Meteorological Causes of Flashflood in Pila Village (Slovakia) on 07/06/2011.

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Abstract
Several villages on the Eastern foothill of Male Karpaty Mountains were affected by flashflood, especially Píla village, in the afternoon on 7th June 2011. Meteorological conditions in the atmosphere just before the flashflood occurrence are analyzed in this short case study. The mentioned flashflood was caused by a few thunderstorm cells initiated by instability in warm wet air mass and supported by upward motions on the slopes of Male Karpaty Mountains.

Keywords*: flashflood, convective phenomena, intensive thunderstorms, stability indexes*

Introduction

Flashfloods, caused by heavy rainfall over a small area, are associated with convective phenomena, which is a global name for the phenomena of strong updraft movements that produce a huge vertical clouds (Cb), thunderstorms, downpours, hailstorm, strong wind gusts and tornadoes. It is difficult to forecast the convective phenomena, because of their complexity, small spatial dimensions, fast, dynamic and nonlinear development. Their precise local prediction and quantification is currently possible to be forecasted for a period not longer than a few tenths of minutes. However, they also represent one of the most dangerous weather events that occur in our country. In most cases, it is mostly impossible to stop the flood wave caused by heavy rainfall and within several minutes, a small stream of average flow turns into a massive and fast-flowing river, taking away everything on its way.

Weather situation

The main synoptic structure, controlling the flow over Europe during 7 June 2011, was cyclone over Ireland (Fig. 1). The deepening upper level trough was spread from the aforementioned cyclone to Spain and north-west Africa. Central Europe area was at its front side. Over Central Europe area there was a slight south-west flow prevailing in the upper level of the atmosphere, with the mean sea level pressure 1010hPa and only a small pressure gradient. The pressure field as well as the upper flow remained substantially unchanged.

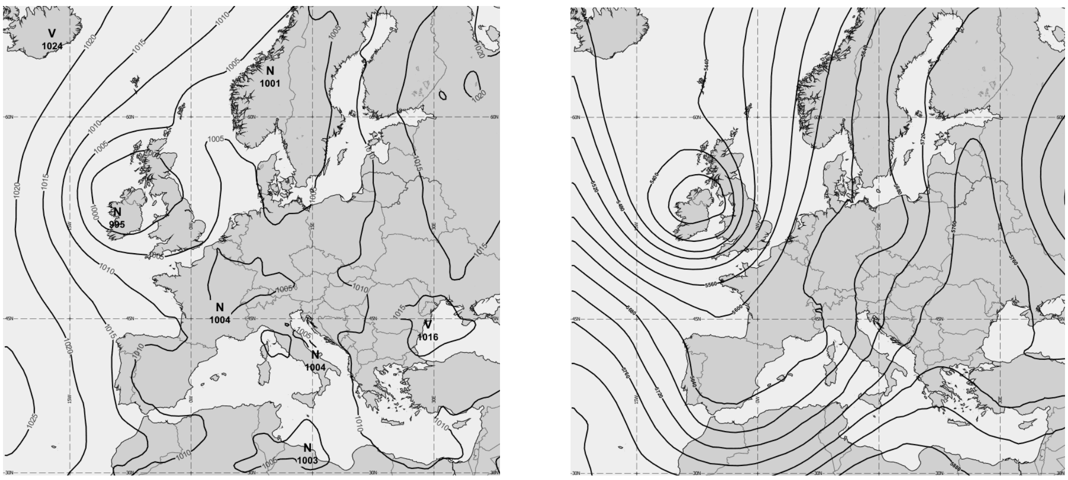

Fig. 1: Pressure field over Europe on 7 June 2011, 12 UTC (on the left: isobars of mean sea level pressure, on the right: absolute topography 500 hPa level)

The warm and moist air mass was spread over the Slovak region on 7/June/2011. The air temperature at 850 hPa level was 12 to 14℃, maximu m daily air temperature in western Slovakia was 25 to 29 ℃ on 6th and 7th June. This very warm air was being over this area since 30 May (8 days) and maximum air temperature in Bratislava was about 4℃ higher than the long-term average value for this season. Relative humidity at 700 hPa level ranged from 60 to 90% during the midday hours, at 925 hPa level it even ranged from 85 to 94%.

The higher amount of low level humidity is shown also by vertical time-section for Bratislava calculated from the ALADIN model, the value of humidity of more than 70% can be seen in all layers from the ground upwards to the height of about 3.5 km. Higher amount of humidity in the lower troposphere contributed to slight to moderate air mass instability.

When examining the wind field in the lower levels of the troposphere, we can find considerable vertical shear. Wind speed was not high, but the wind direction was changing with increasing height from the southeast to the southwest. According to the analysis and short-term forecasts of the ALADIN model the ground wind was of 5 m/s SE (direction 151°), at the 500 hPa level speed of 10 m/s S (direction 206°). In later afternoon, the wind had to be turned up more to the southeast and east. It could be a reason for a positive impact on the growing of massive Cb clouds and their longer existence.

A probability of intensive rainfall in Modra area was very small - based on forecast outputs. ALADIN numerical model predicted 24-hour rainfall (for the period from 07.06.2011, 06 UTC to 08.06.2011, 06 UTC) over Modra area only about 9 mm. The forecast output of ECMWF numerical model for the same date and area was about 7 mm. The probability of precipitation of total amount over 10 mm was about 21% for Modra region (Fig. 3). The figures show the higher rainfalls was logically predicted for mountainous regions of central Slovakia. In accordance with the forecast, the total rainfall of 20-30 mm was observed in the Central Nitra river basin, South Turiec area and Upper Nitra river basin - in storms.

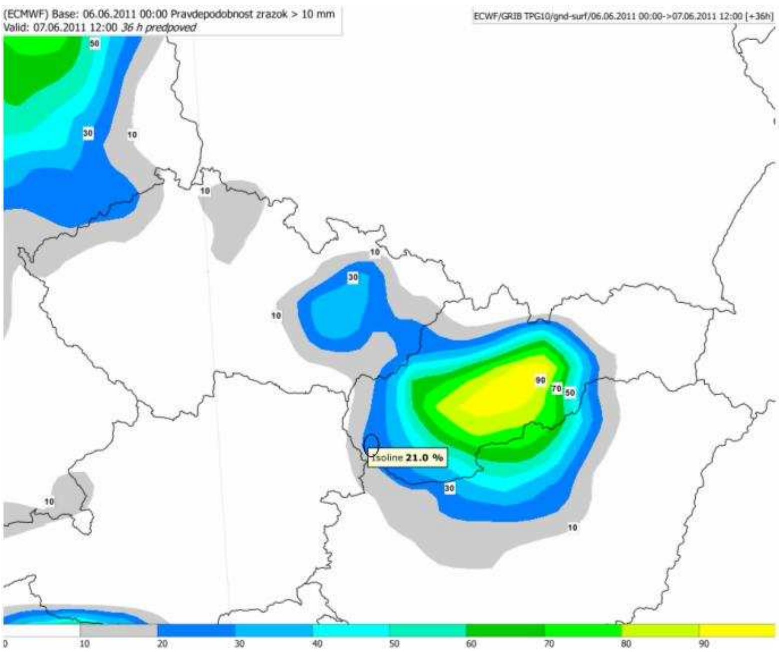

Fig. 3: Rainfall amount probability >10 mm calculated by ECMWF model, run 6.6.2011, 00 UTC, 36-hour forecast for 7.6.2011 12 UTC (black ellipse is the Modra area)

Stability indexes

Stability indexes are used in case studies and storms forecasting. We use following indexes: K – index, Convective Available Potential Energy index (CAPE), Convective Inhibition index (CIN), Storm to Relative Environment Helicity index (SREH) and Energy Helicity Index (EHI). These indexes are calculated by local numerical prediction model ALADIN SLOVAKIA (Aire Limiteé Adaptation Dynamique Dévelopment Inter National) for Central Europe area. These indexes are calculated every one hour and new values of indexes are available every six hours in the operational run.

Individual indexes calculated by local numerical prediction model ALADIN had been favourable for convection development in Malé Karpaty a already one day before severe storm occurrence. On 7 June single indexes values were favourable for convection development in the area as well.

K – index value used for air mass evaluation was favourable for convection development not only in Malé Karpaty region but all over the Slovakia territory. Over Malé Karpaty area K – index of about 30 K was observed. It means, that the probability of the storm coccurrence varies within the range of 60 to 80% and it is very probable that the intensity will be moderate [1].
Index CAPE expresses the potential energy of updraft motion. The updraft motion is necessary for the convection development. The higher CAPE value is the bigger acceleration of updraft motion is and the probability of the storm occurrence increases. CAPE index values were favourable for convection development in the western half of Slovakia. Over Malé Karpaty area index CAPE values varied within the range of 1000 to 2200 J/kg (Fig. 4). It means, that the severe storm can occur in this area.

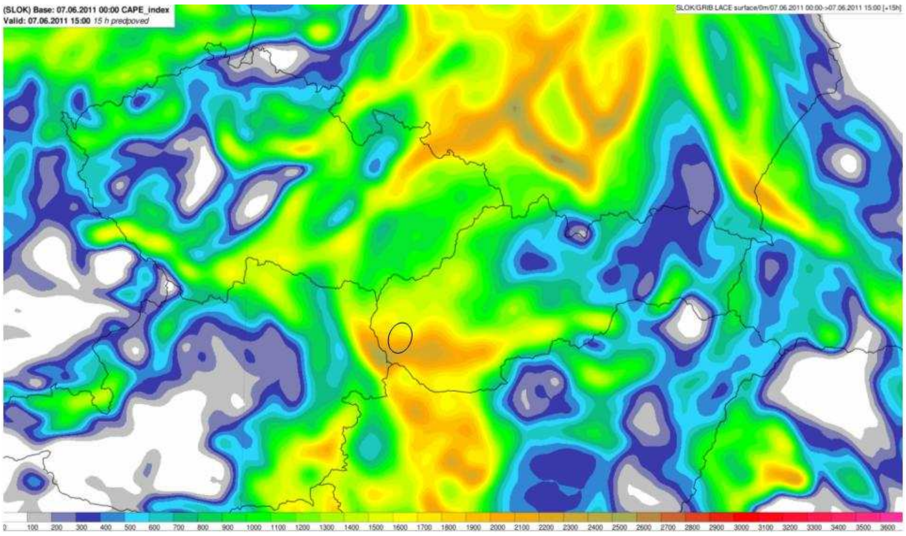

Fig. 4: CAPE index is calculated by local numerical prediction model ALADIN 7.6.2011, 00 UTC, 15 hours prediction (Modra is the area within black ellipse)

CIN index values represents the braking energy of the updraft motion. The probability of the storm occurrence is very small when the index CIN value is greater than 200 J/kg in the summer months. The CIN index value is less than 15 J/kg so probably cumulus cloudiness occurs. CIN index value was less than 15 J/kg over Slovakia.
KO index is used for identifying convective instability. Over Modra area KO index of about -4 K was observed and the probability of the storm occurrence was very high. The most significant storm activity occurs when index KO value is less than 2 K [2].

The course and development of the storm, results

On 7.6.2011, the convection temperature from morning outputs were set to about 24 °C and in western Slovakia this value was already reached in mentioned region at 9 UTC and the development of convective clouds started. At 11 UTC it was already possible by means of meteorological radar to observe first isolated convective cells over Malé Karpaty area.

In slight southeast flow the Malé Karpaty Mountains obstacle supported the upward movements and by means of this orography above mentioned convective cells were further growing and they moved to North slightly. The first intensive rainfall was observed in Modra - Piesky station at 12-12:30 UTC, immediate intensity was of 100 to 140 mm/h and during next 3 hours 65 mm precipitation was observed. The next significant storm cells were created south of the Danube River between Mosonmagyaróvár and Györ and then proceeded over our territory, but there is no evidence of any damage caused by them. At 12:20 UTC in northwest Hungary it was observed the creation of another convective cells that were shifted to the north to the Malé Karpaty Mountains and at 13:30 UTC they joined the cells situated above the ridge of the mountains. Storm cells progressed slowly to the north, but on the southern edge of multicell system another new cells in the foothills of the Karpaty with the same track were created. Rapid development of dynamic cell development started mainly between 13:30 and 14:30 UTC. The most developed cells reached the intensity of radar echoes of over 55 dBZ (Fig. 5) and the power of the strong updrafts is visible by means of so called "overshooting tops" reaching borders of the troposphere (Fig. 6, 7) [4]. Intensive precipitation occurrence over the Malé Karpaty foothills was confirmed also by VIL product during the time from 14:00 to 14:30 UTC (Fig. 5 black ellipse). 5-minute radar outputs over the period from 14:00 to 14:30 confirm that in the area it was possible to observe cells of water content 61 to 68 mm. The cells of similar water content could be observed in north west of Hungary as well in the vicinity of Slovak-Hungary border (Fig. 5 red ellipse). However, no relevant material damage was reported from this area. At 14:40 UTC over Malé Karpaty there were cells of lower water content a sign of weakening storm.

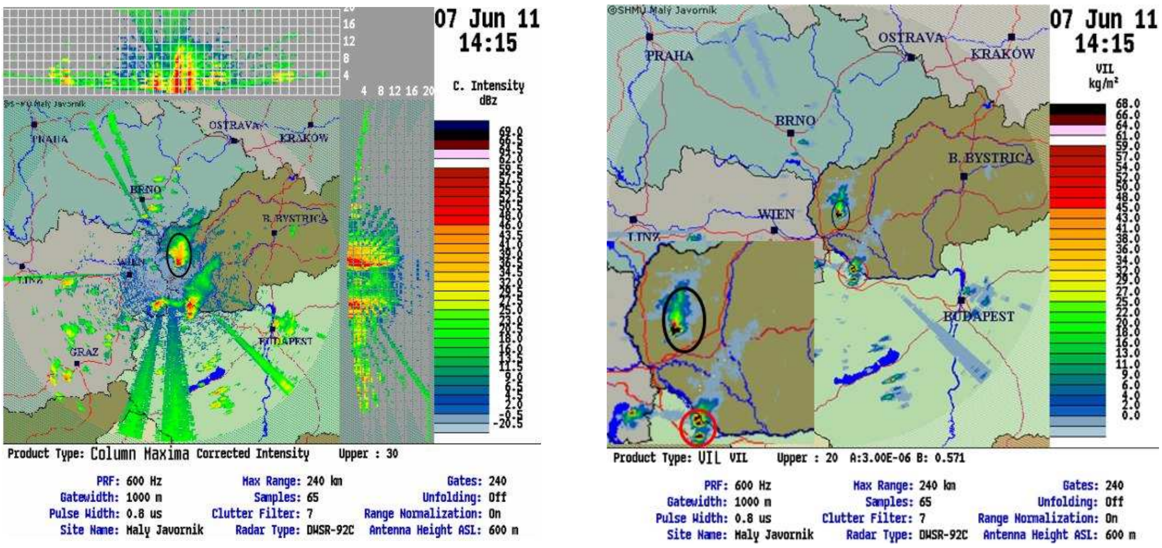

Fig. 5: High radar reflectivity of storm cell over Píla village area (on the left) and storm cell of very high water content which affected area very close to Modra (on the right).

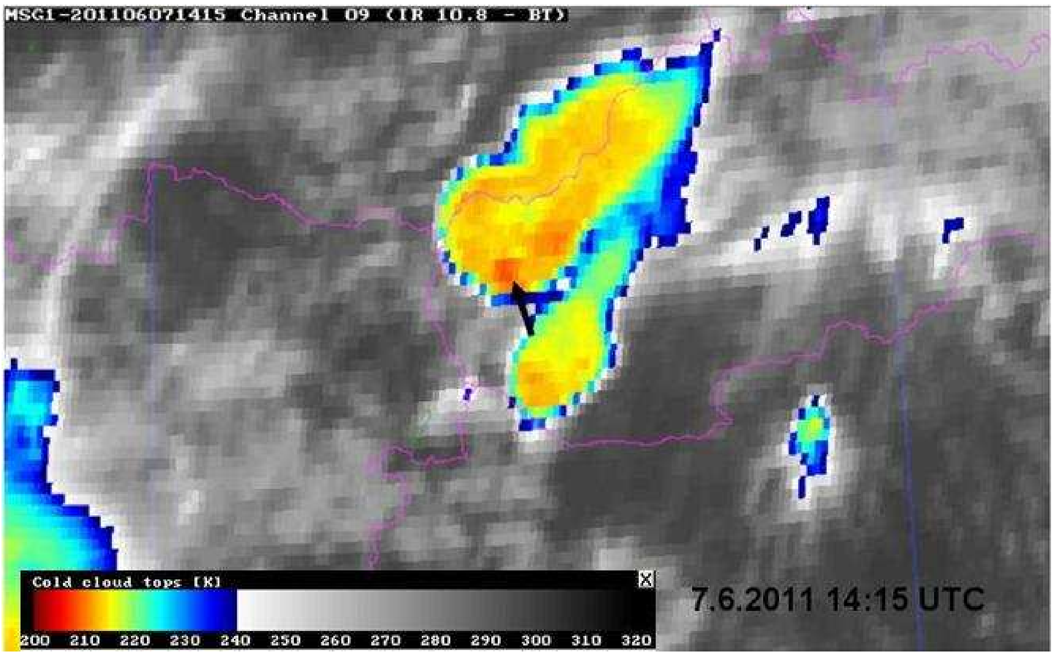

Fig. 6: The storm cells from meteorological satellite MSG-1, product Channel 09 (IR 10.8 - BT). Tops of the clouds highlighted in IR band

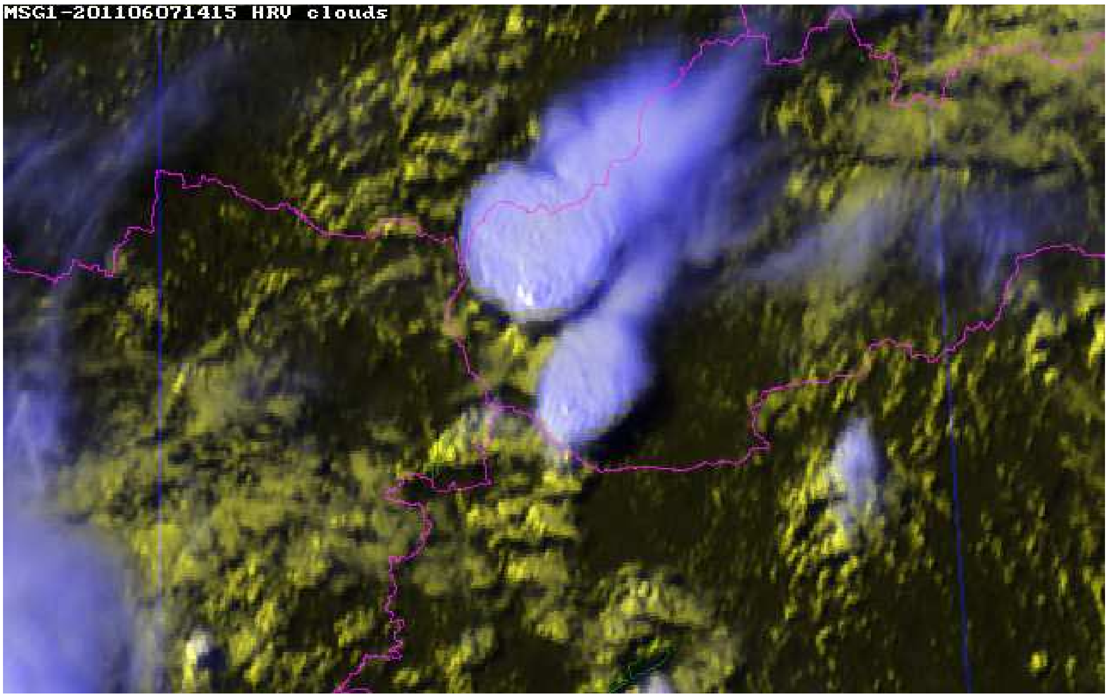

Fig. 7: The storm cell in the highest growth stage from meteorological satellite MSG- 1, product HRV + IR 10.8 μm. In the picture at 14:15 UTC in the RGB band it is possible to distinguish small overshooting tops of Cb clouds.

Meteorological station Modra – Piesky observed intensive rainfall, associated with these cells, at about 14:00 - 14:30 UTC, then the Častá station at 14:30 – 15:15 UTC with immediate intensity of over 150 mm/h and 1-hour precipitation amount of 43 mm. Slow movement of several storm cells in combination with suitable terrain of Gidra creek valley resulted in flashflood and Gidra creek culminated at 15 UTC at level of 226 cm, high above the third stage emergency [3]. Total 24-hour rainfalls in the affected area and the vicinity observed by following rainfall gauge stations: Modra - Piesky 104 mm, Častá 61 mm, Smolenice 42 mm, Modra 31 mm, Pernek 27 mm, Sološnica 26 mm, Pezinok 25 mm, Limbach 19 mm.
It is important to notice the raingauge station in Modra – Piesky is located on northwest ridge of Malé Karpaty Mountains, so there is a high probability the southeast foothill had higher total amount of precipitation because of mentioned orographical and synoptic situation.

Forecasts and warnings

High relative humidity in the lower layers of warm air mass has created a presumption for formation of storms and convective phenomena, which was taken into account also the issued weather forecast. In the forecast there was a warning on storms occurrence with occasional occurrence of hails. However, more developed wind shear was missing so there were not good conditions for developing dangerous convective phenomena. The risk was in slow movement of storm clouds caused by slow flow and so there was a possibility of higher total amount of precipitation over the area.
With regard to the above mentioned situation meteorologists on duty expected the occurrence of storms and in text forecasts the storms were predicted for western Slovakia (forecasts issued on 6.6.2011 and 7.6.2011) "showers and thunderstorms locally, occasionally with hail".
The first warning of storms valid for the affected area was issued on 6.6.2011 at 18:35 UTC, it was a first level storm warning valid up to 7.6.2011 18:00 UTC:
"*In the districts of Bratislava, Pezinok, Trnava, Hlohovec, Piešťany, Trnava, Galanta, Šaľa, Dunajská Streda isolated strong storms with hail are expected, which can cause a potential danger for human activities.*
The storms can be accompanied by short intensive downpours, and total amounts of precipitation may reach 20 to 40 mm and wind gusts of 17-25 m/s. "
This warning was repeated on 6.6. at 20:44, 21:05, 07.07 at 03:06 and 5:25. At 9:22 there was a higher probability of storm occurrence from isolated to same places and validity was extended to

19:00 UTC. Due to intensive development of storms the warning was increased to the second level of storm warning at 14:44 UTC:
"*In the districts of Bratislava, Pezinok, Trnava, Hlohovec, Piešťany, Trnava, Galanta, Šaľa, Dunajská Streda are expected isolated strong storms with higher risk to human activity.*
The storms can be accompanied by a flashflood rainfall with totals of 40 to 60 mm and wind gusts of 25 m/s. The intensity of the accompanying phenomena in a given time of year is above the average and the damage probability is high."
Warning was repeated at 15:08, at16:49 UTC the second level warning was extended to the south of Central Slovakia and Stredné Pohronie (Central Hron river basin), at 17:17 UTC the guess of total rainfalls were increased for western Slovakia to 40-70 mm and at 18:26 this warning was repeated. The validity of warnings was up to 19:30 UTC. At 22:02 UTC it was issued a new first level storm warning with regard to the storms, moving from eastern Austria towards the Malé Karpaty Mountains. However, these ones didn´t reach a high intensity of rainfalls.

Discussion and conclusion

Flashflood on 7.6.2011, when Píla and surrounding village were affected, was caused by heavy rainfalls associated with storm cells, which were created and moved along the Malé Karpaty Mountains. High humidity in the lower atmosphere in combination with high temperature created good conditions for storms creation. Strengthening of vertical wind shear in the afternoon hours and weak southeastern flow towards the slopes of the Malé Karpaty Mountains supported the creation of multicellular storm system. The individual storm cells proceeded through the affected area and the new ones were created right at the foothill.
Weak flow caused slow movement of storm cells and so intensive rainfalls lasted over the affected region for longer time. Intensive rainfalls resulted also in highlighted specific orography of affected area and the Gidra stream basin was hit above the Píla village by heavy rainfalls in most of the area. Large amount of precipitation fallen in a short time was drained down into the valley and caused the flashflood.
It is necessary to state that such conditions are not exceptional and their occurrence in the summer in our territory is not rare at all. The situation of 7.6.2011 is an example of a typical flashflood where favourable combination of all weather conditions, relief shape and relief orientation results in dangerous meteorological phenomenon with large property damage and threat to human lives. Flashfloods in Slovakia region occur every year and the majority of storm situations pose a potential risk of dangerous weather phenomena. Dynamics of storm development is very huge and the actual methods used for short-term weather forecasts, based on ALADIN model, respectively ECMWF model outputs do not enable to predict these phenomena sufficiently and reliably, particularly with regard to the exact specification of the risk areas and time step.
Therefore the meteorological, hydrological and radar measurements in real time are a key element for on-time detection of possible dangerous phenomena and for warning issuing.

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