ATMOSPHERIC INSTABILITY IN URBAN AREA OF CLUJ-NAPOCA, ROMANIA

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***ABSTRACT*. – Atmospheric instability in urban area of Cluj-Napoca, Romania.** An analysis of the distribution of precipitation amounts in the range of 10-50 mm/24h in 2006-2011 was made, having as result a distribution of precipitation of amounts larger than 20 mm mainly in the summer and a distribution of precipitation with values of less than 20 mm in all seasons. A total of 32 cases of heavy rain with intensity greater than 10 mm/h were identified, these being most common in July. From the analysis of the probability of precipitation not exceeding certain thresholds, it was found that values of 10 mm/h have a probability of non-exceedance 10% for a non-returning period of 1.1 years. In the second part of the paper, a case of pronounced instability - the afternoon of May 20, 2011, in Cluj-Napoca area - that prompted large amounts of water from rain associated with lightning and brief strong wind, which led to flooding on large portions of the city was studied.

Keywords: instability, precipitation, rain, floods, Cluj-Napoca

1. INTRODUCTION

In the late spring and in the summer season, mass instability situations have higher frequency (of appearing) than the front ones and often lead to more intense phenomena. Worldwide, there are concerns for studying quantitatively significant rain fallen in a short period of time over some cities, and the way the urban zones influence precipitation.

Impacts of urban processes and urbanization on a localized, heavy summer rainfall in Beijing (Miao et al., 2011), the effects of a large city on a heavy rainfall in Tokio, Japan (Inamura et al., 2011) and the impact of the urban heat island effect on precipitation over a complex geographic environment in northern Taiwan (Lin at al., 2011) were investigated. Extreme weather events, among which the heavy precipitation during one day is included, represent a major risk for the population and the economy.

Worldwide research on the background of daily precipitation totals for the analysis of the evolution during longer time periods and a larger number of meteorological stations were done by Alfnes and Forland (2006), who studied the daily precipitation in Norway between 1900-2004. The extreme precipitation totals for various durations (from 1 to 5 days) for the 1901-2000 period have been

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analyzed in Slovakia in connection with global warming (Gaál and Lapin, 2002). Studies relating to extreme precipitation on the entire Europe were also realized (Haylock and Goodess, 2004).

In Romania the annual maximum of daily precipitation amounts for successive years over the period 1961-1996 and the absolute maximum of the maximum daily precipitation amounts were determined by Cazocioc (2007). The maximum daily amount of precipitation is one of the extreme climate indices with potentially strong and dangerous hydrological consequences. Urban surfaces tend to cause the rainfall to be more locally concentrated. High-rise urban cores may bifurcate the path of rainfall as well as increase the area percentage of heavy rainfall.

2. DATA AND METHODS

Data from the hourly and daily meteorological measurements obtained from meteorological station Cluj-Napoca for the 2006-2011 period was used. For the synoptic analysis, ground level and altitude maps of the standard isobaric surfaces of 500 and 850 hPa maps were used. Radar data from the Doppler WSR-98D radar at Bobohalma were analyzed: Reflectivity, Composite Reflectivity, VIL's, OHP's, and atmospheric soundings survey data from Cluj-Napoca and Satellite imagery from the Meteosat satellite, visible in RGB 17.

3. DAILY PRECIPITATION IN THE 2006-2011 PERIOD

Precipitation amounts with values greater than 10 mm in 24 hours between 2006-2011, and precipitation with values above 10 mm/h which induce torrential rainfall were analyzed.

The absolute maximum of daily precipitation amounts (57.4 mm/24 h) was recorded on the 26th of August 2007. The analysis of the temporal variability of the daily precipitation amounts between 2006-2011 is shown in fig. 1.

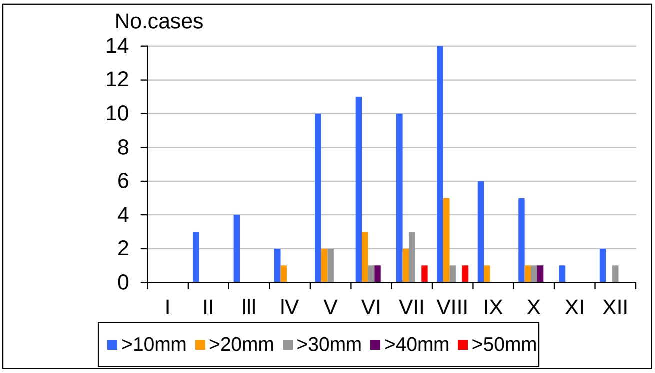

Fig.1. ***Daily precipitation between 2006-2011***

Cases with rainfall between 10 and 20 mm/24h were mainly recorded in the summer months, with a maximum of 14 cases in August, such cases were also present in other months of the year, except January. Amounts ranging from 20 to 30 mm/24h were recorded starting in April, until October, with a maximum of 5 cases in August. Values between 30 and 40 mm/24h are most common in June, but also present in May, July, August, October and December. Precipitation amounts greater than 40 mm/24h were reported in June and October, and those that exceed 50 mm/24h are typical to the summer months July and August. Larger amounts of precipitation are more common in summer months, caused by thermal convection due to higher temperatures and heat island influence the city.

A total number of 32 cases of heavy rains with intensities greater than 10 mm/1h in the 2006-2011 interval were identified. They are most common in July (37%), followed by August (28%), June (19%) and May (16%), which is presented in fig. 2.

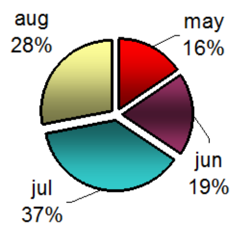

Fig. 2. ***Heavy rain***

An analysis to determine the probability of non-exceedance was performed (Haidu et al., 2002), using the Hyfran program. Probabilities of non-exceedance values greater than 10 mm/h and their non-returning period were obtained. Previously, several non-parametric tests were performed in order to test whether the data was independent and identically distributed. The empirical formula for probability used for this application was Gumbel's formula, plotted in fig. 3. A series of 32 values ranging between 10.2 mm/h and 24.6 mm/h, for a period of 6 years (2006-20011) to a confidence level of 99% were used.

For the 10.4 mm/h value, the probability was of 10%, for a non-returning period of 1.11 years.

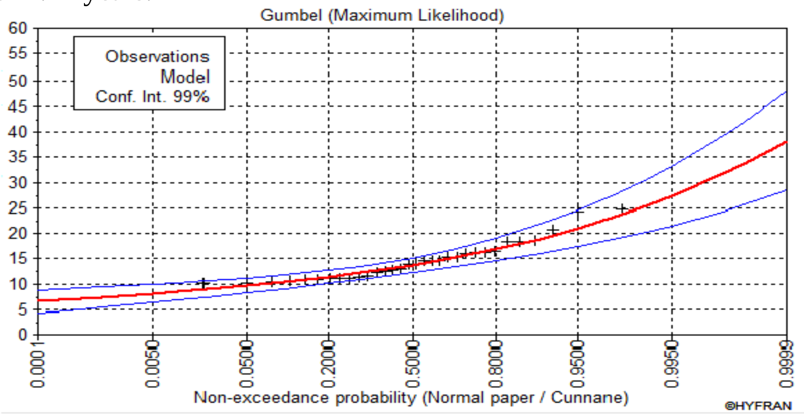

Fig.3. ***Curve of empirical probability of non-exceedance***

For a quantity of precipitation of 15 mm/h, the non-returning period is 3 years, with a probability of non-exceedance of 67% and for amounts over 25 mm/h the non-returning period is 100 years, with a probability of non-exceedance of 99%, fig. 3.

4. CASE STUDY – 20TH OF MAY 2011

The events that took place in the afternoon of the 20th of May 2011 have been associated to mesoscale processes, which play a major role in initiating thermal convection. Water drainage in the case of rain falling on the surfaces in urban areas is done different, depending on the amount of rain water and the torrential character of the rain which is due to the modification of the thermal radiative. Reducing the time period of the concentration of rainwater is a result of the replacement of natural drainage network with a dense drainage network and has as consequence an increase of speed of gully erosion of water on roads and on other water drainage networks whose hydraulic resistance coefficient (roughness) is small (Stanescu, V., A., 1995).

For urban flood warning and the forecast of short duration rainfall events, the weather radar enables real-time surveillance of large areas. Weather radar applications are also used to determine the path of movement of the rain, it being a modern tool used for investigating the atmosphere, useful in urban flood warning. The duration of a weather event is with the speed and size of the convective system that produces the event in along the direction of movement of the system. The amount of precipitation is what distinguishes a regular type rain from that which can cause flooding.

4.1. Synoptic situation

For the synoptic analysis maps of altitude, geopotential field and temperature from 850 to 500 hPa and soil maps from wetterzentrale.de were used. At ground level, on the 20th of May 2011, at 00 UTC, our country was under the influence of a high pressure field caused by the expansion to the south of the ridges of the Eastern European Anticyclone. In Romania the pressure at ground level was high, measuring 1025 hPa. The Island Low is active in the north and northwest parts of Europe, and the trough connected to it dominates the coasts of Great Britain and the Scandinavian Peninsula, where three low pressure centers with values of 995 hPa and 1000 hPa have developed, one in the northern part of the Scandinavian Peninsula and the other ones above Northern Ireland and Northern Russia.

At the 500 hPa isobaric level, it can be seen that the central area of Europe is located at the 573-574 gpdm level. The area of high level geopotential extends from the northeast part of the continent to the southeast part, reaching the south of Spain. Above Romania values of 573-574 gpdm are recorded.

Above the western part of Europe a ridge is active, linked to the Island Low, extended over the northern part of Europe and having several low pressure centers , one on the north of Great Britain with values of 515 gpdm and a cold air mass with temperatures of -38°C, and one centered on northern Russia, having values of 538 gpdm and -26°C, which in the next few days will come across the continent with the ridge moving towards the south, southeast (fig.4).

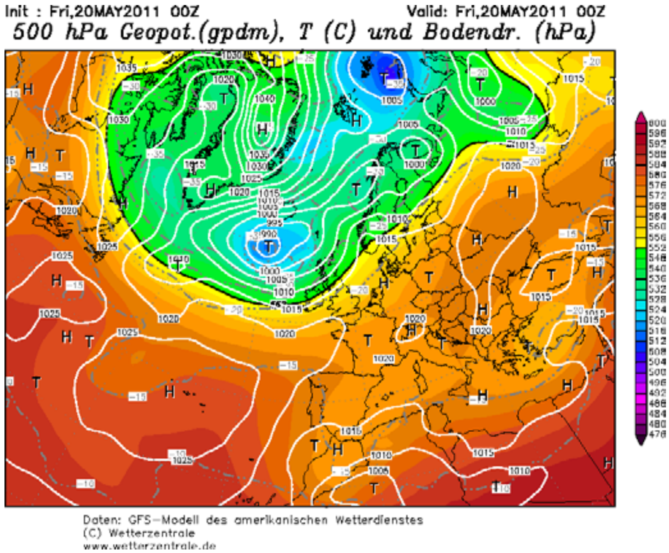

Fig.4 . ***Geopotential fields at 500hPa and distribution of isopleths at 20.05.2011***

At the 850 hPa isobaric level, above Romania, the extension of a ridge can be observed that crosses the European continent from south-west towards north-east, with a low pressure centers with values of 156 gpdm. The thermal ridge with temperature values of 10°C situated the north of our country determines a warm and wet air advection from low levels, being a basic ingredient of ascending at a synoptic scale, causing a mass instability which favors the onset of convective events during the afternoon of the 20th of May.

4.2. Radar and satellite data analysis

Data and radar images were received from the WSR98D radar from Oradea and Bobohalma, using OmniWeatherTrack and PUP applications, which allow the display on the screen the radar products. On the 20th of May 2011, several convective cells developed in the Cluj-Napoca area. For the composite reflectivity, which shows the highest intensity on a vertical column regardless of the height of storms, the threshold of 40dBZ was used as a marker to identify areas where the deep convection can be triggered, and the 50 dBZ threshold was used to locate areas with mature thunderstorms, which could produce severe weather phenomena.

Intense convective activity in the Cluj–Napoca city area is observed at 18:23 UTC, with values up to 45 dBZ, according to the Bobohalma radar estimates. (fig. 5).

For the VIL Index (Vertical Integrated Liquid), for the estimation of liquid water contained in a storm, the value of 25 kg/m^2 was used as the threshold for potential production of large quantities of precipitation. VIL is also used for the probability of the creation of hail and detecting the presence hail. For values greater than 20 kg/m^2, it can be associated with severe hail. At 18:29 UTC, near the city of Cluj-Napoca, the Bobohalma radar estimated that the liquid water contained in the storm had values of 25 kg/m^2 (fig.6). For the OHP products (1 hour precipitation), which shows the horizontal distribution of rainfall expected over a period of one hour, the threshold of 25 mm was used as lower limits for the accumulation of amounts of precipitation that can cause damages. For the time period when the systems reached the maximum level of development near the city of Cluj-Napoca the OHP product had maximum rainfall amounts of up to 50.80 mm (fig. 7).

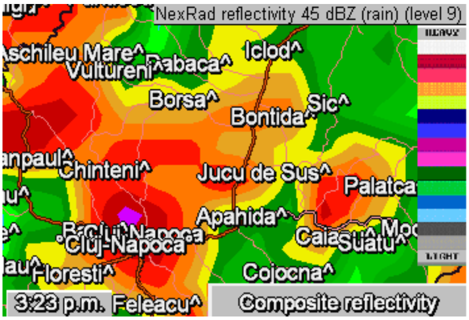

Fig. 5. ***Composite reflectivity, at 18:23***

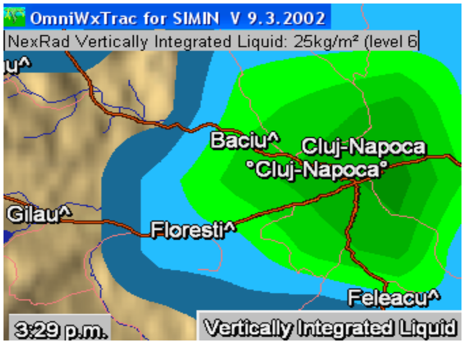

Fig. 6. ***VIL, at 16:29 UTC (RDBB)***

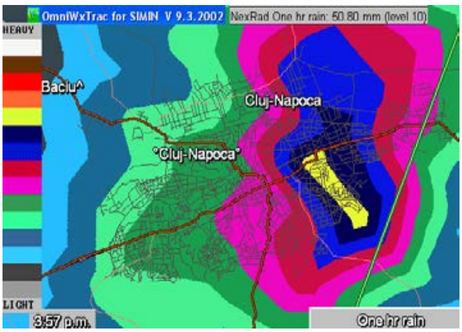

Fig.7. ***OHP, at 16:57 UTC (RDBB)***

4.3. Sounding data analysis

Instability index value determined from the sounding survey at 00 UTC, reflect the degree of mass instability in Cluj-Napoca on the 20th of May at 00 UTC. *Precipitable water (mm) for entire sounding* (C_a), which represents the amount of liquid water (in mm) that could fall on the ground after precipitating the entire volume of water vapor existing in a vertical column 1 m^2 section, extended from the ground up to level of 100 hPa, has values over 21 mm. The *K Index* (KI), which is used to identify convective environments that produce heavy rain and the likelihood of non-frontal storms, shows a probability of thunderstorms between 40-59%. *Lifted Index* (LI), has a value of 0.77 associated with weak instability, with showers. *Vertical Total Index* (VTI), which is directly related to the vertical thermal gradient between the 850 and 500 hPa levels, representing the intensity of vertical transport, turbulent air had values of 30.5°C, indicating the production of strong convective storms, at values larger than 25 °C. *Total Total Index* (TTI) another severe weather index, with a value of 52.00 indicates the production of powerful storms. All indices reflect an increased degree of instability.

In Cluj-Napoca, on the 20th of May, the weather was warm and generally unstable. The sky was variable, temporarily cloudy during the afternoon when rain fell, accompanied by lightning. The rain had torrential character. The maximum amount of water was: 22.2 l/sqm.

The evolution of meteorological parameters: air temperature, precipitation and wind evolution at weather station can be seen in fig.8. The maximum intensity of rain in the afternoon of the 20th of May was 1 mm/min. Hail fell in some areas of the city.

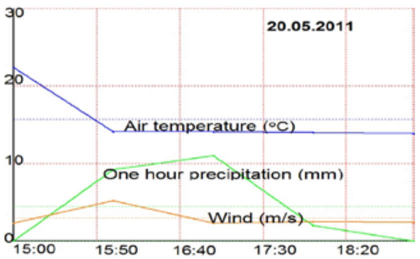

Fig. 8. ***Evolution of meteorological parameters on 20.05.2011***

Due to the large amount of water fallen in a short period of time and its concentration on the impervious surfaces of the city, there were floods. According to the representatives of the Inspectorate for Emergency Situations (ISU), the rain led to flooding of basements of houses and buildings from different districts of Cluj. Rain disrupted the traffic in the city and sewers system could not cope with the large quantities of water. The Alexandru Ioan Cuza Street was filled with water, its level reaching almost to the knees of passerby, and the underground parking from the "Leul" center was flooded by all the water discharged from the street.

5. CONCLUSIONS

An analysis of the distribution of precipitation amounts in the range of 10-50 mm/24h in 2006-2011 was made, having as result a distribution of precipitation of amounts larger than 20 mm mainly in the summer and a distribution of precipitation with values of less than 20 mm in all seasons.

The absolute maximum of precipitation in 24 hours was registered on the 26th of August 2007 (57.4 mm).

From the analysis of the frequency of the probability of non-exceedance of certain thresholds, it follows that values of 10 mm/h have a probability of non-exceedance of 10% for a non-returning period of 1.1 years.

A total number of 32 cases of heavy rain with intensity greater than 10 mm/h were identified, this being most common in July.

Thermal instability in the afternoon of the 20th of May caused precipitation with torrential character with lightning and hail to occur.

Large amounts of rainfall in a short time period led to a rapid concentration of flood waters in the urban area, causing flooding of streets, yards and basements in the lower area of the city.

For the prevention and protection against floods as natural hazards in urban areas, experts from all areas can contribute by locating high-risk flood areas and creating vulnerability at floods due to heavy or torrential rains maps of the city.

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REFERENCES

1. Alfnes F., Forland, E., J., (2006), *Trends in extreme precipitation and return values in Norway 1900-2004.* Norwegian Meteor. Institute-Report 2/2006, 40 pp.
2. Cazacioc L., (2007), *Spatial and temporal variabilityof extreme daily precipitation amounts in Romania*. Romanian Journal of Meteorology, vol.8, no.1-2, 2007
3. Gaál, L., Lapin, M., (2002), *Extreme several day precipitation totals at the Hurbanovo observatory (Slovakia) during the 20th century.*Contributions to Geophysics and Geodesy, vol **32/3**.
4. Haidu, I., Sorocovschi, V., Imecs, Z., (2002), *Utilizarea S.I.G. pentru estimarea riscului de producere a evenimentelor extreme: excesul de umiditate si seceta din Campia Transilvaniei,* Riscuri si catastrofe, vol.2.
5. Haylock, M., R., Goodess, C., M., (2004), *Interannual variability of European extreme winter rainfall and links with mean large-scale circulation*. International Journal of Climatology, **24,** no. 6, 759-776.
6. Inamura, T., Takeki, I., Hiroshi, M., (2011), *Diagnostic study ofthe effects of a large city on heavy rainfall as revealed by an ensemble simulation: a case study of central Tokio,* Japan. J. Appl. Meteor. Climatol., **50**, 713-728.
7. Lin, C., Wan-Cin, C., Pao-Liang, C., Yang-Fan, S., (2011), *Impact of the urban heat island effect on precipitation over a complex geographic enviroment in northern Taiwan.* J. Appl. Meteor. Climatol., **50**, 339-353.
8. Miao, S., Fei, C., Qingchun, L., Shuiyong, F., (2011), *Impact of Urban Proccesses and Urbanization on Summer Precipitation: a case study of heavy rainfall in Beijing on August 2006.* J. Appl. Meteor. Climatol., **50**, 806-825.
9. Stănescu, V.,A., (1995) *Hidrologie Urbana,* Editura Didactică şi Pedagogică, R.A. – Bucureşti.
10. www.wetterzentrale.de