Evaluation of the Accuracy of Numerical Weather Prediction Models

David Šaur

Tomas Bata University in Zlin,
Faculty of Applied Informatics,
Nad Stranemi 4511
saur@fai.utb.cz

Abstract. This article is focused on numerical weather prediction models, which are publicly available on the Internet and their evaluation of the accuracy of predictions. The first part of the article deals with the basic principles of creating a weather forecast by numerical models, including an overview of selected numerical models. The various methods of evaluation of the accuracy of forecasts are described in the following part of the article; the results of which are shown in the last chapter. This article aims to bring major information on the numerical models with the greatest accuracy convective precipitation forecasts based on an analysis of 30 situations for the year 2014. These findings can be useful, especially for Crisis Management of the Zlin Region in extraordinary natural events (flash floods).

Keywords: Numerical weather prediction models, flash floods, crisis management, convective precipitation.

1 Introduction

A central issue in current meteorology is forecasting of convective precipitation. Five summer floods with torrential rainfall occurred in the Czech Republic in the years 2009-2014. The fundamental problem in forecasting of convective precipitation lies in its specific spatial and temporal evolution. Convective precipitation is formed over the territory of a small size (from 1x1km up to 10x10 km), takes approximately 30-60 minutes and is accompanied by extreme weather events (heavy rainfall, hail, strong wind gusts, tornadoes and downbursts). In order to obtain an accurate and a quality prediction of convective precipitation is necessary to analyze the available numerical weather prediction model by appropriate evaluation methods. There have been several investigations into the causes of accuracy evaluation of numerical weather prediction models (Keil et al. 2014, Singh et al. 2014, Liu et al. 2013 and Comellas et al. 2011). These studies several researchers examined the accuracy of predictions of convective precipitation using numerical weather prediction models for selected areas. [7], [8], [9], [10] Analyzed results of numerical weather prediction models were investigated

R. Silhavy et al. (eds.), *Artificial Intelligence Perspectives and Applications*,
Advances in Intelligent Systems and Computing 347, DOI: 10.1007/978-3-319-18476-0_19

in the summary reports of floods in the Czech Republic (Sandev et al. 2010, Kubát 2009). The causes of verification of the convective precipitation forecast have been investigated (Dorninger and Gorgas 2013, Sindosi et al. 2012, Amodei et al. 2009, Zacharov 2004 and Rezacova 2005, Atger 2001 and McBride et al. 2000). [11], [12], [13], [14], [15]

None of these studies managed to provide results of weather forecast evaluation from a larger number of numerical models. The main contribution of this paper is to create an overview of the most accurate numerical weather prediction models. The outputs from numerical weather prediction models, that have achieved the best ratings, will be used in the prediction system of convective precipitation for crisis management Zlín Region. Forecasting system will generate a summary report about the future development of convective precipitation, which will be distributed to other crisis management bodies of the region. Forecasting system of convective precipitation will be designed as a software application that will be part of the solution dissertation and regional project "Information, notifying and warning system of the Zlín Region".

2 Numerical Weather Prediction Models

Numerical weather prediction models are information resources that are designated to collect data from meteorological and aerological stations, processing, evaluation and creation of forecasts. These models are based on the initial state of the Earth's atmosphere (measured station data), which are part of the differential equations describing the laws of physics, especially thermodynamic and kinetic laws. The principle of the creation of weather forecasts can be expressed in these primitive equations: [1], [2]

$$(A)=\Delta A/\Delta t \tag{1}$$

Where:

ΔA - weather change at a specific location
Δt - period during which the change occurred and
$F(A)$ - functions describing the change of weather changes meteorological situation A. [1], [2]

Equation 1 can be written as:

$$F(A) = \frac{A_{forecast}-A_{now}}{\Delta t} \tag{2}$$

$$A_{forecast} = A_{now} + F(A)\Delta t \tag{3}$$

The most important parameter in the selection of the numerical model is the resolution of the grid model indicated by the size of the area, characterized by convective cell size. Each grid cell contains meteorological data in the horizontal and vertical directions. Numerical weather prediction models are divided according to the size of the resolution:

- Global models with lower resolution (>0.10°-10x10km) and
- Regional models with higher resolution (<0.10°-10x10km). [1], [2]

Based on years of experience and work with numerical weather prediction models were selected the following models:

1. Global numerical models – model COAMPS, EURO4, GEM, GFS, NAVGEM, MM5, RHMC and UKMET (numerical model ECMWF was not included here due to lack of data on precipitation for selected weather situations).
2. Regional numerical models – model ALADIN CR and ALADIN SR.

Table 1. The parametres of numerical models (forecast meteorological parametres - legend: T - temperature, s – rainfall, v - wind, t - pressure of 500 hPa, o - clouds, d - visibility, RH - relative humidity CAPE - Convective Available Potential Energy , LI - Lifted Index, EHI - Energy Helicity Index) [3]

Models	COAMPS	EURO4	GEM	GFS
Country of origin	USA	GB	France, USA, Canada	USA
Type of model	global	global	global	global
Resolution (km)	20x20	11x11	11x11	25x25
Area prediction	Europe	Europe	Europe	The whole world
The number of predicted days	4 days	2 days	10 days	16 days
Predicted meteorological parametres	T, s, v, t	T, s, v, t, o, d, RH	T, s, v, t, RH, CAPE, vorticity, LI, EHI	T, s, v, t, o, d, RH, all indexes instability

Models	NAVGEM	MM5	RHMC	UKMET	ALADIN CR a SR
Country of origin	USA	USA	Russia	GB	Czech and Slovakia Republic
Type of model	global	regional	global	global	regional
Resolution (km)	100x100	9x9	250x250	11x11	4x4
Area prediction	The whole world	Czech Republic	The whole world	The whole world	Czech Republic
The number of predicted days	6 days	3 days	3 days	3 days	2,5 (ČR) 3 (SR) days
Predicted meteorological parametres	T, s, v, t, RH	T, s, v, t, o	T, s, v, t, RH	T, s, v, t, vorticity	T, s, v, t, o, RH, VI

Table 1 shows individual numerical weather prediction models, which will be part of evaluation of accuracy predicted convective precipitation.

3 Methods of Evaluation of the Accuracy of Weather Forecasts

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

- Percentage evaluating of the accuracy of numerical weather prediction models
- Verification of convective precipitation forecast

3.1 The Percentage Evaluating of the Accuracy of Numerical Weather Prediction Models

This method compares the precipitation total predicted by numerical weather prediction models with the precipitation measured on the ground meteorological stations. The maximal predicted precipitation total is compared with the measured precipitation total. The accuracy of the numerical model is given by the following formula:

$$X = \frac{S_{predicted}}{S_{measured}} \times 100\ (\%) \tag{4}$$

Where Spredicted is the maximal predicted precipitation totals in milimetres and Smeasured is the maximal precipitation totals measured on a ground meteorological station. The maximal precipitation totals are evaluated for convective precipitation clouds with characteristic occurrence of an extreme local precipitation. The aim of this method is to determine which numerical models predict with greater accuracy these local extreme phenomena. We can also evaluate the accuracy of forecasting of precipitation in given territory, time of the occurrence of a precipitation and more options. This method is commonly used in the evaluation of the weather forecast in the summary report of flood events in the Czech Republic in 2009 and 2010. [4]

The percentage evaluating of the accuracy of numerical weather prediction models contains a table with the date and the location, the measured and the predicted values of precipitation totals, including the evaluation of the percentage of the numerical model.

3.2 Verification of Convective Precipitation Forecast

The convective precipitation forecast can be verified by various techniques. Methods of verification predictions of convective precipitation are:

- Standard methods with verification criteria Skill Scores (SS),
- Non-standard methods using radar precipitation estimates.

Standard methods are most commonly used for verification of convective precipitation to achieve more accurate results than non-standard evaluation methods because radar precipitation estimates are very imprecise, especially convective precipitation clouds.

The standard method is based on the pivot table which consists of four fields. This table lists the frequency of cases where the phenomenon was predicted and where it actually occurred, and in all possible combinations. [5], [6]

		Forecast	
		+	-
Measurement	+	a Intervention	b Error
	-	c False Alarm	d Correct preclusion

Fig. 1. The pivot table in standard method [6]

Where:

- **a - Intervention** is the number of cases when the phenomenon was predicted and actually occurred – good forecast of phenomenon.
- **b - Error** is the number of cases when the phenomenon was not predicted and occurred – wrong forecast of phenomenon.
- **c - False** alarm is the number of cases when the phenomenon was predicted and did not occur – wrong forecast of phenomenon.
- **d - Correct** preclusion is the number of cases when the phenomenon was not predicted and did not occur – good forecast of phenomenon. [6]

The pivot table describes that the categories a and d are successful while b and c are unsuccessful. The value of d very often exceeds the value a in the case of extreme events.

Standard methods analyze forecasts with verification criteria, which are divided into two categories:

- category **d** – criteria True Skill Statistic (TSS), Probability Skill Score, Fraction Correct (PSS, FRC) and Heidke Skill Score (HSS),
- category **a,b,c** – criteria Probability of Detection (POD), False Alarm Ratio (FAR) and Critical Success Index, “Threat Score” (CSI).

Verifikační kriterium, Skill Score	Kód	Reference	Rovnice	Hranice
Probability Of Detection	POD	Wilks (1995), Huntrieser (1997), Metelka (2001), Marzban (1998)	$POD = \frac{a}{a+b}$	$0 \le POD \le 1$
False Alarm Ratio	FAR	Wilks (1995), Huntrieser (1997), Metelka (2001), Marzban (1998)	$FAR = \frac{c}{a+c}$	$0 \le FAR \le 1$
Critical success index, "Threat score"	CSI	Wilks (1995), Huntrieser (1997), Marzban (1998)	$CSI = \frac{a}{a+b+c}$	$0 \le CSI \le 1$
True Skill Statistics	TSS	Huntrieser (1997), Marzban (1998)	$TSS = \frac{a}{a+b} - \frac{c}{c+d}$	$-1 \le TSS \le 1$
Heidke Skill Score	HSS	Wilks (1995), Huntrieser (1997), Marzban (1998)	$HSS = \frac{2(ad-bc)}{(a+b)(b+d)+(a+c)(c+d)}$	$-1 \le HSS \le 1$
Probability Skill Score, FRaction Correct	PSS, FRC	Metelka (2001), Marzban (1998)	$PSS = FRC = \frac{a+d}{a+b+c+d}$	$0 \le PSS \le 1$

Fig. 2. Verification criteria Skill Scores [6]

For purposes of this article, this information is defined as a basic knowledge to evaluate the accuracy of numerical weather prediction models.

4 Comparison of Methods to Evaluation of the Accuracy of Numerical Models

The percentage evaluating of the accuracy and verification of prediction of numerical models was performed by extensive analysis, which is part of the IGA / FAI / 2014/003. The first method Percentage evaluating of the accuracy of numerical weather prediction models was performed only in this project, but second method Verification of convective precipitation will be also included in this part of this article. The objective comparison of these methods will create a rank of the most accurate numerical weather prediction models.

4.1 The Percentage Evaluating of Accuracy of Numerical Weather Prediction Models

The results of the first method “The percentage evaluating of the accuracy of numerical weather prediction models” are presented based on the analysis of numerical weather prediction models in the IGA project for the year 2014. The accuracy of predictions X is calculated as the ratio of the maximal predicted precipitation by numerical models and maximum measured precipitation.

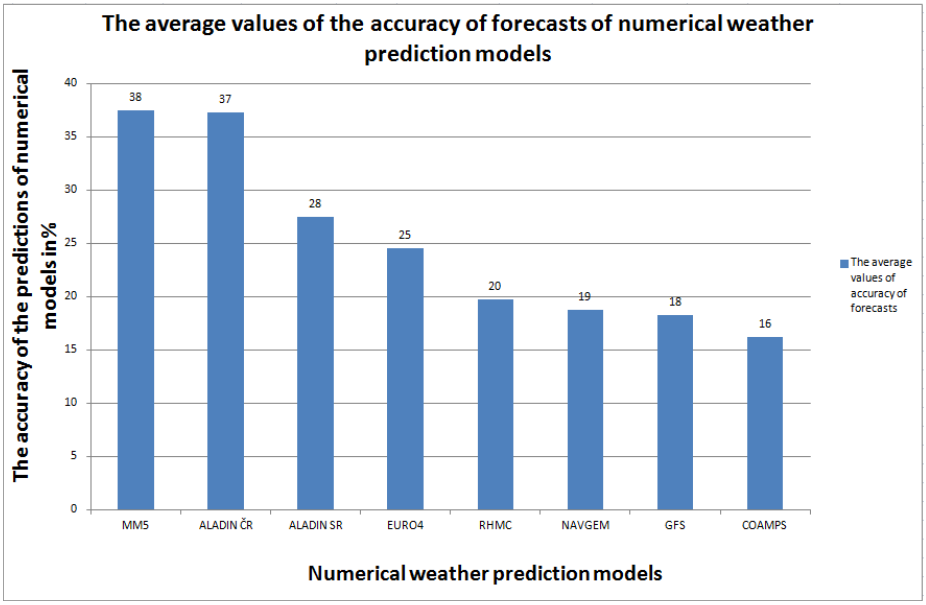

Fig. 3. The average values of the accuracy of forecasts of numerical models

Figure 3 shows the average values of the accuracy of convective precipitation forecasts by numerical models. These values were counted from the analysis of 30 situations that happened in the Zlin Region in 2014. Highest average values of prediction accuracy were achieved by MM5 and ALADIN numerical models due to a better resolution compared to other numerical models.

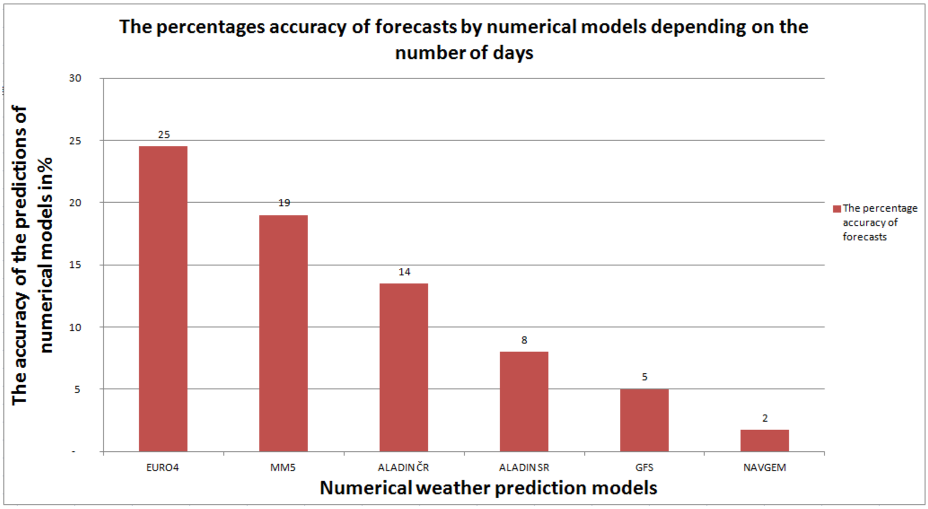

Fig. 4. The percentage of the accuracy of forecasts of numerical models

Figure 4 illustrates an overview of numerical weather prediction models for the number of predicted events. Numerical model EURO4 reached the highest percentage value of the accuracy of a convective precipitation forecast, despite the fact that it is a global model with higher resolution than the regional model ALADIN CR. The second numerical model is MM5 with the accuracy 19%, which was developed in the USA, and is the only nonhydrostatic model used in the Czech Republic. This numerical model has the best properties for forecasting of convective precipitation. Model ALADIN CR ended up in the third position in spite of the fact, that it is a regional model with the lowest possible resolution 4x4 km.

4.2 Verification of Convective Precipitation Forecast

The aim of this method is to evaluate the accuracy of precipitation forecast numerical models using the two verification criteria HSS and CSI.

The first category d includes a verification criterion Heidke Skill Score (HSS). This criterion is more appropriate criterion for assessing the category d than verification criteria CSI and TSS while HSS is not dependent on the frequency of the occurrence of the predicted phenomenon. [6]

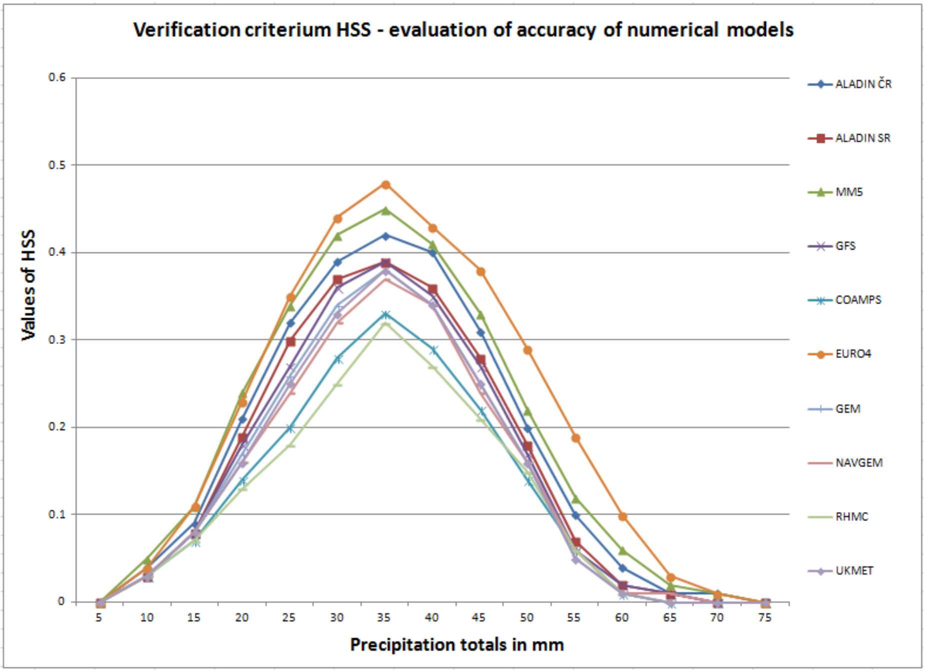

Fig. 5. Verification criterion HSS for different values of the precipitation

Figure 5 demonstrates that the results of the evaluation of the accuracy of the precipitation forecast for the individual numerical models using the verification criterion

HSS. The highest values were achieved at precipitation totals 35-40 mm by numerical models EURO4, MM5 and ALADIN CR.

The second category of without a value d (contains the values of a, b, c) includes a verification criterion Critical Success Index, "Threat Score" (CSI). CSI criterion is often used criterion for the prediction of extreme events. CSI represents the ratio of correct predictions of the number of phenomena and false alarms, and depend on the frequency of the occurrence of the predicted precipitation totals. [6]

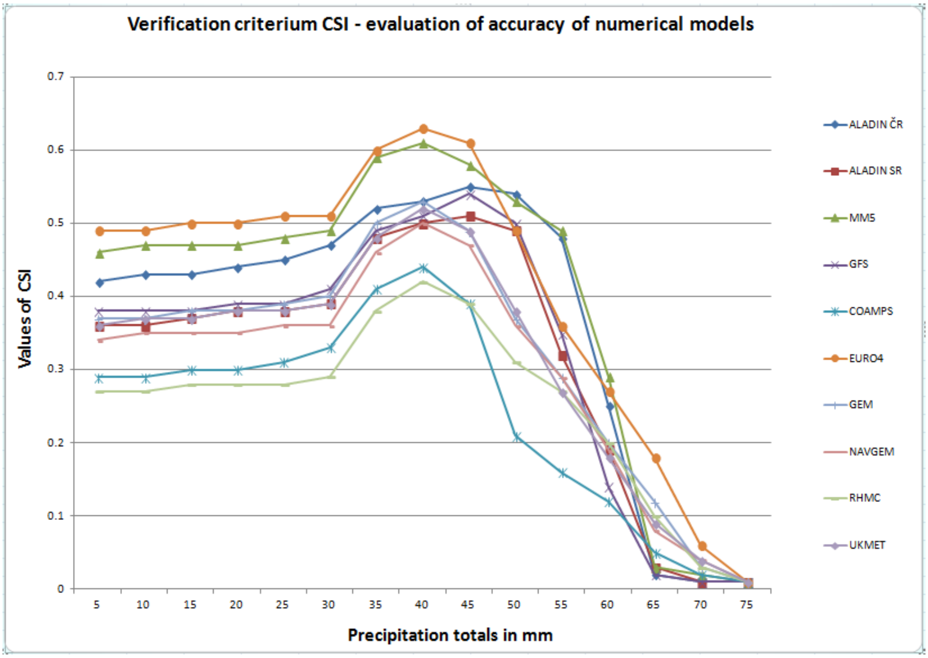

Fig. 6. Verification criterion CSI for different values of the precipitation

Figure 6 illustrates that the results of the evaluation of the accuracy of precipitation forecast for the individual numerical models using the verification criterion CSI. Generally, the less the phenomenon occurs, the CSI is higher and vice versa. The CSI highest values were achieved for the same numerical models as the previous criteria (model EURO4, MM5 and ALADIN CR). [6]

4.3 Summary Evaluation of Numerical Weather Prediction Models

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

- The percentage evaluating of the accuracy of numerical weather prediction models:
  - The average value of the accuracy of forecast – numerical model MM5, ALADIN CR and ALADIN SR.

– The order of numerical models with the greatest accuracy predicted by the number of situations – numerical models EURO4, MM5 and ALADIN CR.

- Verification of convective precipitation forecast – for both verification criteria HSS and CSI, the best results were obtained by numerical models EURO4, MM5 and ALADIN CR.

5 Conclusion

The aim of this paper is to analyze selected numerical weather prediction models based on a comparison of the two methods of evaluation of the forecasts accuracy. Evaluation of numerical models related only to situations with the occurrence of convective precipitation (intense rainfall and storms). This type of precipitation clouds occurs very frequently in the summer, causing extensive material damage. Consequently, these situations have been selected for evaluation for the year 2014, in which there were heavy (over 30 mm / hour) to very heavy rainfall (over 50 mm / hour).

Numerical models EURO4, MM5, ALADIN CR and ALADIN SR attained the best results of the accuracy of convective precipitation forecast in the first method Percentage evaluation the accuracy of numerical weather prediction models. The outputs of the graphs verification criteria HSS and CSI inform us that the best results were achieved by numerical models EURO4, MM5 and ALADIN CR.

For the purpose of providing for sufficient foreknowledge to crisis management of the Zlin Region has been found that the best results obtained the global numerical model EURO4 and MM5, and the regional model ALADIN CR. The overall results indicate that these numerical models can be used in practice for a short-term forecast for one to two days in advance. The limitations of this study are clear: Forecasting of convective precipitation is a very difficult problem due to insufficient resolution of the numerical models and the occurrence of a large number of factors affecting the development of this type of precipitation. The results of the percentage evaluation also showed that the accuracy of convective precipitation forecast has not reached by 50%. The lack of resolution models mean that we cannot be certain the accuracy of the numerical models outputs, and therefore it is necessary to complement with warning information from the Integrated Warning Service of the Czech Hydrometeorological Institute (CHMI SIVS) and predictive information from the Portal of the CHMI.

Acknowledgments. This article was supported by the Department of Security Engineering under internal grant IGA/FAI/2015/025 “Forecast system of convective precipitation” (sponsor and financial support acknowledgment goes here).

References

1. Saur, D., Lukas, L.: Computational models of weather forecasts as a support tool for Crisis Management. In: Proceedings of the Contributory 7th International Scientific Conference Safe Slovakia and the European Union, p. 10. College Security Management in Košice, Kosice, http://conference.vsbm.sk, ISBN 978-80-89282-88-3

2. Jaros, V.: Computational modeling of weather. Brno, The diploma thesis. Masaryk University, Faculty of Informatics (2010), http://is.muni.cz/th/140509/fi_m/dp140509.pdf
3. WeatherOnline, http://www.weatheronline.cz/cgi-bin/expertcharts?LANG=cz&CONT=czcz&MODELL=gfs&VAR=prec
4. Ministry of the Environment of the Czech Republic. Evaluation of spring floods in June and July 2009, the Czech Republic, http://voda.chmi.cz/pov09/doc/01.pdf (cit. December 08, 2014)
5. Zacharov, P., Rezacova, D.: Comparison of efficiency of diagnostic and prognostic characteristic the convection environment. Meteorological Bulletin (2005), http://www.mzp.cz/ris/ekodisk-new.nsf/3c715bb7027b1c65c1256bb3007b7af2/272beff860536f1dc12573fc00429823/$FILE/MZ%202005_3.pdf#page=3 (cit. December 08, 2014), ISSN: 0026 – 1173
6. Zacharov, P.: Diagnostic and prognostic precursors of convection. [Diploma thesis] Prague: Faculty of Mathematics and Physics UK, KMOP, 61 p. (2004), https://is.cuni.cz/webapps/zzp/detail/44489/
7. Keil, C., Heinlein, F., Craig, G.C.: The convective adjustment time-scale as indicator of predictability of convective precipitation. Quarterly Journal of the Royal Meteorological Society 140(679), 480–490 (2014), Dostupné z: http://doi.wiley.com/10.1002/qj.2143, doi:10.1002/qj.2143 (cit. February 04, 2015)
8. Singh, D., Bhutiany, M.R., Ram, T., Ye, A., Tao, Y., Miao, C., Mu, X., Schaake, J.C.: Station-based verification of qualitative and quantitative MM5 precipitation forecasts over Northwest Himalaya (NWH). Meteorology and Atmospheric Physics 125(3-4), 107–118 (2014), Dostupné z: http://link.springer.com/10.1007/s00703-014-0321-9, doi:10.1007/s00703-014-0321-9 (cit. February 04, 2015)
9. Liu, Y., Duan, Q., Zhao, L., Ye, A., Tao, Y., Miao, C., Mu, X., Schaake, J.C.: Evaluating the predictive skill of post-processed NCEP GFS ensemble precipitation forecasts in China's Huai river basin. Hydrological Processes 27(1), 57–74 (2013), Dostupné z: http://doi.wiley.com/10.1002/hyp.9496, doi:10.1002/hyp.9496 (cit. February 04, 2015)
10. Comellas, A., Molini, L., Parodi, A., Sairouni, A., Llasat, M.C., Siccardi, F.: Predictive ability of severe rainfall events over Catalonia for the year 2008. Natural Hazards and Earth System Science 11(7), 1813–1827 (2011)
11. Dorninger, M., Gorgas, T.: Comparison of NWP-model chains by using novel verification methods. Meteorologische Zeitschrift 22(4), 373–393 (2013)
12. Sindosi, O.A., Bartzokas, A., Kotroni, V., Lagouvardos, K.: Verification of precipitation forecasts of MM5 model over Epirus, NW Greece, for various convective parameterization schemes. Natural Hazards and Earth System Science 12(5), 1393–1405 (2012)
13. Amodei, M., Stein, J.: Deterministic and fuzzy verification methods for a hierarchy of numerical models. Meteorological Applications 16(2), 191–203 (2009), Dostupné z: http://doi.wiley.com/10.1002/met.101, doi:10.1002/met.101 (cit. February 04, 2015)
14. Atger, F.: Verification of intense precipitation forecasts from single models and ensemble prediction systems. Nonlinear Processes in Geophysics 8(6), 401–417 (2001)
15. Mcbride, J.L., Ebert, E.E.: Verification of quantitative precipitation forecasts from operational numerical weather prediction models over Australia. Weather and Forecasting 15(1), 103–121 (2000)