Comparison of Success Rate of Numerical Weather Prediction Models with Forecasting System of Convective Precipitation

David Šaur

Abstract The aim of this article is to compare a success rate of a chosen numerical weather prediction (NWP) models with a forecasting system of convective precipitation based on an analysis of ten historical weather events over the territory of the Zlin Region for the year 2015. This paper is based on a previous article "Evaluation of the accuracy of numerical weather prediction models". The first chapter is a theoretical framework describing the current forecasting systems of convective precipitation, which are selected NWP models and forecasting system of convective precipitation. This chapter describes the principle of creating predictions and selection of individual NWP models. Furthermore, they are provided with basic information about the prediction of convective precipitation. The second chapter outlines the principles of the methods used for evaluating the success rate of forecast precipitation. In the discussion, results of these methods on selected historical weather situations are published. Finally, the work contains an overview of the most accurate NWP models in comparison with the forecasting system of convective precipitation. This refined predictive information of convective precipitation may be especially useful for the crisis management authorities for preventive measures against the occurrence of flash floods.

Keywords Numerical weather prediction models · Flash floods · Crisis management · Convective precipitation

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1 Introduction

Increase in the occurrence of extreme weather events is connected to global warming. This climatological phenomenon has affected us since 1950, and its consequence is an increase in average temperature and humidity in the atmosphere. Elevated values of the average air temperature and humidity has resulted in increased occurrence of dangerous accompanying phenomena such as heavy rainfall, hail, strong gusts, tornadoes and electrical atmospheric discharge. In addition, increased occurrence of dangerous accompanying phenomena is supported by the appearance of the seven flash floods in the years 2007−2015 [1, 2].

The main cause of torrential rainfall is convective precipitation cloudiness. Convective precipitation can be characterized as an occurrence of rainfall in a small area with varying dynamic of rainfall intensity field. The size of the area tends to be several kilometers and duration of this phenomenon is in tens of minutes. Consequently, prediction of convective precipitation is extremely problematic in terms of its specific temporal and spatial development [1].

Firstly, evaluating the success rate of predictions NWP models and other forecasting systems is a difficult problem to be solved in many scientific research meteorological institutes in the Czech Republic and abroad. Verification forecast convective precipitation has been investigated in many works in the world [3–5]. This problem has been studied in the Institute of Atmospheric Physics in the Czech Republic [6, 7].

Secondly, most of the NWP models are not set for the prediction of local disturbances in the pressure gradient and therefore have a very low success rate. The proposed predictive algorithm of convective precipitation particularly includes those factors that are taken into account in NWP models. The purpose of convective precipitation forecast system is to provide information specifying the current forecast, issued by the Czech Hydrometeorological Institute. The main output is predicting the convective precipitation for lower territorial units (municipalities with extended power) 6−24 h in advance.

The current selection of NWP model is based on the results of the previous article, in which evaluation of success rate of predictions of historic weather situations was conducted for the year 2014. This article differs in research datasets used in the analysis of historical weather situations for the year 2015. The first method includes a proposal for a modified evaluation technique of success rate of convective precipitation forecast. The second method uses the same verification criteria Skill Scores with a different datasets for the year 2015, in which the focus is on the comparison of success NWP models and forecasting of convective precipitation. The main objective is to demonstrate a higher success rate of forecast system of convective precipitation in comparison with NWP models for deployment in operational mode of forecasts and warnings in crisis management Zlin region.

2 Forecasting System of Convective Precipitation

At present, the convective precipitation forecast is realized through the NWP model, nowcasting methods using radar rainfall measurements. However, the success of the forecasting system has not reached 50 % in predicting convective precipitation for the year 2014. Therefore, one of the main objectives of my dissertation is to propose the predictive algorithm for convective precipitation, which will process and evaluate data from NWP models and also increases the forecast success rate over 50 %.

The theoretical part describes two forecasting tools:

- Numerical weather prediction models.
- Forecasting system of convective precipitation.

2.1 Numerical Weather Prediction Models

Numerical weather prediction (NWP) models are systems which forecast the future development of individual meteorological variables in the atmosphere. The first step is the analysis of the current state of the atmosphere using meteorological radars, satellites and balloons. Initial values in the fields of air temperature, such as the wind flow and moisture are results of the analysis. Subsequently own model calculation is conducted by integrating of prognostic equations for temperature, humidity, wind, mean sea level pressure, liquid and solid phase of water and clouds after the individual time steps. An important feature of these prognostic equations is their non-linearity, resulting in a sensitive dependence on initial conditions. It means that if slightly modified input data have entered than the results may vary considerably after several days [2, 8].

In practice, NWP models are divided into global and regional models. The main parameter is resolution or network step, which expresses the size of the surface area. Global models simulate the entire state of the atmosphere. Local Area Models (LAM) are focused on a limited area. Resolution of global models is about 50 km or more; local area models are less than 10 km away [8, 9].

These NWP models were chosen for evaluate the success rate of convective precipitation based on step size of network and their availability on the Internet:

1. Global models—models GFS, EURO 4, GEM and UKMET.
2. Regional models (LAM)—models ALADIN Czech Republic (CR) and ALADIN Slovakia Republic (SR) [1] (Table 1).

Table 1 Parameters of NWP models [1, 15]

Models	GFS	EURO4	GEM	UKMET
Country of origin	USA	GB	France, USA, Canada	GB
Resolution (km)	25 km	11 km	11 km	11 km
Area prediction	The whole world	Europe	Europe	The whole world
Time step	4, 10, 16, 22 h.	00, 05, 11, 17 h.	00, 12 h.	03, 06, 12, 24 h.
Time advance	16 days	2 days	10 days	3 days
Models	ALADIN CR	ALADIN SR		
Country of origin	Czech Republic	Slovakia Republic		
Resolution (km)	5 km	5 km		
Area prediction	Czech Republic	Slovakia Republic		
Time step	03, 06, 12, 24 h.	03, 06, 12, 24 h.		
Time advance	2.5 days	3 days		

The time step is the time period over which the precipitation total predicts for the modeled area. Time advance is the duration at which the precipitation forecast are issued [8].

2.2 *Forecasting System of Convective Precipitation*

The aim of this predictive system will evaluate information on the current and future development of convective precipitation to produce a report which will be distributed to other crisis management authorities of the territorial unit (Fig. 1).

The algorithm of convective precipitation forecast consists of eight steps in the calculation of partial predictions and works with multicriterial evaluation methods. The main criteria are the individual indexes of convection, meteorological elements and parameters of the morphometric analysis which are compared to the statistics of historical weather events. The weight of each criterion is set to 1 to simplify the algorithm. The main objective of algorithm is to find a combination of values of meteorological parameters. The output forecast is 13 probability values (%) for individual municipalities with extended powers by the equation:

$$P = \left(\sum n / \sum m \times 4\right) \times 100(\%), \qquad (1)$$

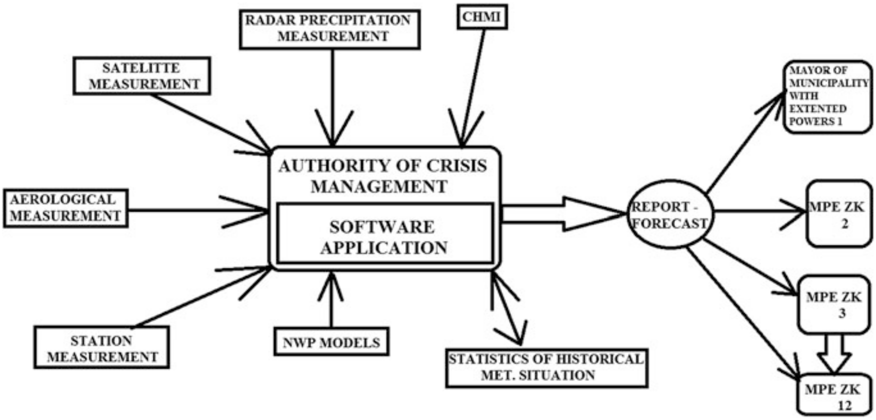

Fig. 1 Scheme of the forecasting system of convective precipitation

Table 2 Coefficients of rainfall intensity and probability occurrence of thunderstorms

Coefficients	0	1	2	3
Intensity level	Weak thunderstorms	Strong thunderstorms	Very strong thunderstorms	Extremely strong thunderstorms
Rainfall intensity (mm/hours)	0–29	30–49	50–89	above 90
Probability of occurence (%)	0–24	25–49	50–74	75–100

where n is a sum of coefficients of partial prediction. For example, prediction instability of the atmosphere which consists of 10 indices of convection and m is the total number of predicted parameters multiplied by four coefficients of probability of location and rainfall intensity according to Table 2.

The main parameters of forecasting system of convective precipitation:

- Time advance to 6–24 h in advance.
- Time step after three hours.
- Forecast of place of occurrence (from individual sites to municipalities with extended powers).

3 Methods of Evaluation of the Weather Forecast

Evaluation of the success rate and quality of weather forecast of numerical weather prediction models is realized by these methods:

- Percentage evaluating of the success rate of numerical weather prediction models and forecasting system of convective precipitation
- Verification of convective precipitation forecast

3.1 The Percentage Evaluating of the Success Rate of Numerical Weather Prediction Models and Forecasting System of Convective Precipitation

Percentage evaluation of the success of numerical models is a method that compares the outputs of individual NWP models with outputs from 13 ground meteorological stations. In the first phase of the evaluation predicted and measured precipitation totals are converted into coefficients of rainfall intensity for the selected time interval (Table 2). In the second phase outputs (coefficients) are compared to the selected numerical model and 13 ground meteorological stations, of which is determined by success rate of predictions:

- Place of occurrence of convective precipitation.
- Rainfall intensity.

Coefficients of probability of place occurrence of precipitation assume values if the total precipitation is predicted and measured. Coefficients are found if the predicted or measured total precipitation does not occur.

Coefficients of rainfall intensity assume values if the coefficients of the predicted and measured precipitation are totals equal. Conversely, coefficients are found for different values of the predicted and measured precipitation totals.

Percentage values of successful predictions are calculated after completing coefficient values or blank spaces of place of occurrence and rainfall intensity:

$$P_{place,\, intensity} = \frac{X}{13} \times 100(\%), \qquad (2)$$

The overall forecast success rate is determined as the average a success rate of percentage place of occurrence and rainfall intensity according to Table 2.

3.2 Verification of Convective Precipitation Forecast

Verification of precipitation forecast has been a discussed problem in recent years. Skill Scores are used for verification predictions that determine the accuracy of forecasts by:

Table 3 Contingency table in standard methods [13, 14]

Event forecast/observed	Yes	No	Marginal total
Yes	a	b	a + b
No	b	d	c + d
Marginal total	a + c	b + d	N = a+b + c+d

- Standard methods with verification criteria (contingency table).
- Non-standard methods using radar precipitation estimates [1].

Skill Scores are verification statistical criteria for comparing the score of the forecast with a score of forecasts obtained by the standard method with the same set of data. Skill Scores takes values from $-\infty$ to $+1$. Positive values indicate improvement in prognosis compared to the standard. Negative values demonstrate lower forecast accuracy than standard. Verification forecast of convective precipitation by standard methods, which are based on contingency tables, is the most convenient than the model output with the high resolution [10–12].

Contingency table contains four fields and shows the number or frequency of cases where the phenomenon was/was not predicted, and in fact occurred/did not occur in all possible mutual combinations [12] (Table 3).
where:

- **a** is the number of cases when the phenomenon was predicted and actually occurred—good forecast of phenomenon.
- **b** is the number of cases when the phenomenon was not predicted and occurred —wrong forecast of phenomenon.
- **c** is alarm is the number of cases when the phenomenon was predicted and did not occur—wrong forecast of phenomenon.
- **d** is preclusion is the number of cases when the phenomenon was not predicted and did not occur—good forecast of phenomenon [1, 12].

Skill Scores are statistical methods which depend on the category. For example, the verification criteria TSS, PSS (FRC) and HSS fall into the category d. Verification criteria POD, FAR and CSI belongs to the category of a, b, c [1, 12]. The two most common types of Skill Score are used for the purposes of evaluation of the success forecasts:

- Heidke Skill Score (HSS) a
- Critical Success Index (CSI) or Threat Score(TS).

Heidke Skill Score (HSS) is a statistical verification criterion, which is focused on the fractional improvements in prognosis using standard methods. The value of HSS can determine according to the equation:

$$HSS = \frac{2(ad - bc)}{[(a + c)(c + d) + (a + b)(b + d)]} \tag{3}$$

The main advantage of HSS is independence of the frequency of forecasting the phenomenon and simplicity of calculation. HSS is intended for verification forecasts of indexes of convection, other meteorological elements and additional calculations of climatological series, e.g. the average air temperature [12, 13].

Critical Success Index (CSI) is intended verification criterion for predicting infrequent events, such as dangerous accompanying phenomena (strong wind gusts and tornadoes) and intensive convective precipitation.

$$CSI = \frac{a}{a+b+c} = \frac{a}{a+b+c+d-d} = \frac{a}{N-d} \tag{4}$$

where N is the number of all cases. CSI is dependent on the ratio of category d and the number of all cases. Consequently, the CSI depends on the frequency occurrence of the predicted phenomenon [12, 14].

4 Discussion of the Evaluation of Success Rate of NWP Models and Forecasting System of Convective Precipitation

The percentage of successful evaluation and verification of predictions selected NWP model is based on analysis of ten historical weather situations over the Zlín Region in 2015, which are also part of the project IGA/FAI/2015/025. Results of both of these methods are discussed in this paper which builds on the previous article "Evaluation of the accuracy of numerical weather prediction models". The most NWP models compared with a success rate of forecasting system of convective precipitation discussed in [1].

4.1 The Percentage Evaluating of Accuracy of Numerical Weather Prediction Models and Forecasting System of Convective Precipitation

The results of this method are based on the analysis of ten historical meteorological situations with the most intense convective rainfall for the case of the Zlín Region in the IGA project for the year 2015. The success rate of predictions is calculated as the ratio of the maximal predicted precipitation by numerical models and maximum measured precipitation [1].

Figure 2 shows the average values of selected success rate NWP models (blue columns) compared with the average value prediction success forecasting system of convective precipitation (red columns). Forecast system of convective precipitation reached 53 % save percentage. The success of individual NWP models differed.

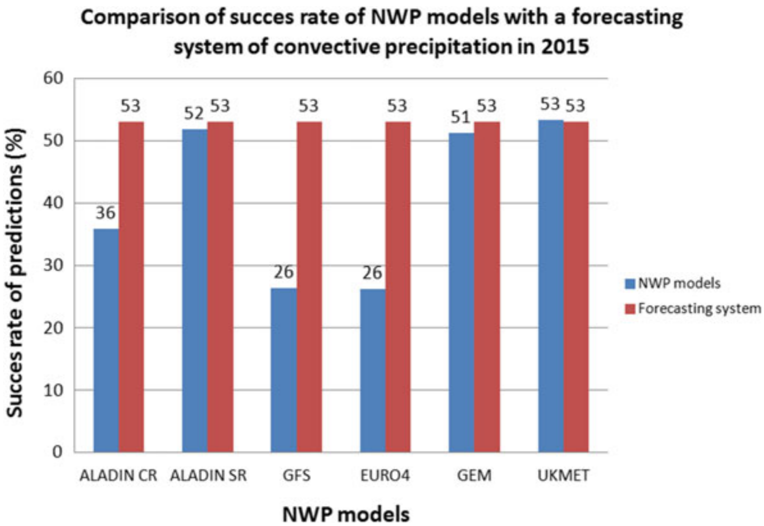

Fig. 2 The average success rate forecasts of selected NWP models and forecasting system of convective precipitation

The highest average values of success were achieved in NWP ALADIN model SR, GEM and UKMET for fine resolution. NWP ALADIN model SR with a resolution of 4 km reached the highest levels of success in some historical weather conditions (70–80 % success rate). NWP models GEM and UKMET provide good long-term results of permanent success rate predictions, but also convective precipitation in recent years. High values of successful predictions are due to the good qualities of prediction pressure fields over Europe.

4.2 Verification of Convective Precipitation Forecast

This method is focused on evaluation of the success rate of precipitation forecast numerical models using the two verification criteria HSS and CSI.

Figure 3 illustrates the resulting evaluation of the success precipitation forecast for each NWP models based on verification criterion HSS [1]. High values HSS (0.38–0.4) was achieved during precipitation amounts from 25 to 30 mm with the numerical models ALADIN CR, GEM, EURO4, UKMET due to their high resolution of 5–11 km. GFS model reached the lowest values for HSS precipitation totals from 5 to 35 mm because of the high resolution of 25 km. The biggest difference of HSS (from 0.1 to 0.17) was among the GFS model and prediction system of convective precipitation in the precipitation totals between 20 and 35 mm.

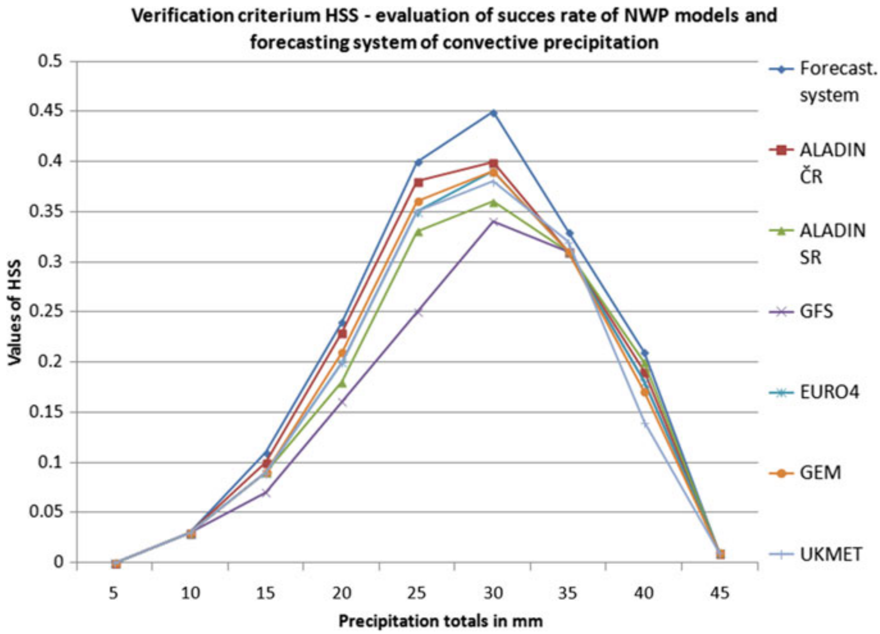

Fig. 3 Verification criterion HSS for different values of the precipitation [1]

The second category with categories a, b, c includes verification criterion of Critical Success Index (CSI). CSI the criterion is used to forecast extreme phenomena. [1].

Figure 4 demonstrates the results of the evaluation of the success precipitation forecast verification using criterion CSI. Graphs individual curves of values CSI replicate the trend of development for all NWP models and forecasting system of convective precipitation. Forecast system of convective precipitation reached the highest values of CSI. NWP models GEM, UKMET and ALADIN CR had the highest CSI values during rainfall totals from 20 to 25 mm. Maximum difference of values CSI (over 0.15) were achieved in the GFS model as with the verification criterion HSS.

4.3 Summary Evaluation of NWP Models and Forecasting System

For the best results, evaluation of the accuracy of the convective precipitation forecast achieved these tools by following methods:

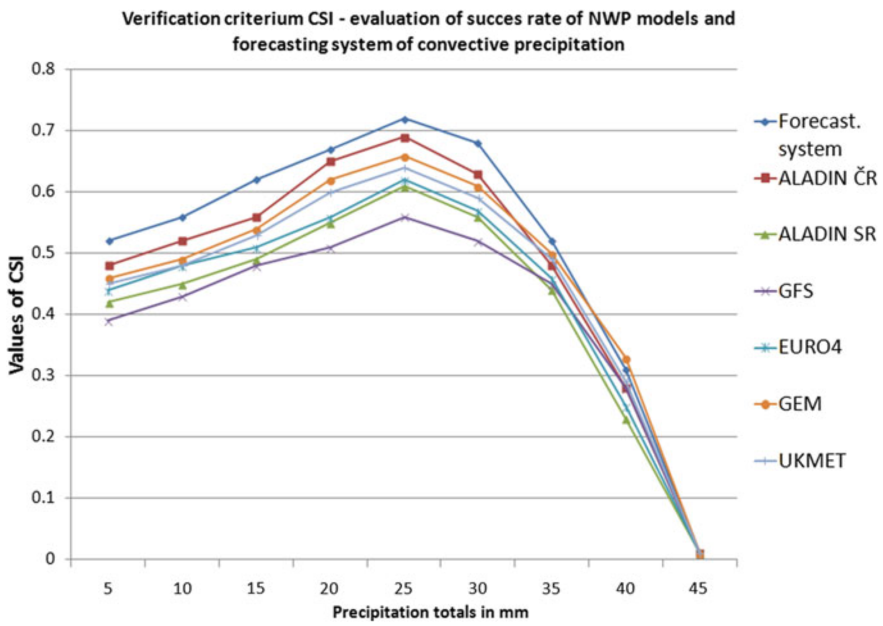

Fig. 4 Verification criterion CSI for different values of the precipitation [1]

- The percentage evaluating of the accuracy of numerical weather prediction models:
  - The NWP models ALADIN SR, GEM a UKMET with success rate of predictions of 50–60 % due to low resolution of 5–11 km.
  - Success rate of forecasting system of convective precipitation is 53 %.
- Verification of convective precipitation forecast:
  - Deviation of the HSS and the CSI reaches the order of tenths; properties NWP models and forecasting systems are sufficient for the prediction of intense rainfall, which could cause flash floods.
  - The highest values of verification criteria and CSI and HSS reached forecasting system of convective precipitation (precipitation amounts of 20 –30 mm/hr).
  - Outputs of graphs values of HSS and CSI demonstrated that the high success rate forecasts was attained in NWP models with low resolution (5–11 km).
  - Forecasting system obtained the highest success rate of convective precipitation forecasts for proper configuration of meteorological parameters fulfilling the physical conditions of formation of atmospheric convection.

5 Conclusion

The aim of the article was to evaluate the success rate of convective precipitation forecasts for selected NWP models and forecasting of convective precipitation for the Zlín Region in 2015. Success rate of predictions was evaluated by the same verification methods as in the previous article, but with different data sets and compared with the predictive system of convective precipitation. Selected historical weather situation characterized weak storms with precipitation amounts of less than 30 mm/hr. and strong storms with precipitation totals from 30 to 50 mm/hr.

NWP models GEM, UKMET, ALADIN ČR and ALADIN SR achieved a success rate of over 50 %, so they are generally applicable to an approximate estimate of the future occurrence of convective rainfall for the Zlín Region. NWP models and forecasting system of convective precipitation reached their highest levels of verification criteria HSS and CSI in predicting precipitation totals with an intensity of 20–30 mm/hr. This rainfall intensity constitutes a threshold formation of torrential rainfall. High values of both verification criteria show good predictive properties of NWP models and forecasting system for predicting intense convective precipitation, which can cause flash floods.

Further research will focus on evaluating the success rate of forecast system of convective precipitation and NWP models based on analysis weather situations in the following years. The main methods of evaluating the success rate of predictions will be current statistical verification criteria Skill Scores including additional verification criteria and other verification methods. The aim of the research will be to identify most suitable methods for evaluating the success of convective precipitation forecasts by comparing the overall success rate of the predictions of verification methods.

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