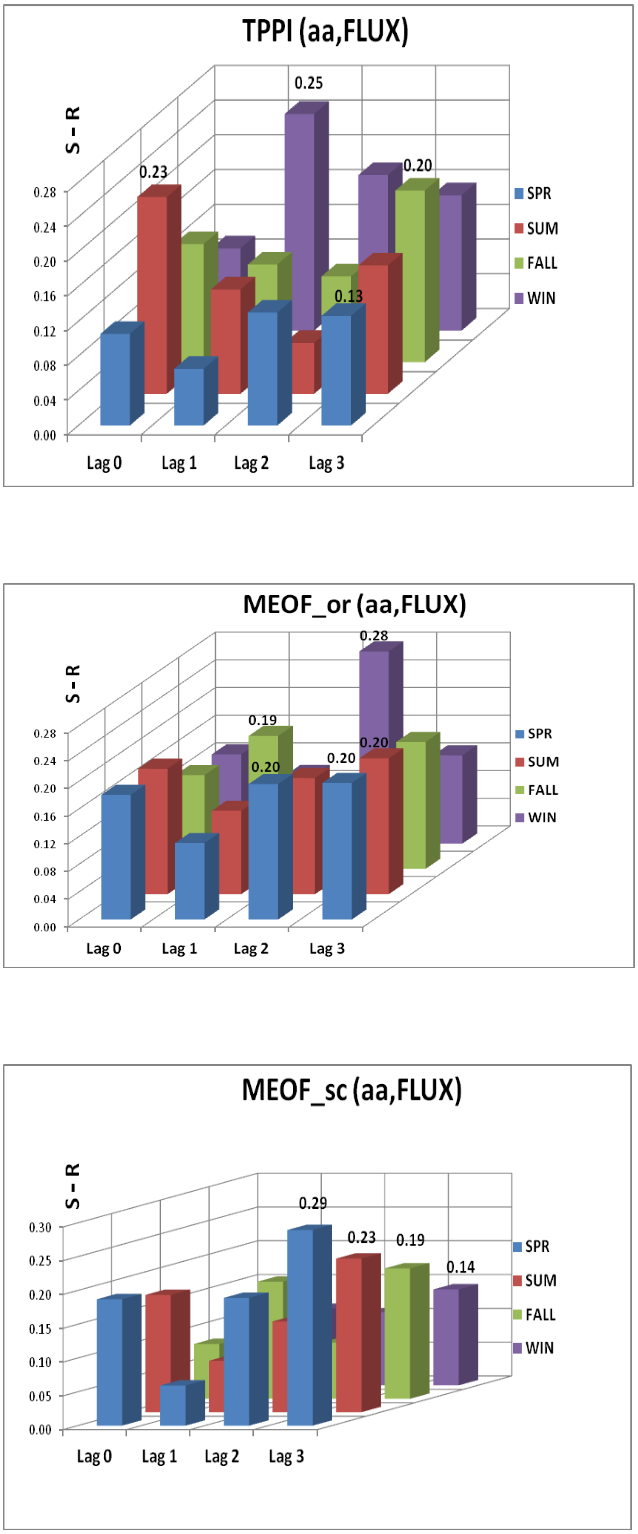
TPPI (aa,FLUX)
S - R
0.28
0.24
0.20
0.16
0.12
0.08
0.04
0.00
0.25
0.23
0.20
0.13
SPR
SUM
FALL
WIN
Lag 0
Lag 1
Lag 2
Lag 3
MEOF_or (aa,FLUX)
S - R
0.28
0.19
0.20
0.20
0.20
SPR
SUM
FALL
WIN
Lag 0
Lag 1
Lag 2
Lag 3
MEOF_sc (aa,FLUX)
S - R
0.30
0.25
0.20
0.15
0.10
0.05
0.00
0.29
0.23
0.19
0.14
SPR
SUM
FALL
WIN
Lag 0
Lag 1
Lag 2
Lag 3

FIG. 2A.

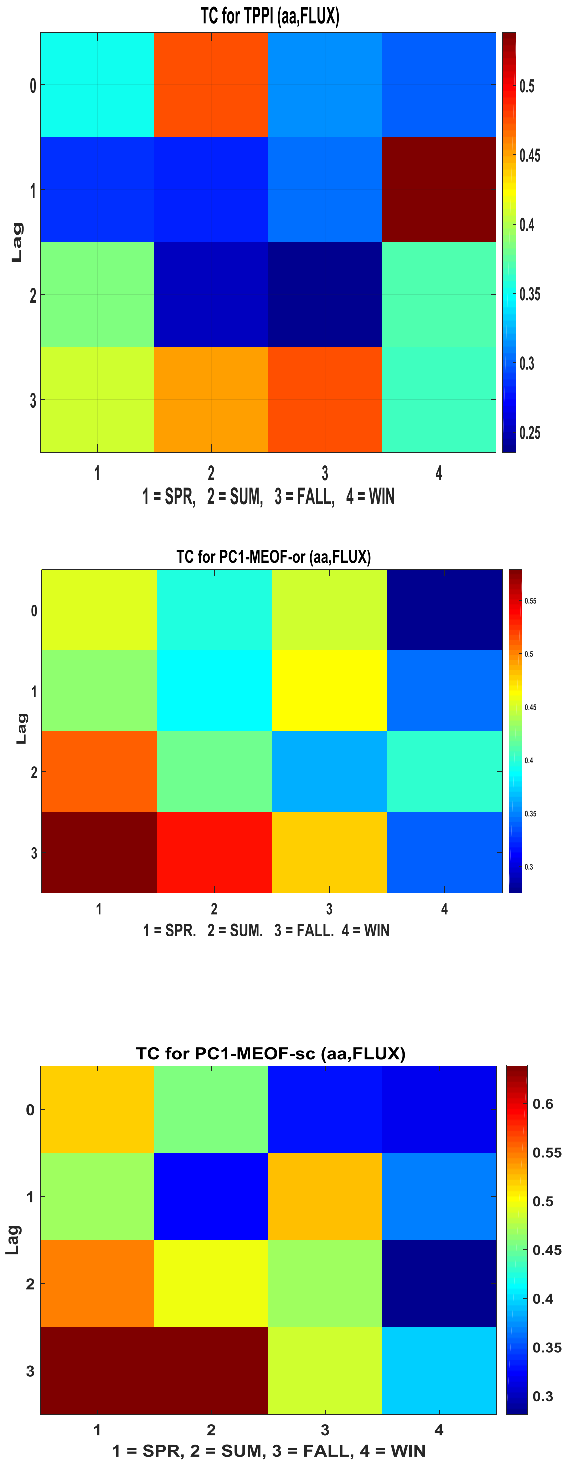
TC for TPPI (aa,FLUX)
Lag
1 = SPR, 2 = SUM, 3 = FALL, 4 = WIN
TC for PC1-MEOF-or (aa,FLUX)
Lag
1 = SPR. 2 = SUM. 3 = FALL. 4 = WIN
TC for PC1-MEOF-sc (aa,FLUX)
Lag
1 = SPR, 2 = SUM, 3 = FALL, 4 = WIN

FIG.2B.

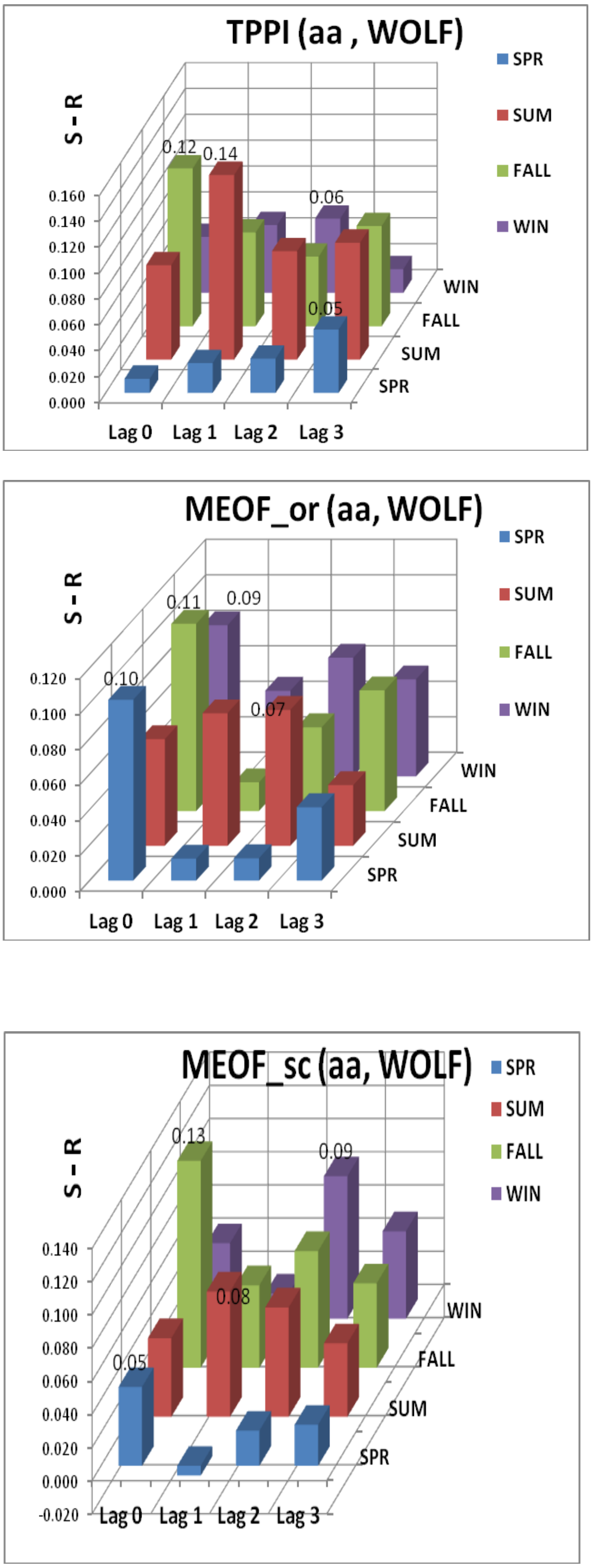
TPPI (aa , WOLF)
S - R
0.160
0.140
0.120
0.100
0.080
0.060
0.040
0.020
0.000
0.12
0.14
0.06
0.05
Lag 0
Lag 1
Lag 2
Lag 3
SPR
SUM
FALL
WIN
MEOF_or (aa, WOLF)
S - R
0.120
0.100
0.080
0.060
0.040
0.020
0.000
0.11
0.09
0.10
0.07
Lag 0
Lag 1
Lag 2
Lag 3
SPR
SUM
FALL
WIN
MEOF_sc (aa, WOLF)
S - R
0.140
0.120
0.100
0.080
0.060
0.040
0.020
0.000
-0.020
0.13
0.09
0.08
0.05
Lag 0
Lag 1
Lag 2
Lag 3
SPR
SUM
FALL
WIN

FIG. 3A.

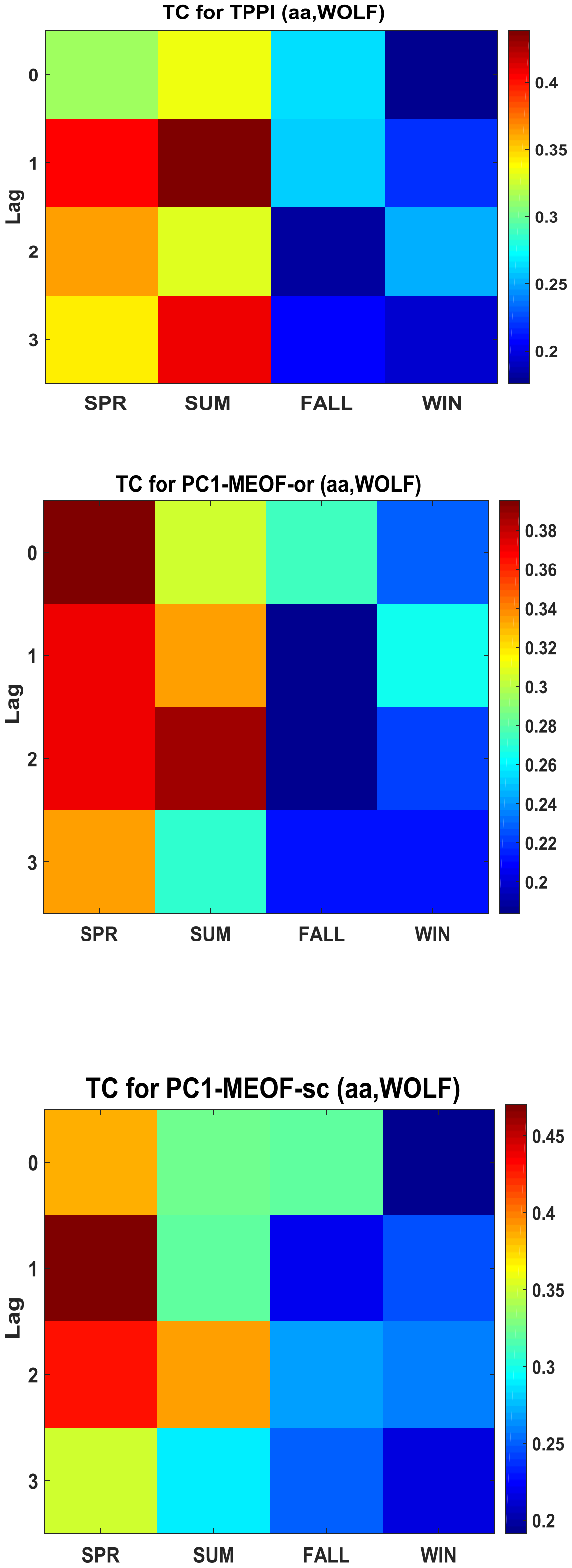
TC for TPPI (aa,WOLF)
Lag
0
1
2
3
SPR
SUM
FALL
WIN
0.4
0.35
0.3
0.25
0.2
TC for PC1-MEOF-or (aa,WOLF)
Lag
0
1
2
3
SPR
SUM
FALL
WIN
0.38
0.36
0.34
0.32
0.3
0.28
0.26
0.24
0.22
0.2
TC for PC1-MEOF-sc (aa,WOLF)
Lag
0
1
2
3
SPR
SUM
FALL
WIN
0.45
0.4
0.35
0.3
0.25
0.2

FIG. 3B.

**FIG.2A.** The difference between synergy and redundancy (S-R) for the drought indices: TPPI, original Palmer drought indices (or) and self-calibrating (sc), quantified by the first component of development in MEOF, considering as predictors aa and solar flux, for the period 1948-2000.
**SPR**=Spring; **SUM**=Summer; **FALL**= Autumn; **WIN**=Winter

**FIG. 2B.** Total correlation (TC) estimated by means of mutual information (eq.3), for the TPPI and Palmer indices, considering the simultaneous influences of aa and solar flux for the 1948-2000 period.

**FIG. 3A**. Same as Fig. 2A but with WOLF number instead of solar flux and for 1901-2000.
**FIG. 3B**. Same as Fig. 2B, but for WOLF number instead of solar flux and for 1901-2000.

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