INSTABILITY INDICES AS AN INDICATOR OF THUNDERSTORMS IN EASTERN BULGARIA - PRELIMINARY RESULTS

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Abstract. The work is directed to test the ability of some instability indices to be used as an indicator of lightning from convective clouds. Three instability indices (CAPE, Lifted Index and K Index) are calculated using environmental conditions of 98 days with precipitation, detected in eleven synoptic stations located in eastern Bulgaria in the period April – September 2006. For the statistical analyses the cases have been divided in two samples – ordinary precipitating clouds and thunderstorms. The results reveal that the distributions of the studied indices are significantly different in the both samples. The critical values (thresholds) of the three instability indices that may separate the studied cases into two groups (ordinary clouds and thunderstorms) are established. The best discrimination between thunderstorms and ordinary precipitating clouds is obtained using the threshold values of Lifted index. The performed multiple discriminant analysis shows that the classification function obtained by combination of instability indices does not improve the skill to predict the occurrence of thunderstorms in comparison to the single use of Lifted index.

Key words: Instability indices, thunderstorms, discriminant analyses

Introduction

It is well known that standard weather prediction methods have a limited ability to forecast severe weather events (tornado, hail, strong wind, thunderstorms, etc.) especially to predict the location of their development. That is why several studies (Doswell et al. (1996), Rasmussen et al. (1998), Craven et al. (2002), Markowski et al. (2002), Brooks et al. (2003), Brooks et al. (2007), and Doswell et al. (2003)) focus on the determination of critical values of various parameters “describing” the environmental conditions for severe events. Furthermore, it is known that the established thresholds depend on geographical regions, season, and climatic conditions.

The aim of the present work is to explore if any of the three instability indices Li, K and CAPE or combination of them can be used as an indicator of thunderstorms development over eastern Bulgaria. The choice of the above parameters is based on the previous studies which reported that Lifted Index (Galway, 1956) and K Index (George, 1960) predict the likelihood of thunderstorms. Vertically integrated measures of instability such as the convective available potential energy, CAPE (Moncrieff and Miller, 1976), provide a more detailed physical representation of the state of the atmosphere (Blanchard, 1998). Based on the analyses of thermodynamic and kinematic environmental characteristics in Europe during the summer months it is concluded (Kaltenbock et al., 2009) that CAPE has considerable skill to predict the occurrence of thunderstorms.

Data and Methodology

The environmental conditions of 98 days with precipitating clouds developed in the afternoon hours over eastern Bulgaria from April to September 2006 are analyzed. The proximity aerological sounding at 1200 UTC are used to calculate three instability indices (CAPE, Lifted Index and K Index; Table 1) for the days when precipitation is detected in eleven synoptic stations of the National Institute of Meteorology and Hydrology (NIMH), located in eastern Bulgaria. Six of the stations are situated along the coast and the others five are inland stations. The proximity soundings are obtained by downloading the data of the numerical model GFS http://www.arl.noaa.gov/ready/cmet.html. Surface level meteorological data (pressure, humidity, temperature and a maximum temperature for the day), taken from http://www.ogimet.com/synops.phtml.en are utilized for processing the data from the soundings.

Table 1. Summary of thermodynamic, kinematic parameters and skill scores used: T is temperature (^{0}C), Td is dewpoint temperature (^{0}C), θ is potential temperature (K), θ_e is equivalent potential temperature (K), g is the acceleration of gravity (m s^{-2}), z is height (m), LFC - the level of free convection, EL - the equilibrium level of the parcel, TP_{500} – temperature of a parcel after it has been lifted pseudo-adiabatically to 500 hPa from its original level, x - the number of correctly classified thunderstorms cases, y - the number of incorrectly classified thunderstorms cases, w - the number of incorrectly classified ordinary clouds cases. Subscripted numbers indicate constant pressure levels.

Parameter	Code and units	Equation
Convective Available Potential Energy	CAPE, J kg^{-1}	$CAPE = g \int_{LFC}^{EL} \frac{\theta - \theta_e}{\theta_e} dz$
Lifted index	Li, deg	$Li = T_{500} - TP_{500}$
K index	K, deg	$K = (T_{850} - T_{500}) + T_{d850} - (T_{700} - T_{d700})$
Probability of detection	POD	$POD = \frac{x}{x+y}$
False alarm ratio	FAR	$FAR = \frac{w}{x+w}$

All precipitating cases (373) were divided into two samples – ordinary (without lightning) precipitating clouds (216) and thunderstorms (precipitation concurrent with lightning) (157), according to synoptic reports in eastern Bulgaria. The ordinary precipitating clouds (without lightning) and thunderstorms hereafter are denoted as *or* and *th* respectively.

The descriptive statistics (mean, mode, median, etc.) for the three instability indices (CAPE, Li, and K) are estimated. The statistical analyses (F- and t-test with significance level α=0.05) is performed to establish if there is a statistical significant difference between any of the instability indexes (CAPE, Li and K) in the both considered samples - ordinary precipitating clouds, *or* and thunderstorms, *th*.

The distributions of the CAPE, Li and K values in the *or* and *th* samples are investigated.

The discriminant analyses (StatSoft, Inc., 2001) is carried out to establish if any of the three instability indices Li, K and CAPE or combination of them is able to classify the clouds as ordinary precipitating cloud or thunderstorm. The probability of detection (POD) and false alarm ratio (FAR) are calculated (Donaldson et al., 1975) for the derived classification functions (see Table 1). The critical values (thresholds) of the three instability indices (CAPE, Li and K) that may separate the studied cases in two groups (ordinary clouds and thunderstorms) are established.

Results

The results presented in Fig. 1 reveal that the frequency distribution of the CAPE *th* values (black columns) is shifted towards larger values in comparison to the frequency distribution of CAPE *or* (grey columns). The maximum percentage (mode) of CAPE *or* is less than 250 J kg^{-1}, while the mode of CAPE *th* is approximatelly 1050 J kg^{-1}. The results also reviel that thunderstorms may developed at very low CAPE values (CAPE < 200 J kg^{-1}) however, their percentige is less than 3 %, while ~ 27 % of ordinary clouds develop at CAPE < 200 J kg^{-1}.

The more detailed analysis of the frequency distribution shows that ~57 % of the considered thunderstorms and ~18 % of ordinary precipitating clouds developed at CAPE values in the interval for “moderate instability” (1000–2500 J kg^{-1}), while most of the ordinary clouds (80 %) developed at CAPE values in the interval for “marginal instability” (0-1000 J kg^{-1}). The above mentioned classification of the degree of instability is in accordance with the study http://www.crh.noaa.gov/lmk/soo/docu/indices.php, performed for the USA regions.

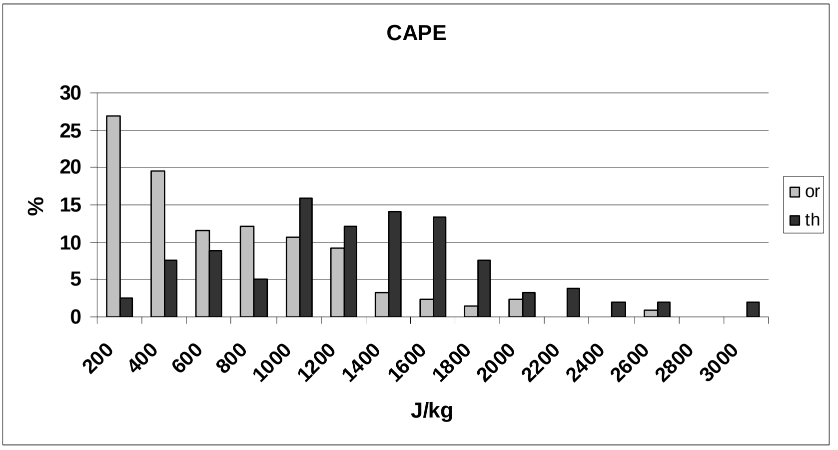

Fig.1. Frequency distribution of CAPE values (in percentages) at the development of ordinary precipitating clouds (grey columns) and at the development of thunderstorms (black columns)

Fig. 2 and Fig. 3 show the frequency distributions of Li and K values for the both samples - ordinary clouds, *or* and thunderstorms, *th*. It is seen (Fig. 2) that the frequency distribution of the Li *th* values (black columns) is shifted towards lower (negative) values in comparison to the frequency distribution of Li *or* (grey columns), while the percentages of higher K values are larger at the development of thunderstorms in comparison to the development of ordinary precipitating clouds. The detailed analysis of the frequency distribution of Li indicates that according to the classification http://www.crh.noaa.gov/lmk/soo/docu/indices.php most of the thunderstorms (~53 %) developed at “moderate instability” (-3 to -6 deg), 11 % at “strong instability” (Li < -9 deg) and 33 % at “marginal instability” (-3 < Li < 0 deg). Most of the ordinary clouds (46 %) developed at “marginal instability”, 19 % at “moderate instability” and only 2 % at strong instability. It has to be mentioned that 33 % of the considered ordinary precipitating clouds developed according to http://www.crh.noaa.gov/lmk/soo/docu/indices.php at stable atmosphere (0 < Li < 3 deg) when “there is a week probability for convection if a strong lifting is present”. The highest percentage (66 %) of K values at the development of ordinary precipitating clouds are K < 30 deg, while ~64 % of thunderstorms developed at K > 30 deg.

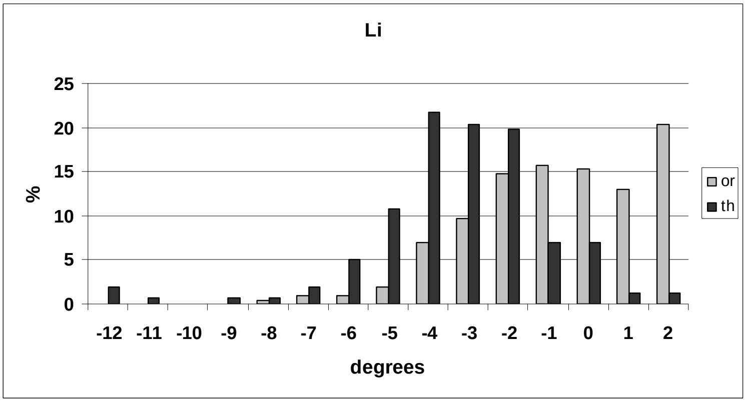

Fig.2. Frequency distribution of Li values (in percentages) at the development of ordinary precipitating clouds (grey columns) and at the development of thunderstorms (black columns)

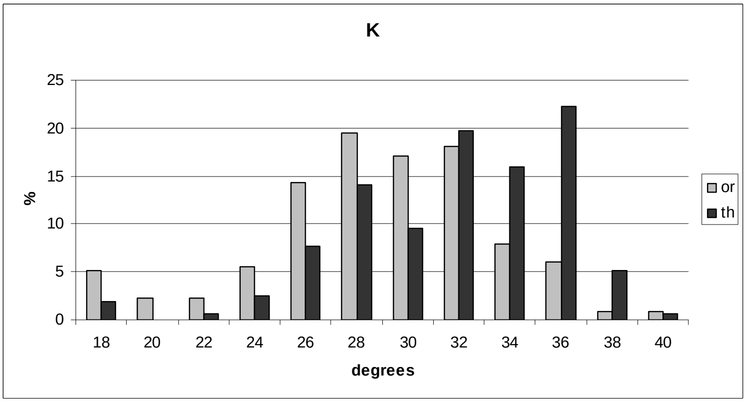

Fig.3. Frequency distribution of K values (in percentages) at the development of ordinary precipitating clouds (grey columns) and at the development of thunderstorms (black columns)

The statistical analyses (t- and F-tests with a significance level α=0.05) indicates that the differences in the mean values of the three indices for thunderstorms and ordinary precipitating clouds are statistically significant. The Box and Whiskers plots for CAPE (Fig.4a), Li (Fig.4b) and K (Fig.4c) illustrate that there is a well pronounced difference between their corresponding mean values at the development of thunderstorms, *th* and at the development of ordinary precipitating clouds, *or*. The results reveal that thunderstorms over eastern Bulgaria developed at significantly higher mean values of CAPE and K and significantly lower mean values of Li, compared to the corresponding mean values at the development of ordinary thunderstorms.

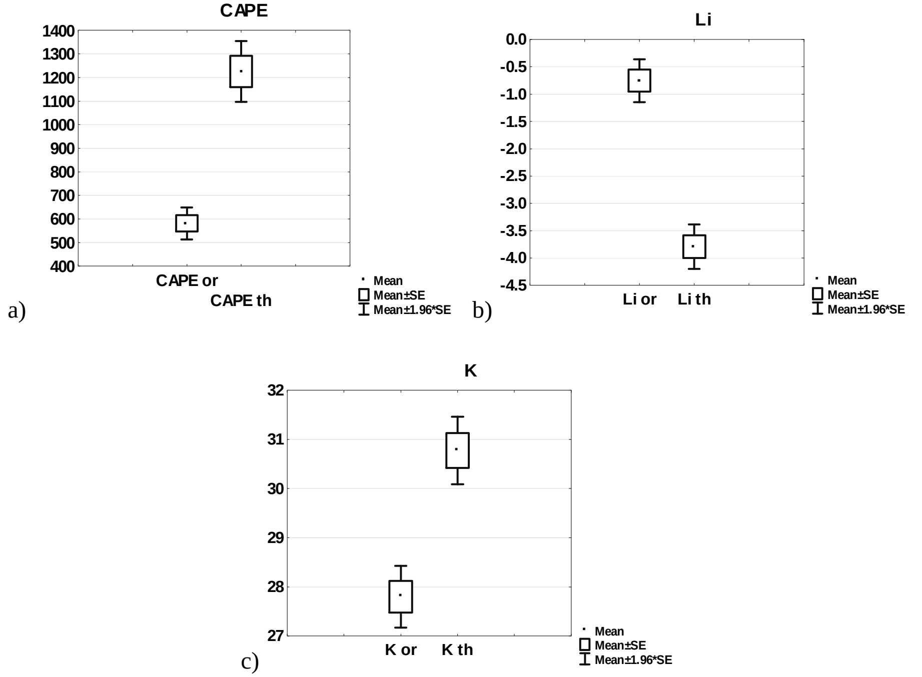

Fig.4. Box and Whiskers plot of a) CAPE , b) Lifted index, Li and c) K values for ordinary precipitating clouds ***or*** and thunderstorms ***th***.♦Mean±SE±1.96*SE

Table 2. Threshold values of instability indices for the type of clouds, percentage of correctly determined cases - thunderstorm th or ordinary or, and skill scores POD and FAR

Index	Threshold	Correct classification %			POD	FAR
		all	th	or		
CAPE, J kg^{-1}	903	72.9	67.5	76.9	0.68	0.32
Li, deg	-2.3	73.9	80.3	69.4	0.80	0.34
K, deg	29	63	67.5	59.7	0.68	0.45

The threshold values of CAPE, Li and K at the development of thunderstorms over eastern Bulgaria derived by general discriminant analysis (StatSoft, Inc., 2001), the percentage of correctly classified cases (*th* or *or*) and calculated skill scores are presented in Table 2. The results show that when thunderstorms developed over eastern Bulgaria 67.5% of CAPE and K values are higher than the established threshold (903 J kg^{-1} and 29 deg respectively) and at the development of ordinary clouds 76.9 % of CAPE values and 59.7 % of K values are lower than the established thresholds. The best results are obtained using the threshold values of Lifted index. At Li < -2.3 deg - 73.9 % of the cases are correctly discriminate in accordance to the type of clouds (ordinary precipitating or thunderstorms). This threshold is very close to the reported (Kunz, 2007) Li threshold for thunderstorm development over Southwest Germany. The calculated skill scores (POD, FAR) given in

Table 2 reveal that only Lifted index, Li has approximately a good forecasting ability (POD = 0.8 and FAR = 0.34) for occurrence of thunderstorms in eastern Bulgaria.

In an attempt to obtain better discrimination between the ordinary precipitating clouds and thunderstorms the multiple discriminant analyses (StatSoft, Inc., 2001) with various combination of the instability indices are carried out (Table 3). At F(th,or) > 0 the case is classified as thunderstorm; at F(th,or) ≤ 0 the case is classified as ordinary cloud. The percentage of correctly classified cases in accordance to the type of the clouds (*or* or *th*), the POD and FAR values indicate that the combination of instability indices does not improve the classification ability of the derived function in comparison to the single use of Lifted index.

Table 3. Classification functions F(th,or) for the type of clouds, and the percentage of correctly classified cases - thunderstorm th or ordinary or, using combination of instability indices and skill scores POD and FAR

Index	Function	Correct classification %			POD	FAR
		all	th	or		
CAPE, Li, K	F(th,or) = 0.0004 CAPE – 0.2988 Li + 0.0167 K – 1.4965	74.3	77.1	72.2	0.77	0.33
CAPE, Li	F(th,or) = – 0.3184 Li + 0.0003 CAPE – 1.0314	74.3	77.7	71.6	0.78	0.33
CAPE, K	F(th,or) = 0.0013 CAPE + 0.0631 K – 3.0172	73.2	70.7	75.0	0.71	0.33
Li, K	F(th,or) = – 0.3742 Li + 0.0127 K – 1.2220	73.7	78.3	70.4	0.78	0.34

Conclusion

Three instability indices - CAPE, Lifted Index and K Index, were calculated using environmental conditions of 98 days with precipitation over eastern Bulgaria from April to September 2006. For the analyses the cases were divided into two samples – ordinary precipitating clouds and thunderstorms. The statistical analyses (F– and t-test) were performed to check if there is a significant difference between CAPE, Li and K values at the development of ordinary precipitating clouds and thunderstorms over eastern Bulgaria. Discriminant analyses were carried out to obtained classification functions and threshold values of the considered indices that are able to discriminate thunderstorms from ordinary precipitating clouds. The main results are:

- The frequency distributions of the considered indices (CAPE, K and absolute values of Li) at the development of thunderstorms are shifted towards larger values in comparison to the frequency distributions at the development of ordinary precipitating clouds in eastern Bulgaria;

- The higher probability of detection of thunderstorms (POD = 0.8) has Lifted index. The established critical Li values (Li = -2.3 deg) are able to discriminate correctly ~74 % of cases in accordance to the type of the considered clouds;
- The combination of instability indices does not improve the classification ability of the derived function in comparison to the single use of Lifted index.

In an attempt to search classification functions (threshold values) with higher probability of detection of thunderstorms it is worth to consider separately the inland and coastal cloud cases developed over eastern Bulgaria, using larger number of precipitating cases.

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http://www.arl.noaa.gov/ready/cmet.html NOAA Air Resources Laboratory.

http://www.ogimet.com/synops.phtml.en Professional information about meteorological conditions in the world

http://www.crh.noaa.gov/lmk/soo/docu/indices.php NOAA's National Weather Service Weather Forecast Office, Science and Technology, NWS Lousville. KY Convective Season Environmental Parameters and Indices.

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Индекси на неустойчивост като индикатори на гръмотевични облаци в Източна България – предварителни резултати

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Резюме. Работата е насочена към установяване, дали някои индекси на неустойчивост могат да се използват като индикатори за гръмотевични облаци. Пресметнати са три индекса на неустойчивост (CAPE, Lifted Index and K Index), като се използват приземни данни и от апроксимирани сондажи за 98 дни с валежи, регистрирани в 11 синоптични станции в Източна България за периода април – септември 2006 г. За статистически анализ случаите са разделени на две извадки – обикновени дъждовни облаци и гръмотевични облаци. Резултатите показват, че разпределението на стойностите на пресметнатите индекси са съществено различни за двете извадки. Установени са критични стойности (прагове) на трите индекса на неустойчивост, които могат да разделят използваните случаи на две групи (обикновени дъждовни облаци и гръмотевични облаци). Най-добро класифициране като гръмотевични или обикновените дъждовни облаци се получава при използване на критичната стойност за Lifted index. С помощта на дискриминантен анализ е получена класификационна функция, комбинация от трите индекса на неустойчивост (CAPE, Lifted Index and K Index), която може да се използва като индикатор на гръмотевични облаци. Резултати показват, че функцията получена от комбинацията на трите индекса на неустойчивост не разделя двете извадки по-добре от функцията, получена при използване само на стойностите на Lifted index.