THE ROLE OF AIR ADVECTION AND ATMOSPHERIC STABILITY INDICES FOR IDENTIFING HEAVY RAIN STORMS IN NORTH-WESTERN ROMANIA

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ABSTRACT. - The role of air advection and atmospheric stability indices for identifying heavy rain storms in north-western Romania. Air advection and convection at different levels in the atmosphere affect its vertical stability. The degree of stability / instability can be determined by using vertical wind profile (hodograph) and stability indices. Analysis of these two elements was used to determine the degree of atmospheric instability for heavy rains in north-western Romania, for the warm season of the 2010-2012 period. The hodographs were made using the atmospheric soundings in Cluj-Napoca, which permitted to determine the air advection intensity between different layers of the atmosphere (sea level-925 hPa, 925-850 hPa, 850-700 and 700-500 hPa). The atmospheric stability indices were used to calculate the intensity of instability. The results show that for an unstable environment a warm advection in the lower layers of the atmosphere and a cold one, in the middle layers are needed. On the other hand, in the case of stability indices, the most useful for assessing atmospheric instability are those that include data about air moisture near the ground level.

Keywords: air advection, hodograph, atmospheric stability indices, rainfall, north-western Romania.

1. INTRODUCTION

Heavy rains are extreme rainfall events with negative effects on both the natural environment and society. This is the reason why conceptual models were used in order to easily identify favorable occurrence situations of these events. Regardless of its nature, atmospheric instability is an essential element in producing heavy rains and that is why knowing certain characteristics of atmosphere structure is very important for anticipating these rains.

Both thermal convection and air advection in a layer affect the vertical stability of the atmosphere. Thus, the determination of air instability in the atmosphere can be accomplished through analysis of hodograph and atmospheric stability indices.

In the common form, the atmospheric stability indices are a measure of potential severe weather and considered to be representative at synoptic scale. ***K Index,*** used to determine the instability of air masses uninfluenced by frontal or cyclonic activity, is considered to show the increase of air masses instability in the

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case of values higher than 20 (George, 1960). ***Vertical Totals Index (VT)*** indicates the occurrence of convective storms when its values are greater than 26, values above 30 indicating moderate storms (Miller, 1967 Miler et al., 1972, 1975). ***Cross Totals Index (CT)*** indicates the occurrence of storms in the case of values higher than 18 (Miller, 1967 Miler at al., 1972, 1975). In the forecasting activity, ***Total Totals Index (TTI)*** is used to determine the location of the area with convective storms, when its values are greater than 44, and ***Lifted Index (LI)*** is used to determine the potential stability of the atmosphere to produce thunderstorms.

2. DATA AND METHODS

The analysis used data about heavy rains from 15 meteorological stations and, respectively, rainfall and hydrometric stations in north-western Romania (North Transylvania Regional Meteorological Centre Archive), in the warm season of the period 2010-2012 (April-October), resulting a number of 136 measuring points (Fig. 1). The torrential characteristic of rainfall was determined based on its intensity (Dragotă, 2006), using the 24 mm / hour threshold (or its equivalent in a shorter time). The data from atmospheric soundings are at least 12 hours prior to the occurrence of convective cells generating heavy rains.

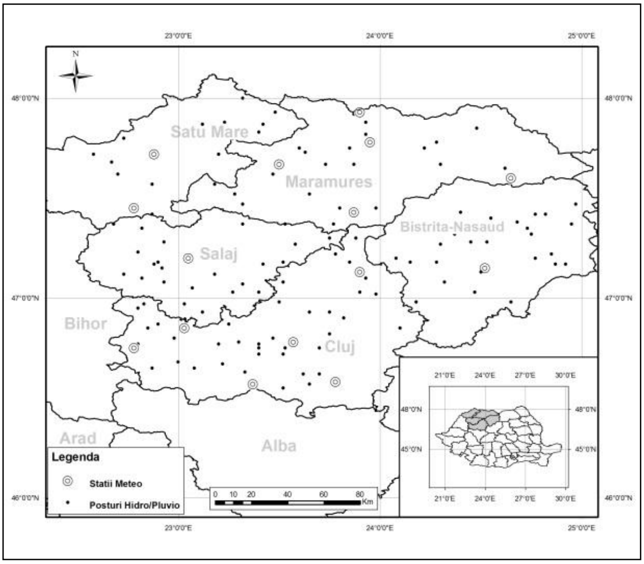


Fig. 1. ***Spatial distribution of heavy rains occurrence in the warm seasons of 2010-2012 period.***

Regarding the methodology, it was determined the type and characteristics of air advection in the lower and middle layers of the atmosphere, as well as the atmospheric stability indices based on the atmospheric soundings in Cluj-Napoca at 00 UTC in the case of each torrential rain. The purpose was to establish the use of these soundings for anticipating instability generating heavy rainfalls in the studied area.

Advection type (warm, cold or neutral) was determined individually for each atmospheric layer analyzed (surface-925 hPa, 925-850 hPa, 850-700 hPa, 700-500 hPa), based on the hodograph resulting of the atmospheric soundings in Cluj-Napoca. Wind direction and speed were determined beginning with the lower levels of the atmosphere (Holton, 2004), and advection area for each atmospheric layer mentioned above was calculated, knowing that instability intensity is directly proportional to the intensity of advection. Finally, the changes in thermal stability of the atmosphere were determined by comparing the area of triangles for each type of advection in the atmospheric layers (http://www.met.wau.nl/education/atmospract/).

Depending on the shape of hodograph, two situations were noticed: the first, in which advection has the same character (hot or cold) for the entire atmospheric column considered; the second, in which advection has a different character. In the first case, the instability occurs when warm advection is greater in the lower layers or when cold advection is more intense in the upper layers. In the second case, atmospheric instability can occur in several situations: warm advection in the lower layers, respectively cold advection or no advection in the medium layers of the atmosphere; warm advection in the medium layer and cold advection in the lower and upper layers of the atmosphere (in this case instability is occurring from the medium to the upper levels of the atmosphere); cold advection in the middle layers and warm advection in the upper and lower layers, generating atmospheric instability between the lower and middle levels of the atmosphere (http://www.met.wau.nl/education/atmospract/).

The mathematical expressions of stability indices are:

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

$VT=T_{850}-T_{500}$, (2), (Miller, 1967)

$CT=T_{d850}-T_{500}$, (3), (Miller, 1967)

$TTI=T_{850}+T_{d850}-2T_{500}$, (4), (Miller, 1967)

$LI=T_{500}-T_{p500}$, (5), (Sadowski and Rieck, 1977), where:

T_{850}, T_{700}, T_{500}, air temperature at 850, 700 and 500 hPa levels;

T_{d850}, T_{d700}, dew point temperature at 850 and 700 hPa levels;

T_{p500}, moist adiabatic temperature of the particle lifted from the surface to 500 hPa level.

Charba (1984) brings some changes in the computation of KI and TTI indices (**K_{MOD}** and **TT_{MOD}**), taking into account air and dew point temperature near the surface level:

$K_{MOD}=(T-T_{500})+T_d-(T_{700}-T_{d700})$, (6)

$TT_{MOD}=T+T_d-2T_{500}$, (7), where:

$T=\frac{(T_{sfc}+T_{850})}{2}$, $T_d=\frac{(T_{dsfc}+T_{d850})}{2}$,

T_{sfc}, T_{dsfc}, air and dew point temperature near the surface.

3. RESULTS AND DISCUSSIONS

In the period under study, 86 days with a total of 444 heavy rainfall events were found, the highest frequency being in June (47.3% of total) and July (26.6%), regardless of the year in question. Diurnal variation shows that they are more frequent in the afternoon and evening, 84.9% occurring between 13:00 and 20:00 hours (Romania Summer Time), with two moments of maximum: 14:00-15:00 and 17:00-18:00, especially in June and July (Fig. 2).

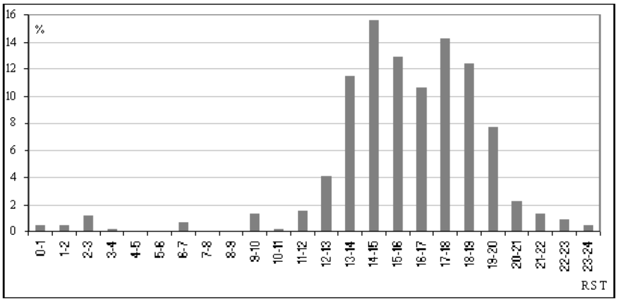
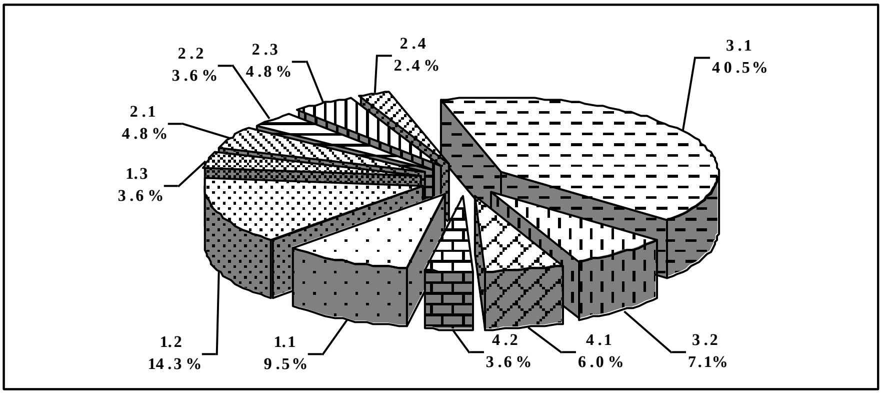


Fig. 2. ***Diurnal variation of heavy rains in 2010-2012 period (%).***

The study of intensity of air advection within the layers mentioned above shows the following situations (Fig. 3): warm advection, with a vertical decrease of intensity; warm advection, with a vertical increase of intensity; warm advection, with vertical increase of intensity and then a decrease of it; cold advection, with vertical increase of intensity; cold advection, with vertical decrease of intensity; cold advection, with vertical decrease of intensity and then an increase of it; cold advection, with vertical increase of intensity and then a decrease of it; warm advection in the lower part of the atmosphere and cold advection in the middle layers; cold advection at the bottom of the atmosphere and warm in the middle layers; cold advection with warm intrusions; warm advection with cold intrusions.

The frequency analysis of advection type reveals high percentages of the cases where low levels of the atmosphere produces a warm advection, and a cold one in the middle layers of the atmosphere (40.5%), followed by the cases where warm advection intensified with the altitude (14.3 %). The other situations had a lower frequency of occurrence. It should be noted that the situations marked in Figure 3 by numbers 1.1, 1.2, 1.3, 2.1, 2.2, 2.3, 2.4 and 3.1 (cumulating 63.1%) generate atmospheric instability, those marked with 4.1 and 4.2 (9.5% of cases), are in favor of conditional instability, while in the case of situation 3.2 (7.1%), it does not directly generate atmospheric instability. A similar situation occurs when the cold advection intensity decreases with altitude (case 2.2). The same situation is when, initially, the cold advection intensity increases, followed by its decrease in the higher layers (case 2.4). In all the above mentioned cases, the cold advection is more intense in the medium layers of the atmosphere (700-500hPa) than in the lower ones.



1.1- vertically decreasing intensity of warm advection; 1.2 – vertically increasing intensity of warm advection; 1.3 – vertically increasing intensity of warm advection, and decreasing of it to the top; 2.1 – vertically increasing intensity of cold advection; 2.2 – vertically decreasing intensity of cold advection; 2.3 – vertically decreasing intensity of cold advection, and increasing of it to the top; 2.4 – vertically increasing intensity of cold advection, and decreasing of it to the top; 3.1 – warm air advection at the bottom of the atmosphere and cold advection at the top; 3.2 – cold air advection at the bottom of the atmosphere and warm advection at the top; 4.1 - cold advection with warm intrusions; 4.2 - warm advection with cold intrusions.

Fig. 3. ***Air advection type frequency (%) based on hodograph from Cluj-Napoca atmospheric soundings, in the cases of heavy rains in 2010-2012 period***

In the case of ***K Index***, the analysis notes extreme values between 13.9 and 40, the highest frequencies being recorded in the case of 31-35 thresholds (45.2%), followed by 26-30 and 21-25 ones (Fig. 4a). Overall, values greater than 31 (expressing the probability of occurrence of convective storms over 60%), predict only half of the expected heavy rains (51.2%) and those over 36, only 6%. $\boldsymbol{KI_{MOD}}$ is characterized by values between 20.2 and 44.6, the highest frequencies belonging to 36-40 thresholds (40.5%) and 31-35 (35.7%); values higher than 31 anticipate 81% of the heavy rains, and those over 36, 45.2% of the torrential rains (fig. 4a).

VT Index values stand between 23.3 and 32.1 pointing out the large share of values below 30, representing moderate storms thresholds (Fig. 4b). The high frequency of lower thresholds of this index (50% belonging to the 27-30 thresholds, and 33.3% in the case of 25-26 thresholds) makes it less useful in predicting storms generating torrential rains.

CT Index is characterized by extreme values of 14.5 and 27.0, pointing out the large share of 20 - 21 thresholds (35.7%) and 22-23 thresholds (22.6%) (Fig. 4 c). The analysis show that in the 73.8% of cases, there is strong potential for storms (CT is greater than 20), in 38.1% of cases the potential of severe storms is weak (values greater than 22), the remaining situations belonging to moderate and high potential.

The ***TT Index*** is characterized by high frequency of 48-50 and 46-48 thresholds, corresponding to moderate and severe storms, which cumulate 50% of the cases (Fig. 4d). Cumulative frequencies reveal that 86.9% of the heavy rains cases correspond to values of TTI higher than 46, 64.3% of them are over 48, and

36.9% of the total heavy rains have values of this index greater than 50 (corresponding to severe storms and tornadoes). In the case of ***TT$_{MOD}$* Index**, it can be noted high percentage of values over 50 (Fig. 4d), the highest frequencies characterizing the thresholds 52-56 (52.1%) and 50-52 (21.4%), severe storms (with TT_{MOD} > 50) summing up to 90.5% of the total.

Lifted Index (LI), used as an additional predictor of latent instability, presents extreme values between -5.8 and 5.5, pointing out the high percentage of the positive values (57%). Overall, the dominant threshold is -2 ... 1 (47.6%), followed by its positive values (Fig. 4e), only 16.7% of cases explaining the occurrence of thunderstorms.

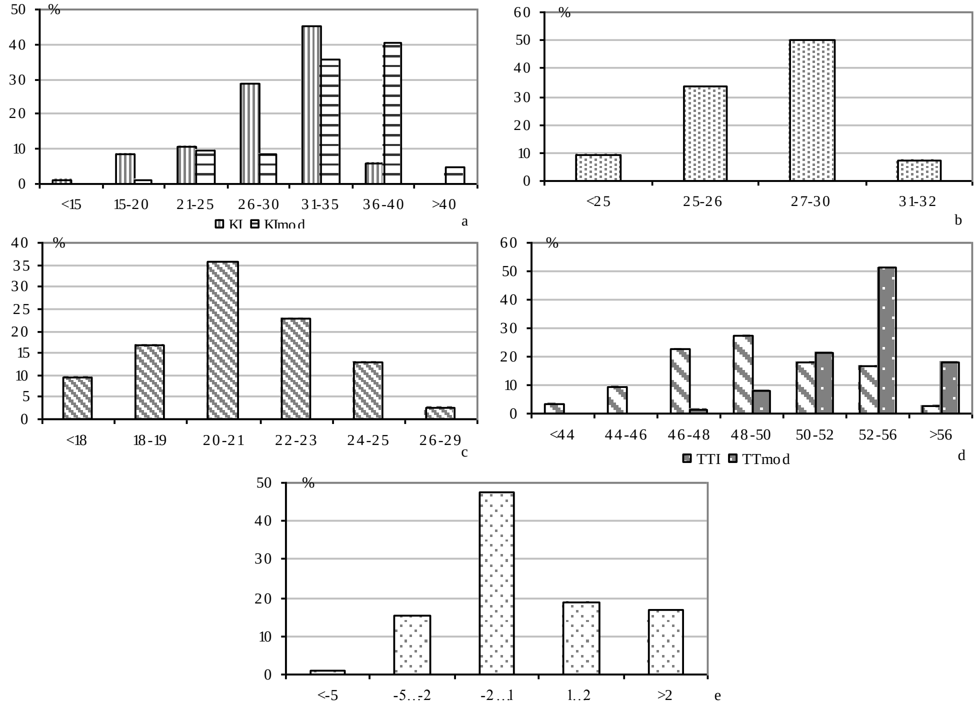


Fig. 4. ***Class values frequency (%) of KI and KI$_{MOD}$ (a), VTI (b), CTI (c), TTI and TT$_{MOD}$ (d), and LI (e) for heavy rains in the period 2010 -2012***

To illustrate the role of the stability indices in spatial extension of heavy rains, for each of the 86 days in which such rains were recorded, a statistics were made considering the number of heavy rains cases per day and the amount of precipitation recorded for each case. For an easier approach of examination, three cases were taken into account: medium and large spatial extension of heavy rains (over 7 cases/day); large quantities of precipitation per each torrential event (>25 mm/event/day) and the mixed case.

In the situation of medium and large number of torrential rain events, the following statistics can be noted: ***LI Index*** has values between -2.6 and 1.6, the dominant values being positive; ***KI*** shows values between 20.1 and 33.9, the most common being above 30 (which indicates a 50% probability of convective storms), and $\boldsymbol{KI_{MOD}}$ is between 24.7 and 40.2; ***VT Index*** has values between 24.3 and 32.1; ***CT Index*** has a range between 19.3 and 23.5, indicating strong potential for storms and weak potential for severe storms; ***TTI Index*** has values of 43.6-53.2, suggesting low intensity storms, and $\boldsymbol{TT_{MOD}}$ is between 48.7-59.6, indicating strong storms.

If large quantities of precipitation per each torrential event is taken into analysis, atmospheric stability index structure is as follows: ***LI*** between -0.2 and 3.1; ***KI*** between 24.9 and 32.3, most of the cases exceeding 30; $\boldsymbol{KI_{MOD}}$ between 26.4 and 36.8, most of the values over 35; ***VT*** between 23.5 and 30.5; ***CT*** between 18.5 and 23.9; ***TTI*** values over 44 (between 44.1-50.4) and $\boldsymbol{TT_{MOD}}$ between 48.9 and 53.5.

For the mixt cases (over 7 cases of heavy rains/day and more than 25 mm of precipitation/event/day), atmospheric stability indices are as follows: ***LI*** between -5.9 and 0.6; ***KI*** between 28.9 and 40; $\boldsymbol{KI_{MOD}}$ between 34.2 and 44.6; ***VTI***, between 24.3 and 32.1; ***CTI***, between 17.3 and 26.0; ***TTI*** between 43.6-57.2; $\boldsymbol{TT_{MOD}}$ between 48.7 and 59.9. It can be seen that, by comparison with previous cases, in the mixed situations each index has higher values.

4. CONCLUSIONS

This analysis took into account the use of certain elements determined by atmospheric soundings in predicting atmospheric instability that generates torrential rain in the north-west of Romania. However, the analysis was not aimed at identifying the place and time of heavy rain occurrence, but at the possibility of its genesis.

The use of hodograph for identifying the type of air advection is useful in determining atmospheric instability, remarking the dominance of the warm advection in the lower layers of the atmosphere and the cold one, in the middle layers. As it has been noticed in 14.3% of the cases, in order for the air to get more unstable, an intense warm advection into the lower and middle atmosphere is essential. Conditional instability caused by the existence of thermal inversions developed in the lower layers of the atmosphere has also an important role in favoring the occurrence of torrential rainfalls (9.5% of cases).

For determining the atmospheric stability, the most useful indices are the ones which include data about the air moisture in the lower atmosphere ($\boldsymbol{K_{MOD}}$, ***CT*** and $\boldsymbol{TT_{MOD}}$). Since most of torrential rain events are a result of convective systems generated or amplified by diurnal heating, the analysis based on atmospheric soundings recorded during daytime (12 UTC) would be more useful.

Finally, it must be noted that the elements presented in the paper, along with some other weather forecast methods, can be used as supporting tools in predicting the probability of heavy rain occurrence.

REFERENCES

1. Charba, J. P. (1984), *Two-to-six hour probabilities of thunderstorms and severe local storms.* NOAA NWS TPB-342, 14.
2. Dragotă, Sofia-Carmen (2006), *Precipitațiile excedentare în România*, Editura Academiei Române, Bucureşti, ISBN: 973-27-1435-2.
3. George, J. J. (1960), *Weather Forecasting for Aeronautics*, New York, Academic Press, p. 407-415.
4. Holton, J. R. (2004). *An Introduction to Dynamic Meteorology*, New York, Academic Press. ISBN 0-12-354015-1.
5. Miller, R. C. (1967), *Notes on analysis and severe storm forecasting procedures of the Military Weather Warning Center*, Tech. Report 200, AWS, USAF. [Headquarters, AWS, Scott AFB, 1L 62225].
6. Miller, R. C., Bidner, A., and Maddox, R. A. (1972), *The use of computer products in severe weather forecasting (the SWEAT index)*, Air Weather Service Aerospace Sciences Review. AWS RP 105-2, No. 72-1, p. 2-9.
7. Miller, R. C., Maddox, R. A. (1975), *Use of the SWEAT and SPOT indices in operational severe storm forecasting*, Preprints. Ninth Conf. Severe Local Storms. Norman, American Meteorological Society, p. 1-6.
8. Sadowski, A.F., Rieck, R.E. (1977), *Stability indices*, NOAA NWS TPB-207, 8 p.
9. *** http://www.met.wau.nl/education/atmospract, accessed on January 14th, 2015.
10. *** Transylvania North Regional Meteorological Centre Archive, Cluj-Napoca.