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VALIDATION OF SEVERAL ATMOSPHERIC STABILITY INDICES FOR THE STORMS GENERATING TORRENTIAL RAIN SHOWERS IN THE NORTH-WEST OF ROMANIA

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ABSTRACT. – Validation of Several Atmospheric Stability Indices for the Storms Generating Torrential Rain Showers in the North-West of Romania. The present study deals with the atmospheric instability types that lead to torrential rain formation in the North-Western part of Romania and with the role that certain stability indices play in establishing the atmospheric instability potential. 35 years of warm season rainfall data from 14 meteorological stations in the North-West of Romania have been analysed in this respect. The Hellman criterion was employed in order to establish the torrential character of the rainfall events, having made use of 271 of such rainfall events in the analysed period (1975-2009). Considering that the synoptic context of the torrential rain occurrence differs according to the instability type existing at the moment of their apparition, the analysis of the stability indices has taken this feature into consideration as well. Hence, three types of instability have been identified (convective lifting, frontal lifting and that produced due to the "cut off" nuclei) their analysis underlining the highest frequency of torrential rains caused by the convective lifting (49.1%), followed by the frontal type (27.7%) and the 'cut off" type (23.2%), their highest percentage being registered in the summer. The values of 5 stability indices have been taken into account (KI, VT, CT, TTI and LI), determined on the basis of the aerologic survey at 00 GMT time, undertaken in Cluj-Napoca, plus two more modified indices (K_{MOD} and TT_{MOD}). Having analysed them, it was possible to identify the most useful ones for determining the convective storms conditions generating torrential rains in the North-West region of Romania.

Keywords: torrential rains, stability indices, frontal lifting, "cut off" nuclei, North-West of Romania.

1. INTRODUCTION

Torrential rain is an extreme pluviometric event with negative social and environmental effects. The registering of significant water quantities over shorter or longer time intervals can lead firstly, to flash-floods and secondly, to a soil suprasaturation and ponding of the water corresponding to the precipitation in excess. In time, there were attempts to build conceptual models that would easily identify the favourable conditions

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for several atmospheric processes. Consequently in Romania among the first baric structures' types classifications and the weather conditions associated to them have been made by a group of researchers in the Meteorological Institute of Bucharest who found 7 baric types (Clima R.P.R., 1962) of interest for the studied region. For the warm season nevertheless there remain only four types (I, V, VI and VII). Other approaches in this respect have been made by Topor N. (1964), and Topor N. and Stoica C. (1965). As technology developed, a series of programs have been implemented that made possible an objective weather type classification, according to several quantifiable criteria in some pre-established points. Hence the automatic classification of the atmospheric circulation types allows an objective analysis of the synoptic situations that determine certain atmospheric processes. The studies and the zonal or regional approaches from the last years have taken another looks into the matter, due to the easiness with which large amount of terrestrial atmospheric parameters data can be dealt with nowadays. As a consequence, at the European level, the automatic classification of weather types has been made, on the basis of an international collaboration (the COST Programme 733). The present study formulates the hypothesis that the atmospheric instability is the essential element for the torrential rain generation and seeks to validate several stability indices, in whose case the probability of torrential rain occurrence in the study area is high. The analysis doesn't refer to the spatial extent of the phenomenon. It just wants to establish its occurrence according to several values of the analysed indices.

2. DATA AND METHODOLOGY

Torrential rain data from 14 meteorological stations in the North-West of Romania has been used for the present study. The stations are set at altitudes ranging between 123 m and 1836 m, their altitude structure being as it follows: Satu Mare (123 m), Supuru de Jos (159 m), Baia Mare (216 m), Dej (232 m), Sighetu Marmației (275 m), Zalău (295 m), Bistrița (366 m), Cluj-Napoca (410 m), Turda (424 m), Ocna Șugatag (503 m), Huedin (560 m), Băișoara (1384 m), Iezer (1785 m) and Vlădeasa 1800 (1836 m). The spatial repartition of the observation points in the study unit can be seen in Fig. 1.

The rainfall data registered in the warm season (April-October) measured with the pluviograph at the mountainous stations situated above 1500 m (Băișoara, Iezer, Vlădeasa 1800) has been taken into account, the annual analysis interval being actually a bit shorter (namely June-September) due to the snow and mixt precipitations occurrence in the other months. The total length of the study period is of 35 years (1975-2009).

The first stage of the employed methodology consisted in the torrential rainfall events identification via the Hellman selection criteria. The thematic altitudinal and sea level maps archive (geopotential values, air temperature, relative humidity, atmospheric pressure) existing on the *www.wetterzentrale.de* archive and www.noaa.gov , have been identified for every torrential event, along with the type of the synoptic structure that they generated, hence leading to the type of atmospheric instability determined. Subsequently, on the basis of the atmospheric survey analysis from *http://weather.uwyo.edu* the following stability indices have been computed: K Index, Vertical Totals, Cross Totals, Total Totals Index and Lifted Index. The final stage consisted in the statistical analysis.

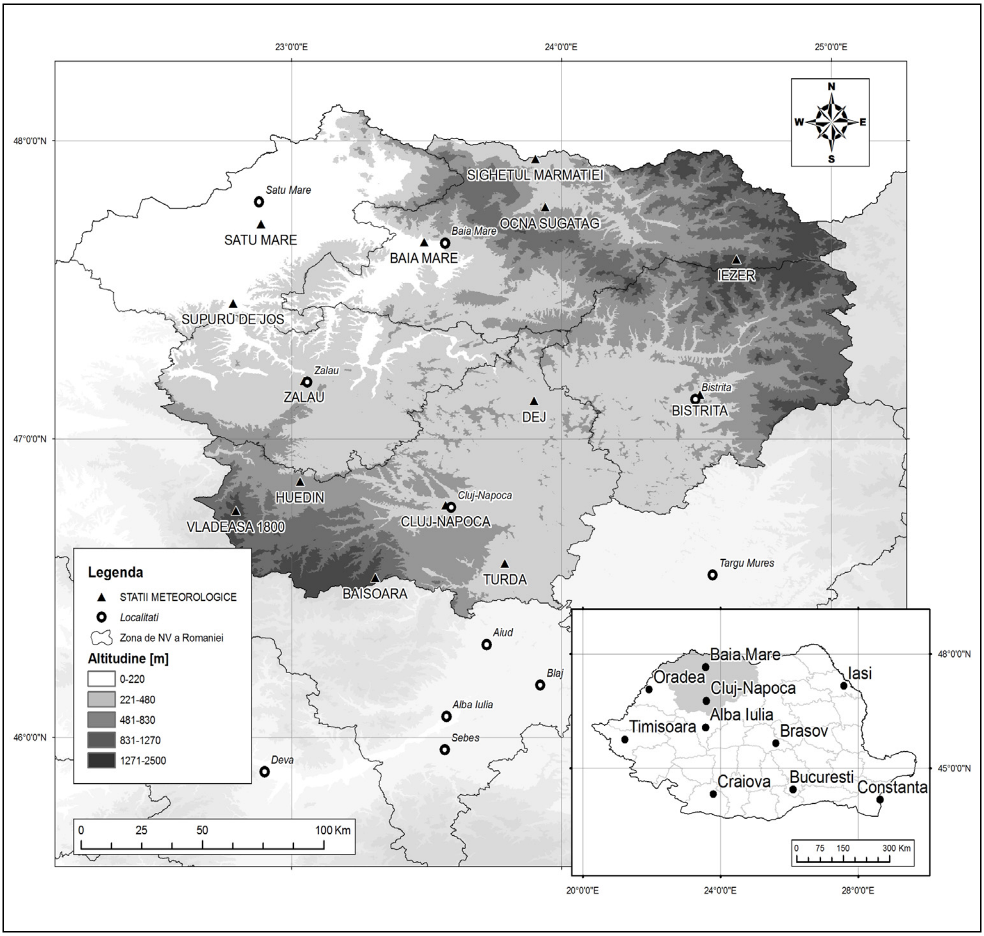

Fig. 1. The meteorological stations in the analysed region.

3. RESULTS

Having analysed the synoptic situations during which the torrential rains have occurred according to the criterion taken into account, the results underline the existence of 3 types of atmospheric instability: convection lifting, frontal lifting and instability associated to the cut off nuclei. The convection lifting is determined by the daily heating of the active surface and its propagation in the superior atmospheric strata due to convection, generating turbulent ascending currents; the frontal lifting occurs due to the forced ascendance of the air as a consequence of the dynamic processes existing at the terrestrial surface level, whereas the instability associated to the cut off nuclei, or the altitudinal nuclei, is produced due to the formation of certain cold nuclei in the medium and superior strata of the terrestrial atmosphere.

A number of 271 torrential rainfall events have been identified during the study period, the analysis of the synoptic materials for each rainfall event indicating the highest percentage for the rains generated by convective lifting (49.1%), followed by those of frontal lifting (27.7%) and last, by the ones due to the „cut off" type nuclei (23.2%).

At a monthly scale, the torrential rains generated by the convective lifting occur starting with May and last till September, having a high percentage in July (15.1%), June and August, summing up to a total of 90.2% of their corresponding class. It is obvious for the respective period that the heating during the day is the predominating type, as the air temperatures registered are the highest (Fig. 2).

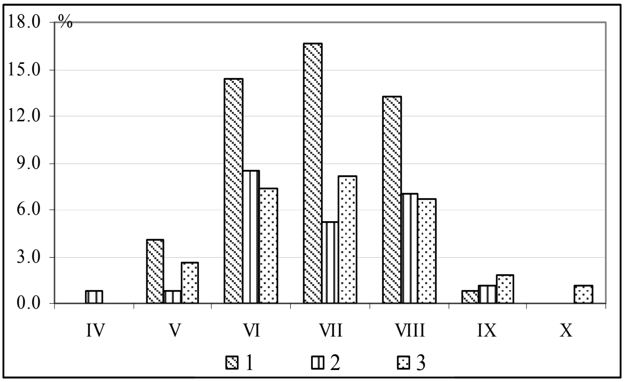

Fig. 2. Monthly frequency of torrential rains according to the instability type
(1- convective lifting; 2- instability associated to the cut off type nuclei; 3- frontal lifting)

A similar monthly structure characterises the frontal lifting torrential rains as well, the frequency in the summer months cumulating to 80% of the total in their class. As compared to the rainfall events generated by mass instability, the frontal ones occur at the beginning of fall as well, hence situations as these being specific to the frontal warm passages or occluded ones that are more frequent at that time.

With respect to the altitudinal nuclei, the highest frequency of rain events is registered all over summer, but their monthly occurrence is different, the highest frequency being in June (Fig. 2). The low percentage values at the middle of the summer are determined by the highly diminished frequency of the cut off nuclei in the analysed synoptic area, the synoptic structures being favourable to the mass induced instability type or the frontal one (in the case of thalwegs or short waves).

The math expressions of the analysed indices are:

$$\mathbf{KI = (T_{850}-T_{500}) + T_{d850} - (T_{700}-T_{d700})}, \text{ (George, 1960)} \quad (1)$$

$$\mathbf{K_{MOD} = (T-T_{500}) + T_d - (T_{700}-T_{d700})},$$

where $\mathbf{T = (T_{sfc}+T_{850})/2}$ and $\mathbf{T_d = (T_{dsfc}+T_{d850})/2}$, Charba (1984) (2)

$$\mathbf{VT = T_{850}-T_{500}}, \text{ (Miller, 1967)} \quad (3)$$

$$\mathbf{CT = T_{d850} - T_{500}}, \text{ (Miller, 1967)} \quad (4)$$

$\mathbf{TTI = T_{850} + T_{d850} - 2T_{500}}$, (Miller, 1967) (5)

$\mathbf{TT_{MOD} = T + T_d - 2T_{500}}$,

where $\mathbf{T = (T_{sfc}+T_{850})/2}$ and $\mathbf{T_d = (T_{dsfc}+T_{d850})/2}$, Charba (1984) (6)

$\mathbf{LI = T_{500}-T_{p500}}$, (Sadowski and Rieck, 1977) (7)

where: - T_{850}, T_{700}, T_{500} air temperature at the level of 850, 700 and 500 hPa;

- T_{d850}, T_{d700} dew point temperature at the level of 850 and 700 hPa;

- T_{sfc}, T_{dsfc} air temperature, namely dew point temperature at the soil level;

- T_{p500} temperature of the moist-adiabatic particle risen from the earth's surface up to the 500 hPa level.

K Index combines the air temperatures at the 850, 700 and 500 hPa and the dew point temperature at the 850 and 700 hPa levels (1).

The index in the form it was conceived, has been used for air mass instability determination, namely for those air masses not affected by the frontal passages or cyclonic ones (George, 1960). On the basis of the analysis, the authors conclude that K values higher than 20 indicate an increase in frequency of the air mass instability. Other authors such as Hambrige (1967), note that values below 20 of this index can account for approximatively 20% of the frequency occurrence of convective lifting generated storms and those values above 40 indicate an almost 100% probability of their apparition. Even more so, Rodgers et all. (1984) uses the values above 30 for the prognosis at the basis of the Mesoscale Convective Complexes development. The threshold index values have been set by taking into account several appreciations regarding the occurrence probability of convective storms (www.theweatherprediction.com), namely: KI=15-20, 19% occurrence probability; KI=21-25, 20-39% occurrence probability; KI=26-30, 40-59% occurrence probability; KI=31-35, 60-79% occurrence probability; KI=36-40, 80-89% occurrence probability and KI= >40, above 90% occurrence probability.

Within the analysed unit, the K index values range between 5.4 and 40.0, existing a series of differences according to the analysed instability type. For the convective lifting it can be noticed that the frequency of the low index values (<25) is greater, and to some extent the same goes when it comes to the highest values, if compared to the situations for the other instability types (Fig. 3, left). Nevertheless no matter what type of instability we would consider, the highest percentage values correspond to the 31-35 threshold, followed by the 26-30 and the values above 35. Overall the KI values higher than 31 anticipate around 60 to 72% of the registered torrential rains in the study area and those values above 36 account for about 85 to 95% of them, constituting according to the author's point of view, a relatively useful index for the prognosis of the storms generating torrential rains, no matter their generating instability type. It can also be noticed that the use of the same index for the potential of occurrence determination of the storms generating torrential rains can be done for the two remaining types of instability, aside the one this index has been conceived for, given the good results.

Charba (1984) modifies the computation for the K (K_{MOD}) index, taking into account the air and dew point temperatures at the soil level (2). Once determined the K modified index in the analysed unit, the highest frequencies of the 36-40 (49.7%) and 31-35 (24.9%) can be seen, followed by the >40 threshold, these accumulating 91.4% of the total situations with torrential rains. The analysis of the K_{MOD} index according to the instability generating type leads to a higher percentage of the 36-40 threshold, for the thermal and frontal lifting, the structure being identical for the two thresholds (31-35 and

>40) (Fig. 3, right). Taking into account the high frequency of the thresholds indicating a high occurrence probability of convective storms (above 80%), the K_{MOD} index is more useful for the prognosis of these storm types, in comparison with the KI index.

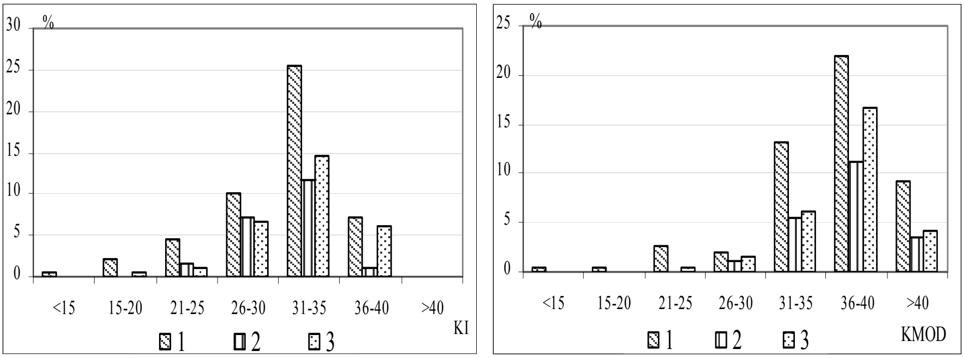

Fig. 3. KI index distribution (left) and K_{MOD} (right) according to value classes, according to the generating instability type (1-convective lifting; 2- „cut off" nuclei; 3- frontal lifting).

Vertical Totals Index (VT) is established on the basis of the temperature difference between the 850 and 500 hPa levels, without taking into account the air humidity (3). The studies undertaken for the present index in the USA (Miller, 1967, 1972, 1975) establish as the lowest values for the convective storm occurrence the values above 26. Those values above 30 indicate moderate storms; VT <25 indicate no storms; VT=25-26 dispersed storms; VT=27-30, dispersed storms/ some are severe/ isolated tornadoes; VT=31-32 dispersed storms and numerous/ a few tornadoes; VT=33-34, numerous storms/ a few tornadoes; VT >34, numerous storms / dispersed and severe/ dispersed tornadoes.

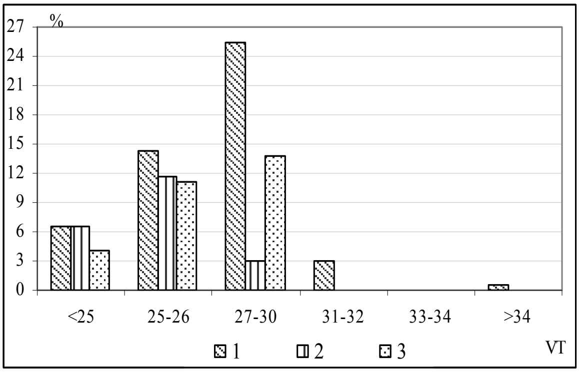

Fig. 4. VT index distribution on class values, according to the instability type (1-convective lifting; 2- "cut off" nuclei; 3- frontal lifting)

In the study area the VT index values range between 21.5 and 30.7, being noticeable the highest percent of the values under 30, a value representing the threshold for the moderate storms (Fig. 4). Regarding the convective and frontal lifting, the highest percent belongs to the 27-30 threshold values (25.4, namely 13.7%) and to the 25-26 threshold (14.2, namely 11.2%), and for the "cut off" nuclei, the one with values of 25-26 and below 25. The high percentage of the small threshold values of this index makes it very little usable for the prognosis of storms generating torrential rain events, especially when we think of the situations when the "cut off" nuclei exist.

The Cross Totals Index (CT), determined on the basis of air humidity in the 850 hPa stratum and of the temperature at the 500 hPa level (4), is characterised by a value of 18 as the bottom level for storm generation. For values under 18 the occurrence potential is lower, whereas the values above 30 indicate a higher probability of moderate storms in intensity and frequency (Miller, 1967, 1972, 1975). Regarding the mentioned extremes, when CT=18-19, there exists a moderate storm potential; CT=20-21, a strong storm potential; CT=22-23, a weak potential of severe storms; CT=24-25, a moderate potential of severe storms, and CT= >25, a high potential of severe storms. For the analysed area, the extreme values of the present index range between 16.3 and 26.6, major differences among the different types of atmospheric instability being inexistent. No matter what the instability type generating torrential rains is, the highest frequency of this index belongs to the 20-21 and 22-23. These thresholds cumulate together between 57.9% of the frontal rains and 73.8% of the ones produced on the background of the "cut off" nuclei generated instability, the superior thresholds of the index being registered at low frequencies (Fig. 5). Taking into account that the two mentioned thresholds do not indicate a high potential for severe storms (such as the ones generating torrential rains), the use of this index in the establishment of the occurrence potential of storms has to be done in correlation with other indices (K_{MOD} or KI).

Total Totals Index (TTI) is determined on the basis of temperature values existing at the 850 and 500 hPa and that of the dew point at the 850 hPa level (5). The index is used in prognosis for the spatial localizing of the formation area of convective storms. Regarding the value corresponding to this index Miller (1967, 1972, 1975), on the basis of the studies made in the USA, established the inferior value at 44, whereas the values higher than 60 are characteristic to the severe convective storms. In practice the values of the TTI have been split in intervals corresponding to the convective storms intensity as it follows: TTI=44-46, low intensity storm; TTI=46-48, moderate storms; TTI=48-50, severe storms; TTI=50-52, severe storms; TTI=52-56, strong storms, possibly tornadoes; TTI= >56, tornadoes.

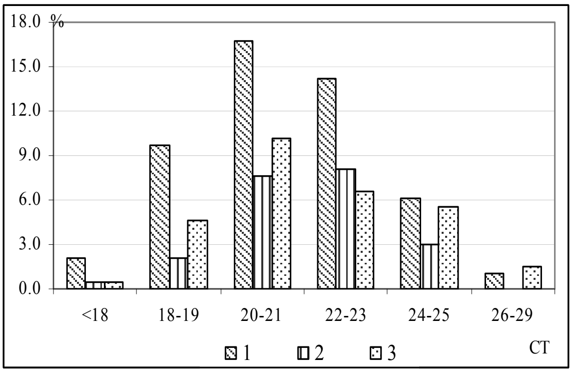

Fig. 5. CT Index distribution on different class values, according to the instability type (1- convective lifting; 2- "cut off" lifting; 3- frontal lifting)

Overall, for the TTI index the highest frequency corresponds to the 48-50 and 46-48 thresholds, values indicating the strong and moderate storms registered especially during the frontal instability type as well as the one produced on the background of the "cut off" type nuclei (Fig. 6, left). For the convective and frontal lifting, a high percentage can be seen in the values above 48, corresponding to the strong storms and tornadoes, the frequencies for each type of instability accumulating up to 60 - 65%, hence the analysed index can be considered a useful tool in the prognosis of torrential rain for the two types of instability cases mentioned.

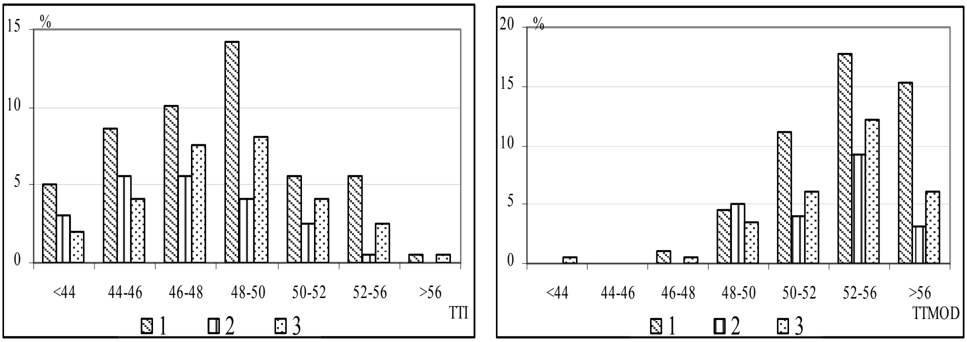

Fig. 6. TTI Index distribution (left) and TT_{MOD} (right), on different class values, according to the instability type (1- convective lifting; 2- "cut off" lifting; 3- frontal lifting)

Charba (1984) proposes a slightly modified relation for the computation of the TTI index, one that takes into account, similarly to the K_{MOD} expression, the temperature and the air humidity at the earth's surface level (TT_{MOD}, expression 6). The structures of the frequency values of the TT_{MOD} index differ from the one of the TT index, high percentage values being noticeable in the cases of the high existing thresholds (figure 6, right). In general the highest frequencies characterise the 52-56 threshold (39.1%) and >56 (24.1%), following the 50-52 threshold (a bit above 20%), being noticeable the fact that the strong storms (with TT_{MOD} >50) accumulate up to 84.8% of the total. During instable conditions the predominance of the 52-56 and >56 thresholds can be seen, when convective lifting and frontal lifting occur, and that of the 52-56 and 50-52 thresholds, for the "cut off" nuclei (Fig. 6, right). Regarding the absolute values, the highest frequency of the TT_{MOD} values, higher than 52 belongs to the convective lifting (about two thirds), followed by the frontal lifting.

The Lifted Index (LI) indicates stability and it is used for the determination of the atmospheric potential of producing severe storms, rain showers. It has been introduced in the prognosis of the convective storms in the USA as an additional predictor of latent instability. The determining of the index is done using values of the air temperature and of the humid adiabatic risen particle from the earth's surface up to the 500 hPa level (7).

The index offers information about the air stability, the higher negative values indicating a supplementary energy for the ascending particle. Hence when LI= >2, no atmospheric instability is foreseen; LI=2...1, isolated convective storms are possible; LI=1...-2, storms and rain showers are possible to occur; LI=-5...-2, storms and rain showers; LI= <-5, severe storms, and rain showers are forecast as well as wind intensifications.

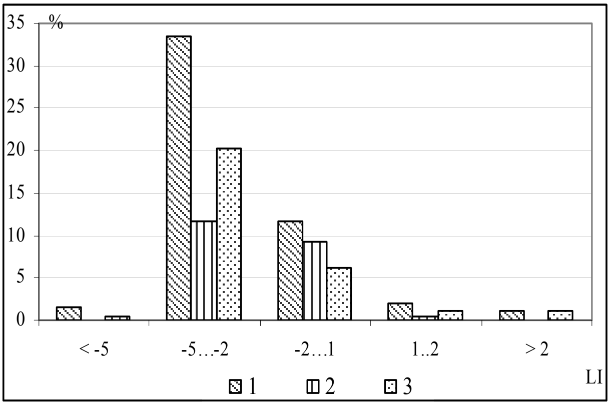

Fig. 7. LI Index distribution on different class values, according to the instability type (1- convective lifting; 2- "cut off" lifting; 3- frontal lifting)

The class structures of the L1 index indicate that no matter what the type of the stability is, the negative values of this index are predominant (between 80 and 88% of the total of each instability type), with the highest percentages in the case of the -5...-2 class (Fig. 7). According to the instability type, the highest frequencies of the lowest values of the index, the one that indicate storms and rainfalls (LI = <-2), are characteristic for the convective and frontal lifting with percent values of 70, namely 72%. These aspects lead to the conclusion that this indicator is a good one for signalling the convective storms formation that generate torrential rains in the study areas during the cases of convective lifting and frontal lifting.

4. CONCLUSIONS

KI is a useful index for the forecast of convective storms generating torrential rainfall events in the study area for all the instability types analysed and especially for the frontal lifting and convective lifting. The VT and CT Index are less used taking into account the high frequency of their low values, but the TTI (which is a combination of the two) is useful, especially for the instability forecast produced on the background of the convective lifting and frontal lifting.

LI is an efficient index for the prognosis of high instability areas especially in the case of convective lifting and frontal lifting. Plus, the K_{MOD} and TT_{MOD} indices come to complete the more or less instable potential of the terrestrial atmosphere in its lower strata, contributing to the establishment of areas with atmospheric instability.

It also has to be mentioned that for a more exact localization of the areas with significant atmospheric instability, these indices have to be correlated with other information regarding the dynamics in the medium and inferior atmospheric strata.

The present analysis shows that the instability produced due to the "cut off" type nuclei is quite difficult to forecast through the atmospheric stability indices, hence supplementary methods are necessary.

Another highlighted aspect is that the stability indices analysed, which take into account the humidity of several atmospheric strata, are the best for identifying the instability potential of the atmosphere (KI, K_{MOD}, TTI, TT_{MOD}, LI).

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