UTILIZATION OF METEOROLOGICAL RADARS FOR FORECAST OF PRECIPITATION AND VISUALIZATION OF INFORMATION

VYUŽITÍ METEOROLOGICKÝCH RADARŮ PRO ODHAD SRÁŽEK A VIZUALIZACE INFORMACÍ

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Abstract

The meteorological radar provides today frequently utilized information on the current weather state and development. In combination with the data from precipitation stations it allows very precise weather estimates and forecasts. Theis paper deals with principles and errors of meteorological radars and types of visualization of radar signals and estimates of precipitation totals within nowcasting.

Abstrakt

Meteorologický radar poskytuje v současné době hojně používané informace o aktuálním stavu a vývoji počasí. V kombinaci s údaji ze srážkoměrných stanic umožňuje velmi přesné odhady a předpovědi počasí. Tento článek se zabývá principy a chybami meteorologických radarů a formami vizualizace radarových signálů a odhadů srážkových úhrnů v rámci nowcastingu.

Key words: meteorological radar, rainfall, visualization

1 INTRODUCTION

Forecasting of the course and rate of precipitation, flow regime and its affect to the development of flood situations represents today a very frequent assignment, as in recent years not only in the Czech Republic relatively frequent occurrence of extreme precipitation-runoff phenomena was recorded.

Reliability of the forecasts and thereby also hydrological models is of course affected by input data. The quality of data varies, and especially the data quantity (number of precipitation stations) is insufficient.

Conventional methods of spatial estimation of precipitation utilizing precipitation measurements involve e.g. Thiessen polygons. This method may be used in the area with only few precipitation stations, however results of this method may not be treated as too authentic, since for each precipitation station a polygon is generated, for which a value is considered relative to the station it represents. Further methods such as kriging, cokriging enable to introduce next variables to the calculation, e.g. elevation, and so improve the entire estimate considerably.

Thanks to a good area coverage and temporal and spatial resolution the radar measurements are able first of all to complete appropriately the network of ground stations, especially in summer time, when convective precipitation occurs quite often and the network of precipitation stations is not able to cover the structure of rainfall field with a sufficient accuracy. The radar data provides an immediate overview on movement and structure of rainfall systems, allows short-term forecasts (3-hour interval is used within CZRAD nowcasting) and warning against dangerous phenomena. On the other hand the radar measurements are rather complicated and final estimates of precipitation rate can be encumbered by many errors.

Radar precipitation estimates can contribute to improvement of precipitation estimates in monitored areas and so also to improvement of results of hydrological modelling.

2 PRINCIPLE OF RADAR MEASUREMENTS

Meteorological radar serves to detect significant cloudiness (storms approx. to 250 km) and estimate immediate precipitation rates up to approx. 150 km from the radar.

The radar measurements are based on the principle of microwave back-scatterring (cm-waves) by water droplets and non-spherical ice particles in rainfall and cloudiness. The transmitter generates high-energy pulses of electromagnetic waves that are radiated by the antenna as a narrow beam into the atmosphere. Part of the energy is reflected (more precisely: scattered back) by targets either meteorological (rainfall) or other ones (terrain, aircrafts and others). Part of the back-scattered energy is captured by the antenna and processed by the radar receiver. According to the antenna position (azimuth, elevation) and time interval between transmitting and intercepting of a pulse the target position is determined. Quantity of the energy reflected is proportional to radar target reflectivity. The meteorological radar is capable to recognize objects less than 1 cm, such as rain drops, snow flakes and hail-stones, as it transmits pulses in the range of microwaves.

The meteorological measurements consist of approx. 15-20 revolutions of the antenna in azimuth with variable elevation angle (elevation). These volume scans are repeated every 5-15 minutes.

In the territory of the Czech Republic two meteorological radars within the Czech weather radar network **(CZRAD)** of the Czech Hydrometeorological Institute are operated. The first one is situated on the hill Praha (860 metres above sea level) in **Brdy** highlands. The equipment is embedded by the fully automatic and remote control radar Gematronik M 360-AC. The other radar is situated on the hill Skalky (730 metres above seal level) in **Drahanská Highlands.** The installation is embedded by the fully automatic and remote control radar EEC DWSR 2501-C (Fig.1).

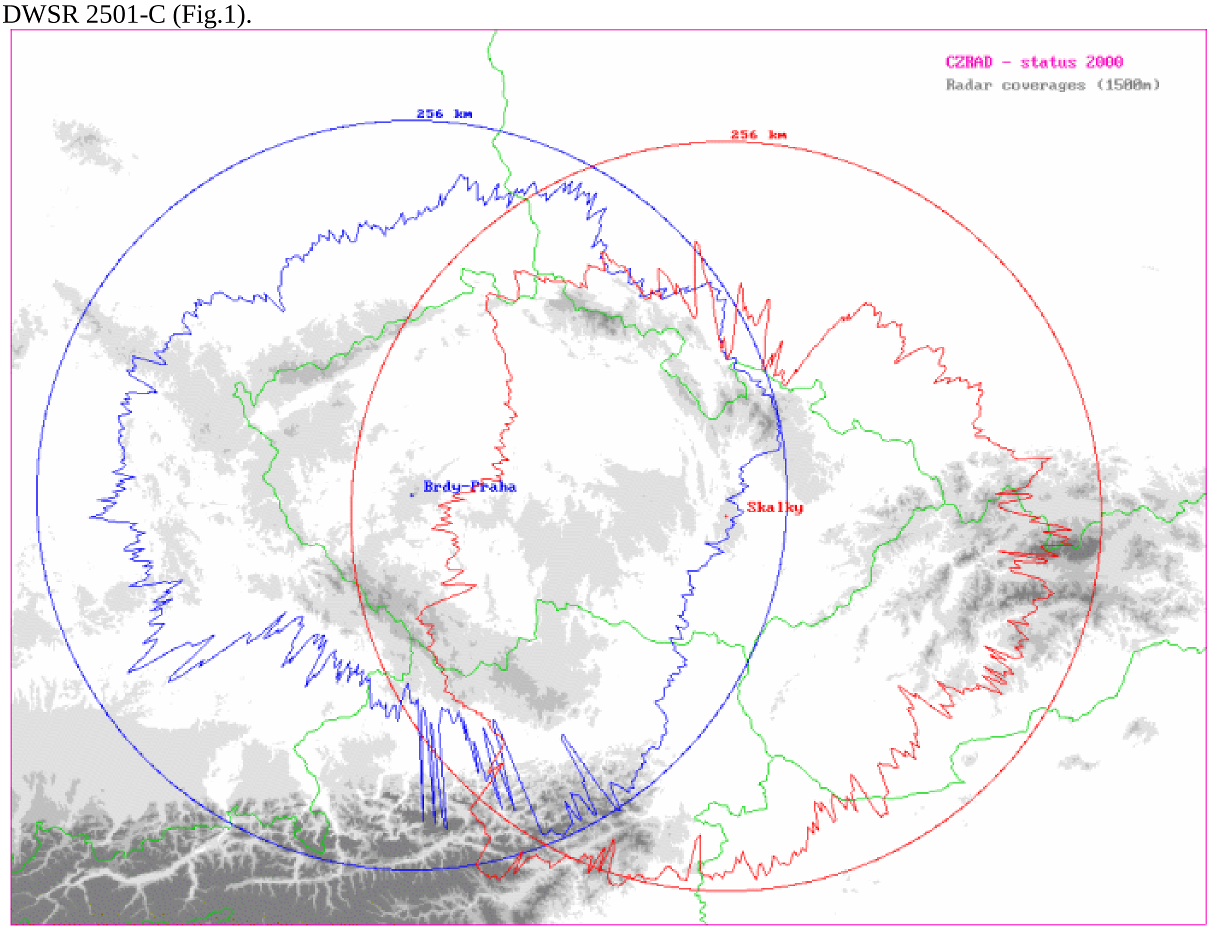

Fig. 1 Maximum ranges of the meteorological radars (circles) of the Czech Hydrometeorological Institute and ranges for determination of precipitation rates up to 1 500 m above ground level (curves). Adopted from the Czech Hydrometeorological Institute .

The data from those two radars cover the entire area and border areas of the Czech Republic by volume scans in 10-min update rate up to 256 km.

To estimate the areal precipitation four types of data are available today:

- Maximum column reflectivity with horizontal resolution of 1 km x 1 km (MAX1)
- Maximum column reflectivity with horizontal resolution of 2 km x 2 km (MAX2)

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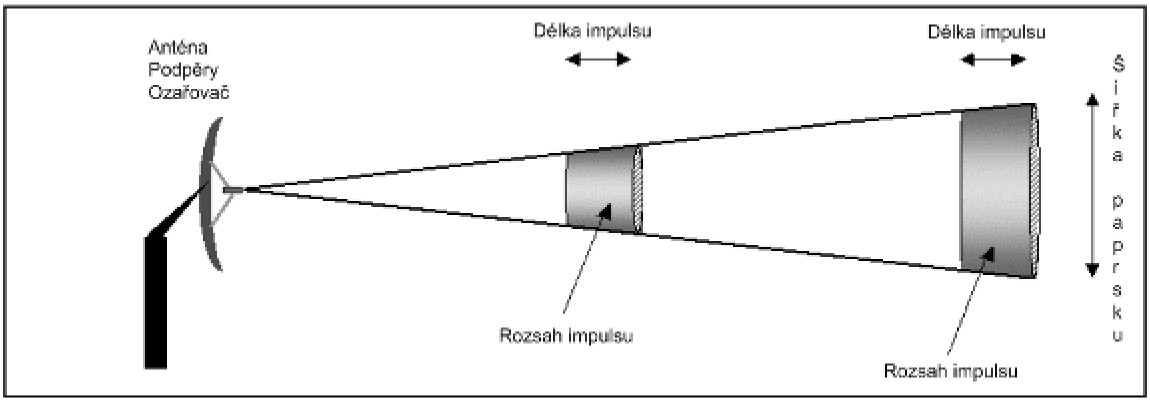
- Reflectivity in a constant height (CAPPI) of 2km above sea level with horizontal resolution of 1 km x 1km (CAP1)
- Reflectivity in a constant height (CAPPI) of 2km above seal level with a correction using vertical profile of reflectivity and with horizontal resolution of 1 km x 1km (COR1)

The maximum reflectivity field is acquired as a maximum value of vertical column reflectivity determined from all the measured elevations (PPI levels) of a given volume scan. The reflectivity field in a constant height is acquired by interpolation in vertical direction from adjacent measured elevations of a given volume scan. Nearby the radar, where no measured PPI level does not overreach the required height level, the reflectivity from the highest measured elevation is used instead of the interpolation. In large distances from the radar, where on the contrary all the PPI levels exceed the required height level the reflectivity from the lowest elevation of the volume scan is used. In case of a correction by means of the vertical profile of the radar reflectivity, the reflectivity in large distances from the radar is extrapolated to the required height level from the lowest unscreened elevation of the volume scan. The vertical profile used for the extrapolation is calculated from the actual volume scan in the area near the radar (30-80 km from the radar), where no problem with invisibility of the lower or upper parts of the atmosphere exists. In case the radar echo is too weak to calculate average profile in this area, the long-term average monthly profile is used (Novák 2002). Parts of the meteorological radar are showed in Fig.2.



Antenna
Supports
Feed
Pulse length
Pulse range

Fig. 2 Individual parts and principle of the meteorological radar transmission

2.1 Errors of radar measurements and multi-sensor analysis

The meteorological radar data are acquired from radar measurements and converted to millimetre totals in given time intervals using known mathematic relations and equations. The data acquired like this are summarized to longer time intervals. Precipitation is mostly calculated for the period of 1, 3, 6, 12 and 24 hours.

According to Šálek (2002) the radar data is encumbered by a great number of errors, so without corrections its utilization in hydrological models would be difficult. At present and in past a series of works dealt with the analysis of errors and with their impact to accuracy of the derived precipitation (e.g. Collier 1996, Austin 1987, Kračmář 2004). The problem is solved by means of multi-sensor analysis. From the methodst of data corrections of multi-sensor analysis mainly calculations of adjustment coefficients and combined analysis are used.

According to the Czech Hydrometeorological Institute the most important effects making the radar measurements incorrect involve the variable width of radar beam and its height above the ground level, growing with increasing distance from the radar and causing a systematic precipitation underrating. The values are affected also by terrain or other obstacles (trees, pylons).

Šálek (2002) shows that relatively large deviations were found within the radar estimates in mountain areas, especially during strong wind and regional precipitation. On windward slopes owing to orographically conditioned ascending movements fog is created that is wash out by precipitation occurring mostly in the middle troposphere. In extreme situations the presented orographic reinforcement can achieve up to hundreds percent, which consequently reveals itself in appropriate errors in radar estimates.

Current issues of radar estimates involve also the evaporation of precipitation particles in dry, below lying layers of the air, which results in a slight overrating of the precipitation total.

In the Czech Hydrometeorological Institute a procedure is in operation since the year 2002 - adjustment of radar estimates of precipitation as well as combinations of adjusted estimates with available precipitation measurements. The adjustment is understood to mean the elimination of systematic error of radar measurements. To adjustment a single adjustment coefficient is applied for the entire radar domain. It is an aliquot part of the sum of all precipitation indications (G_i) and the sum of matching radar estimates (R_i). It is computed in the element of 1x1 km according to the following relation:

$$\mathbf{K = \Sigma\, G_i / \Sigma\, R_i}$$

While calculating the adjustment coefficient a complication occurs, when precipitation measurements and matching radar estimates not always correspond exactly to the relation of real felt rain and radar estimates for the entire area, namely from the above mentioned problem of precipitation measurement representativeness. Therefore a sliding time window is generated and the calculation is performed from at least three days and the average precipitation accumulation received from rain gauges has to exceed 2 mm. Further a weighing of aliquot parts of individual days is carried out, when more distant days are assigned a minor weight. At the same time the number of precipitation stations showing the measured precipitation totals must be higher than five. The adjustment is conducted at a distance of 20 to 150 km and problematic locations such as mountain areas or screened stations are not involved.

Another method of radar data corrections is the combined precipitation estimate. The adjusted radar estimates together with available precipitation measurements enter to the calculation process. A simplified method of optimal estimation is used for calculation, presuming the representativeness of precipitation measurements for a given radar territorial element and the validity of rain gauge data.

In the rest of pixels the resulting optimual estimate is calculated as a linear combination of precipitation measurements and radar estimates. The weights of precipitation measurements decrease with increasing distance from the precipitation station according to a negative exponential function. In a simplified way it is expressed by the following equations:

$$\mathbf{R_m = a{*}G+(1-a){*}R}$$

$$\mathbf{a = \exp(-d/const.)}$$

where R_m is the final combined estimate in a given territorial element, G - the closest precipitation measurements or estimate from the closest measurements, R - the radar estimate and d - the distance from the closest rain gauge.

The field of combinations with effectiveness over 99 % is limited to the locations, where the radar measured the precipitation higher or equal 0.1 mm. Based on the radar-rain gauge relation the system eliminates such stations, when one of them measures substantially higher quantity than the other. At the same time such values are eliminated that are too improbable (rate of precipitation e.g. 500 mm). Any of the above mentioned radar data corrections gives other values of the resulting precipitation (Novák 2004).

3 VISUALIZATION OF PRECIPITATION ESTIMATE IN THE CZECH REPUBLIC AND ABROAD

A basic rule of colour application for quantitative resolution of phenomena is to observe the following principle: The higher phenomena intensity, the higher intensity of colour. It requires the utilization of such set of colour shades, within which the range of intensities of individual phenomena vary in a sufficiently wide interval. In quantitative resolution of phenomena different dark shades are used in transition from colours cold (negative phenomena) to colours warm (phenomena positive, high values) (Voženílek 2002).

The radar information from the Czech radars is presented in the form of maps or animations on websites of the Czech Hydrometeorological Institute (http://www.chmi.cz/meteo/rad/index.html). The Internet applications are used utilizing DHTML technologies, namely JavaScript and PHP. Both of them demonstrate options to estimate the areal precipitation distribution within the Skalky and Brdy radars, specifically the initial radar estimate, radar estimate adjusted according to precipitation measurements, estimate with precipitation data only and combination of adjusted radar and precipitation measurements. A part of each estimate is also a correlation field showing the closeness of the relation of precipitation measurements and appropriate radar estimates. The Czech Hydrometeorological Institute uses in operation the adjusted radar estimate (Šálek 2004).

The reflectivity values correlate with the precipitation rate and during the visualization of radar data the blue colour means the areas of precipitation with weak intensity, green to orange ones indicate the precipitation more abundant, red to brown colours indicate sites with high-intensity precipitation. From the general geo-visualisation point of view this way of interpretation is inappropriate. In cartography the fact, when the so-called spectral scale of colours is used regardless the character of visualised phenomenon, is considered as a mistake. The same intensity of several chromatic colours of the spectral scale is suitable for differentiating qualitative properties of phenomenon, while the precipitation rate is a characteristics unambiguously quantitative. The utilization of monochromatic scale (preferably blue) with depth and brightness gradation would be more advisable. However, this adjustment would require at the same time to reduce the actually used amount of degrees, because an untrained user is not able to distinguish in an monochromatic image more than 8 degrees (Voženílek, 2001).

The reflectivity colour scale has 15 reflectivity degrees quantified in 4 dBZ steps (the unit of reflectivity is $1mm^6/m^3$, for practical purposes the logarithmic unit dBZ is applied), the threshold value of 4 dBZ corresponds to the precipitation rate of approx. 0.06 mm. To recalculation the Mashall-Palmer formula http://www.chmi.cz/meteo/rad/rad_inf.html is used.

Meteorological targets of a convective character (squalls, storms) have distinct high-reflectivity cores that are time-variable. Meteorological targets of a stratiform character (continuous rain) have more monotonous appearance with a small horizontal change of reflectivity values.

Ground reflections look often in radar images like minor incoherent areas or individual pixels with higher reflectivity very variable in space and in time - it sometimes appears or disappears all of a sudden in relation to the beam propagation. The largest are areas of terrestrial targets in night and morning hours. Their elimination is performed through the use of the Doppler filter.

The combined precipitation estimate system is applied also to determination of overlimit precipitation totals. The algorithm consists in searching the highest precipitation totals provided the default value is exceeded. When the critical value is exceeded the Czech Hydrometeorological Institute issues a warning bulletin.

The Czech Hydrometeorological Institute as opposed to some European countries provides very comprehensive and transparent information from the area of meteorology. Sweden, Norway, Finland, Denmark, Estonia and Latvia created the common project NORDRAD, where data are acquired from 32 radars covering whole Northern Europe (http://www.smhi.se/). For short-term weather forcast the meteorological services of the above mentioned countries use the HIRLAM model covering whole Northern Europe and the northern Atlantic Ocean. The radar reflectivity values are visualized in 1-hour intervals in four-colour scale described only in words (blue - weak rain, green - light rain, yellow - medium rain and red - heavy rain). It is possible here to view animation for last 24 hours.

The United Kingdom of Great Britain and Northern Ireland has available in total 19 radars with range of approx. 250 km (http://www.metoffice.gov.uk/). They are visualized on websites in half-hour intervals for last six hours. The colour scale is identical to the one of the Czech Hydrometeorological Institute, however it is divided to 7 categories (from fine rain to very heavy rain) and contains rain rates described only in words, it means that there is no possibility here to read values either in mm/h or dBZ. Advantageous is the option to zoom into a certain area. Recent 6 hours animations mentioned above stand to reason.

The Slovak Hydrometeorological Institute utilizes data from two meteorological radars. The first one located at Malý Javorník provides the radar reflectivity data, precipitation rate, upper limit of radar echo, monitoring of movement and development of thunderclouds, vertical profiles of direction and speed of wind and other. Dual polarization radar located at Kojšovská hola is then one of the most advanced radars that enables to acquire quite a number of additional information. Data from both meteorological radars are used either separately or in a combined form generating maps of the radar reflectivity, upper limits of cloudiness and rate of precipitation (http://www.shmu.sk/sk/?page=1).

The radar reflectivity values are here visualised as well by means of a colour scale from light-blue (low-intensity rainfall) up to violet colour (high-intensive rainfall, maximum 400 mm/h) against a shaded relief. The information is updated every 10 minutes and it is possible to visualize the animation. I evaluate the websites of the Slovak Hydrometeorological Institute as the most transparent.

The Portuguese Hydrometeorological Institute has 2 radars available (http://www.meteo.pt/pt/). They offer on websites relatively wide visualization options, whether it concerns viewing of each radar separately or a common mosaic against a topographic background. The colour scale layout is identical to the one from the Czech Hydrometeorological Institute, here is the option to express values in units dBZ and mm/h and furthermore to depict the amount of rainfall per hour. In half-hour intervals animations for recent 24 hours can be visualized.

Tab.1 Overview of current outputs of individual meteorological services

Country	Radar reflectivity values	Hour totals	Cloudiness
Czech Republic	4 - 60 dBZ	NO	NO
Slovakia	-20 – 70 dBZ	YES	YES
Germany	Description in words	NO	NO
Portugal	0.05 – 300 mm/h	YES	NO
NORDRAD	Description in words	NO	NO
United Kingdom of Great Britain and Northern Ireland	Description in words	NO	NO
OPERA	1/32 – 64 mm/h	In process	In process
Netherlands	Description in words	NO	NO

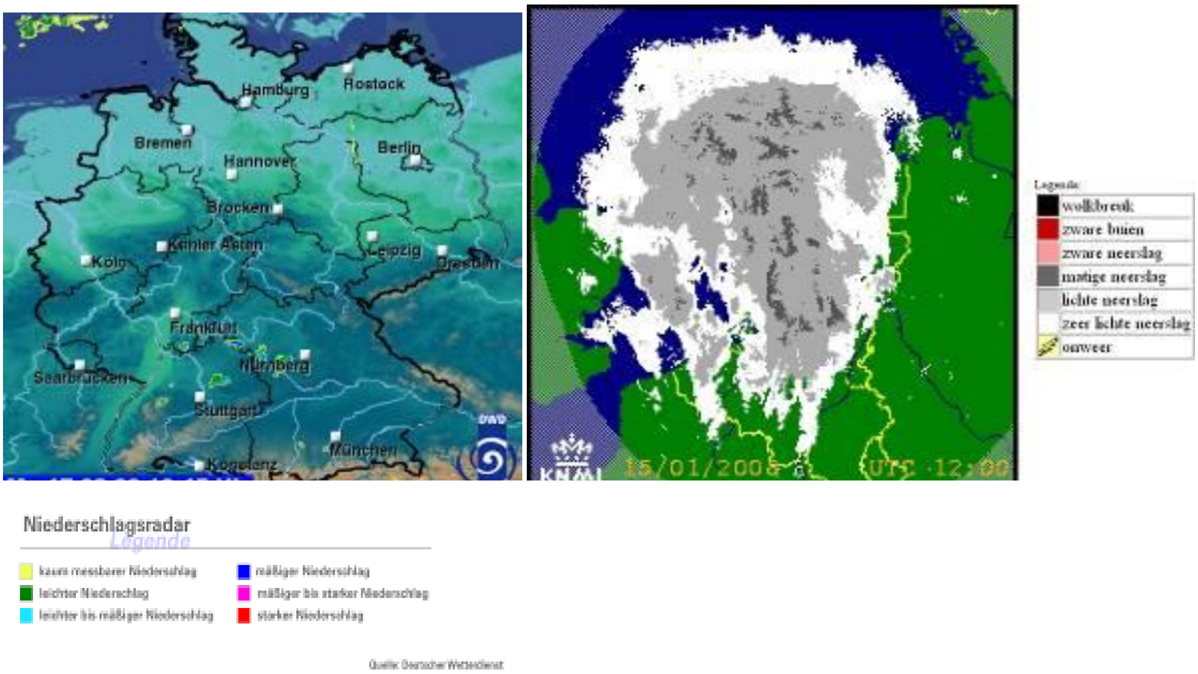
Tab. 2 Comparison of radar reflectivity visualization

Country	Time step	Scale type	Number of degrees	Topographic background	Animati on option
Czech Republic	15 min	Multi-colour	15	YES	YES
Slovakia	10 min	Multi-colour	10	YES	YES
Germany	15 min	Multi-colour	6	YES	YES
Portugal	10 min	Multi-colour	16	YES	YES
NORDRAD	60 min	Multi-colour	4	NO	YES
United Kingdom of Great Britain and Northern Ireland	30 min	Multi-colour	7	YES	YES
Netherlands	5 minutes	Multi-colour	7	YES	YES

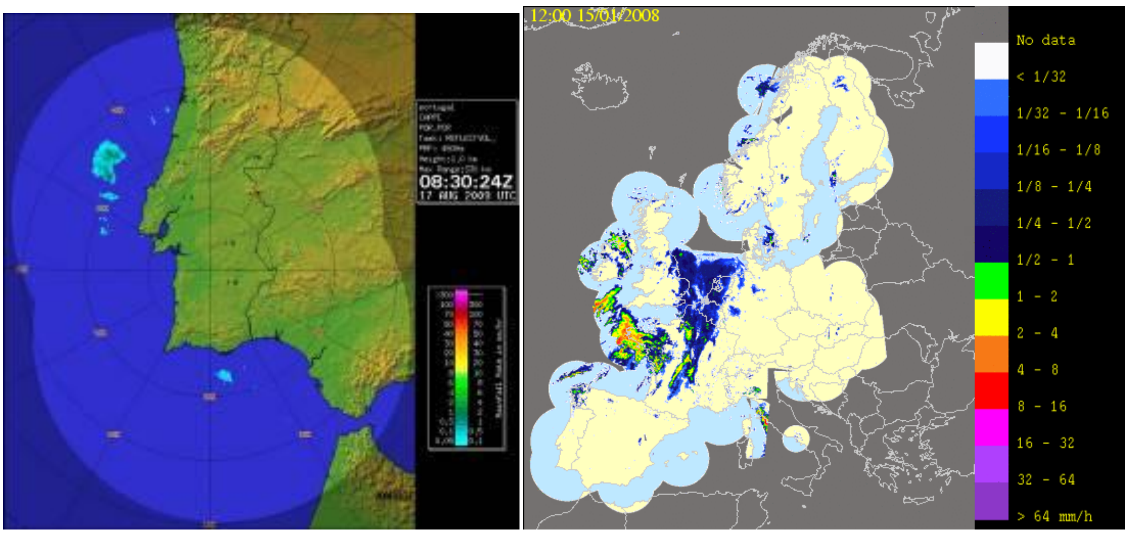
Germany is covered in total by 16 radars (http://www.dwd.de/). The colour scale is divided to six groups (from light-yellow to red) and is evaluated in words. The data is visualized against a blue-toned topographic background, so the viewed reflectivity values are not too much visible. It is possible to view animations with a half-hour interval for recent 4 hours.

We can find another colour visualizations of radar reflectivity values on websites of the Netherlands Royal meteorological institute (http://www.knmi.nl/). The colour scale is here divided to six categories (starting with white representing low-intensity rains, over grey, red up to black representing high-intensity rains). As compared to the scale of the Czech Hydrometeorological Institute, e.g. the white colour is applied to a quite opposite rate.

Since 1999 within the whole Europe the OPERA programme has run (Operational Programme for the Exchange of weather Radar Information). The objective of the programme is to harmonize and improve the operational exchange of weather radar information between national meteorological services. Today 28 European countries are involved and the weather radar network consists of approx. 160 radars, of which some 110 are Doppler radars. The colour scale is divided to 13 categories, however as compared to the other above mentioned services it is illogically sorted in an opposite way.



a) b)



c) d)

Fig. 3 Visualization of radar reflectivity in selected European countries
a) Germany (http://www.dwd.de/)
b) Netherlands (http://www.knmi.nl/)
c) Portugal (http://www.meteo.pt/pt/)
d) composition of the OPERA project (http://www.knmi.nl/opera/)

A fundamental rule of colour application for quantitative differentiation of phenomena consists in observance of the following principle: the higher phenomena intensity, the higher intensity of colour. It requires the utilization of such set of colour shades, in which the range of intensities of individual phenomena vary in a sufficient wide interval. In quantitative resolution of phenomena various dark shades are used in transition from colours cold (phenomena negative) to colours warm (phenomena positive, high values) (Voženílek 2002).

5 CONCLUSIONS

The radar data for short-term forecasts is today widely used not only by specialists. Therefore, it is necessary to track also usability and suitability of the application for the user, it is advisable to track also visual aspects of the application and cartographic principles that are essential in the geo-visualisation area and whose observance facilitates user's perception of the presented results.

At present perhaps all meteorological services offer modified results of radar records. Comparing these visualizations, we can see, except for minor differences, it always concerns a colour scale illustrating rainfall in either qualitative or quantitative forms.

From the point of view of cartography it would be then the most advisable to use the scale monochromatic. However, for lay public the actual scale is more transparent than the scale monochromatic and visualizes not only the radar reflectivity value, but also the convective precipitation.

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RESUMÉ

Meteorologické radary pracují na klasickém principu odrazu mikrovln od vzdálených objektů. Antény meteorologických radiolokátorů zaměřují své paprsky s vlnovou délkou 5,3 cm směrem k mrakům a čekají na jejich odraz od drobounkých vodních kapek, ledových krupek či sněhových vloček. Takovým způsobem se získávají okamžité a přehledné informace o dešťových nebo sněhových srážkách na velkém území. Intenzita odraženého signálu závisí především na vzdálenosti mraků a na velikosti odrážejících srážkových částic. Z výsledků radarového měření je možno určit druh částic, intenzitu srážek, prostorové rozložení oblačnosti i její pohyb.

Vzhledem k zakřivení zemského povrchu jsou radarová data spolehlivá jen do vzdálenosti 100 až 200 km od radarové antény. Proto se kombinují údaje z několika radarů sítě, pokrývající dnes celé evropské území.

Kartografové a meteorologové se v oblasti znázornění hodnot radarové odrazivosti mohou dostat do sporu. Ze stránek různých meteorologických služeb v rámci Evropy, je zřejmá shoda v barevné stupnici tzn. stupnice s prudkými skoky mezi barvami. Z kartografického pohledu je tato stupnice vhodná pro zobrazení kvalitativního jevu a ne jevu kvantitativního jimiž srážky jsou.