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# Evaluation of the stability indices for the thunderstorm forecasting in the region of Belgrade, Serbia

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ABSTRACT

The pre-convective atmosphere over Serbia during the ten-year period (2001–2010) was investigated using the radiosonde data from one meteorological station and the thunderstorm observations from thirteen SYNOP meteorological stations. In order to verify their ability to forecast a thunderstorm, several stability indices were examined. Rank sum scores (RSSs) were used to segregate indices and parameters which can differentiate between a thunderstorm and no-thunderstorm event. The following indices had the best RSS values: Lifted index (LI), K index (KI), Showalter index (SI), Boyden index (BI), Total totals (TT), dew-point temperature and mixing ratio. The threshold value test was used in order to determine the appropriate threshold values for these variables. The threshold with the best skill scores was chosen as the optimal. The thresholds were validated in two ways: through the control data set, and comparing the calculated indices thresholds with the values of indices for a randomly chosen day with an observed thunderstorm. The index with the highest skill for thunderstorm forecasting was LI, and then SI, KI and TT. The BI had the poorest skill scores.



## 1. Introduction

Thunderstorms are the main cause of severe winds, hail, lighting and heavy rain, especially during the summer season. They are a natural hazard and a threat to lives and property all around the world. The general preconditions for thunderstorm formations are atmospheric instability, wind shear, relative humidity and a source of energy to initiate the convection. Due to the fact that the deep convective clouds develop on small spatial and temporal scales (1–10 km and 1–12 h), thunderstorm forecasting is the most demanding task for a weather forecaster. The lack of appropriate horizontal and vertical resolutions in numerical weather prediction models can also pose difficulties in thunderstorm forecasting (Lilly, 1990). In order to improve the thunderstorm forecast, many thermodynamic indices are defined and calculated from the sounding measurements. These so-called convective parameters or stability indices measure the ability of the atmosphere to develop severe weather or thunderstorm activity (Haklander and Van Delden, 2003). Various stability indices allow for the quantification of atmospheric stability and may be used as predictors for the development of thunderstorms, their probability and intensity. The effectiveness of these indices was investigated in many studies (Fuelberg and Biggar, 1994; Huntrieser et al., 1996; Sanchez et al., 1998, 2008; Haklander and Van Delden, 2003; Manzato, 2003; De Rubertis, 2005; Marinaki et al., 2006; Kunz, 2007; Jayakrishnan and Babu, 2014). Most of these studies report a relationship between thunderstorm occurrence and appropriate convective parameters derived from radiosonde observations. As Mohr and Kunz (2013) stated, even if this relation may not be valid for every single event, it can be established to quantify the probability of thunderstorm occurrence on average. Kaltenböck et al. (2009) found that stability indices have considerable ability to predict the occurrence of thunderstorms and the probability of severe events in Europe. Grünwald and Brooks (2011) used sounding parameters from reanalyzed data to examine the relationship of the strength of tornadoes in Europe in association with the convective potential energy, shear and lifting condensation level. The analysis of sounding-derived parameters in the relationship to the occurrence of tornadoes in Poland was the subject of the Taszarek and Kolendowicz (2013) study. Groenemeijer and Van Delden (2007) investigated how radiosonde-derived data can be used to forecast some of the potentially hazardous phenomena that occasionally accompany convective storms. However, the ability of the short-term thunderstorm forecasting using the thermodynamic indices is different for different regions.

As far as we know, no analysis of the stability indices for the Serbian region has been conducted until now. The main objective of this study

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was to evaluate the ability of the various stability indices to properly and in a short term forecast the thunderstorms in the Serbian region. Another objective was to test the thresholds of the existing indices in order to improve their applicability in the observed region.

## 2. The data set

The radiosonde measurements are regularly conducted at the meteorological station Belgrade-Košutnjak, Serbia ($\varphi = 44°46'$ N, $\lambda = 20°25'$ E, h = 203 m). At this location the radiosonde measurements started in 1987. For that purpose the navigation system DigiCORA Rawinsonde Set MW11 was used until 2005, and since then the navigation system DigiCORA III-Sounding System MW31 (RHMZ, 2011) is in use. During the ascent of the radiosonde RS92 the pressure, temperature and relative humidity are measured at different altitudes. These data are then used for calculating the dew-point temperature while the wind speed and direction are measured by the GPS (Global Positioning System) or the Loran-C (Long Range Navigation) method. The accuracy of the pressure measurements is ±1.5 hPa (for the range from 100 to 1080 hPa) and ±0.6 hPa (for the range 3 to 100 hPa). For the temperature measurements the accuracy is ±0.5 °C (until the 100 hPa) and ±1 °C (in the range 5–100 hPa), for the relative humidity measurements ±5%, for the wind speed measurements ±1 m $s^{-1}$ (at heights until to 100 hPa) and ±2 m $s^{-1}$ (the range 100–5 hPa), and for the wind direction measurement ±5° for velocities lower than 15 m $s^{-1}$ (until the 100 hPa), ±2.5° for velocities greater than 15 m $s^{-1}$ (until the 100 hPa) and ±5° (for the heights 100–5 hPa) (RHMZ, 2011). The expert team of the Republic Hydrometeorological Service of Serbia performed logical control of the data. These data were used for the calculation of other parameters. We analyzed 31 variables in total (they are listed later in the text).

We collected the radiosonde data for the period from 2001 to 2010 (ten consecutive years) at two terms: 00 UTC and 12 UTC (downloaded from the web site of the University of Wyoming http://weather.uwyo.edu/upperair/sounding.html). According to Todorović and Vujović (2010), the greatest number of thunderstorms (TS) in Belgrade region (96.9% of all thunderstorms in the 35 year period 1975–2009) occurs in the warm part of the year (Fig. 1). Therefore in this paper for each year we analyzed only the period from April until September. There were 2476 radiosonde measurements in total: 1557 for the term 00 UTC and 919 for the term 12 UTC. Furthermore, the Republic Hydrometeorological Service of Serbia provided the data of both thunderstorm and no-thunderstorm days in the region of nearly 100 km around the station Belgrade-Košutnjak, from the 13 surrounding meteorological stations (Fig. 2).

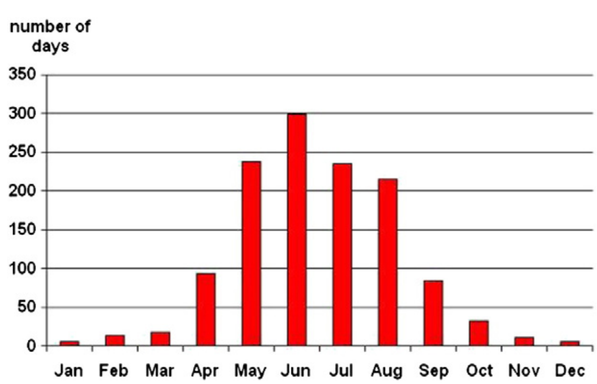


**Fig. 1.** Monthly distribution of the number of days with thunder in the Belgrade region for the period 1975–2009 (Todorović and Vujović, 2010).

## 3. Methods

### *3.1. Definitions of the indices and parameters*

We will give definitions of the stability indices used in this article. Although they are well known, it is beneficial to review them for the sake of completeness which should help the reader to easily follow the discussion.

*Convective Available Potential Energy* (CAPE; Moncrieff and Miller, 1976) is the total amount of work done by the upward buoyancy force that is exerted on an air parcel as it is lifted from its initial level to its final Equilibrium Level (EL): CAPE (J $kg^{-1}$) $= \int R_d(T_p - T)\, d(\ln p)$, where $T_p$ and T are the temperatures of the parcel and the environment, respectively. This is actually the maximum energy available to an ascending air parcel. Compared to the other stability indices, CAPE has an advantage because it is not limited to only one particular atmospheric level.

*CAPE using virtual temperature* (CAPEv) is calculated similarly to the CAPE index, but instead of $T_p$ and T, the values $T_{vp}$ and $T_v$ (the virtual temperatures of the air parcel and the environment respectively) are used.

*Total Totals index* (TT) is calculated as the sum of the 850 hPa temperature and dew-point temperature minus the 500 hPa temperature and dew-point temperature: $TT = (T_{850} - T_{500}) + (T_{d850} - T_{d500})$ (Miller, 1967). The showers and thunderstorms become increasingly likely from the TT values of about 30 °C, and severe thunderstorms are considered to be likely for the TT values of 50 °C or more. TT index fails to consider the latent instability below the 850 hPa level.

*Lifted index* (LI) is defined as the difference between the observed temperature at 500 hPa and the temperature of an air parcel after it has been pseudo-adiabatically lifted from its original level to 500 hPa: $LI = T_{500} - T_{p \rightarrow 500\ hPa}$ (Galway, 1956). It is a measure of stability of the atmosphere between the z = 0 and 500 hPa. For the positive values of LI, the atmosphere is stable. The lower the value (i.e. the greater the negative number), the better are the chances for thunderstorms and the greater risk of severe weather.

*K-Index* (KI) is defined by the following expression: $KI = (T_{850} - T_{500}) + T_{d850} - (T_{700} - T_{d700})$. George (1960) developed this index for thunderstorm forecasting. As we can see from the above equation, KI increases with the decreasing static stability in the layer 850–500 hPa, increasing moisture at 850 hPa and increasing relative humidity at 700 hPa.

*Showalter index* (SI) gives the difference between the observed air temperature at 500 hPa and the temperature of a parcel lifted from 850 to 500 hPa, dry-adiabatically to the saturation level and moist-adiabatically above that: $SI = T_{500} - T_{p850 \rightarrow 500\ hPa}$ (Showalter, 1953). As SI decreases to zero and below zero, the probability of thunderstorm occurrence increases. If the low-level moisture does not reach 850 hPa, SI will underestimate the thunderstorm probability. Note that the SI differs from the LI by the initial location of the lifted air parcel.

*Bulk Richardson Number* (BRN) is a non-dimensional ratio of CAPE to a measure of the vertical wind shear of the environment: $BRN = CAPE/(0.5\, U^2)$, where U is the magnitude of the shear. It is used to characterize convective-storm types for various environments. Generally, values of BRN <45 support a supercell formation, while values greater than 45 support multicell or ordinary cell convection (Weisman and Klemp, 1986).

*Boyden index* (BI) does not take the moisture into account and describes the vertical temperature profile in the layers of 1000 and 700 hPa. It is defined as the difference between 1000 and 700 hPa thickness, and the temperature at 700 hPa, from which 200 was subtracted. This gives the values of nearly 100 (Boyden, 1963): $BI = 0.1(Z_{700}–Z_{1000}) - T_{700} - 200$, where Z is the geopotential height of a pressure level.