DEVELOPMENT OF CELL-TRACKING ALGORITHM IN THE CZECH HYDROMETEOROLOGICAL INSTITUTE

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Abstract. Precipitation and convective storms nowcasting based on weather radar data has been studied in the CHMI (Czech Hydrometeorological Institute) for a long period. Two methods of radar echo prediction on entire radar domain were implemented in 2003 into the operational processing of the Czech Weather Radar Network. The methods work very well but they have some limitations mainly for severe convective storms nowcasting. These limitations resulted into development of cell-oriented algorithm of radar echo prediction.

Cell identification is based on single minimum thresholding of maximum reflectivity data. Wind field from operational prediction algorithm (calculated for entire radar domain) is used as a first guess of cell assignment algorithm in subsequent images. Splitting and merging are also considered within the cell assignment algorithm. Simple calculation of cell motion vector from reflectivity core centres displacement is too inaccurate. Thus, to calculate cell motion vector, special local similarity algorithm is applied on each assigned cell pair.

The paper describes this algorithm and shows evaluation of the algorithm performance. Comparison with operationally implemented algorithm is showed.

1 Introduction

Several severe weather events (floods, flash floods, hail, tornadoes) that occurred on the territory of the Czech Republic within the last decade highlighted the importance of weather radar measurements and their utilization in nowcasting systems.

The Czech Weather Radar Network (CZRAD) consists of two Doppler C-band weather radars, which cover the entire area of the Czech Republic by volume scans in 10-min update rate up to 256 km range (Novak and Kracmar, 2002). Full volume scan is divided into 2 partial subscans measured every 5 minutes.

The maximum radar reflectivity composite field has been selected for radar echo prediction calculations. This composite covers the entire territory of the Czech Republic together with its close surroundings and is the most frequently used radar product of CZRAD. This product has 1km horizontal resolution that enables a better interpretation of radar echoes. It is updated every 10 minutes from full volume scan data.

Several prediction methods of radar echo nowcasting were tested during the last years (Novak et al., 2002) and two of them (COTREC and ALADIN) were implemented into operational processing of CZRAD in the beginning of 2003 (Novak, 2004). Both methods are used for prediction of entire radar image domain. They differ in method of calculation of motion wind field used for radar echo prediction. The implemented methods are:

1. The COTREC (Continuity Tracking Radar Echoes by Correlation) is based on the well known method described e.g. by (Zgonc and Rakovec, 1998) or (Mecklenburg et al., 1999). Wind field is determined by comparison of two consecutive radar images using the mean absolute difference as similarity criterion. The motion wind vector is determined in 3 steps over different radar domains (starting over the whole radar image and finishing with 25 small (44x44 km) boxes). The continuity of the motion wind vector from bigger to smaller domains is checked to reduce unwanted high variability of motion vector. At the end, the successive over-relaxation (SOR) algorithm is applied to smooth the final wind field.

2. In the ALADIN method, wind field is derived from the geopotential at 700hPa calculated from the NWP LAM model ALADIN using geostrophical approximation.

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The second step, time extrapolation of radar echo, is common for both methods. The radar images are extrapolated up to 90 minutes in 10 minute time steps. Extrapolation is based on the method of backward trajectories (for each pixel of the forecasted image, the corresponding pixel in the starting radar image is searched for). Two basic assumptions are made during the extrapolation; motion wind field is considered to be constant in time and the growth/decay factor of radar echo is not applied.

The methods (namely the COTREC) work very well but they have some limitations mainly for severe convective storms nowcasting. These limitations resulted into development of cell-oriented algorithm of radar echo prediction.

2 CELLTRACK – algorithm description

2.1 Identification of reflectivity cores

Several methods like SCIT (Johnson at al., 1998) or TRACE3D (Handwerker, 2002) can be used to define a reflectivity core in radar image. Each method identifies different objects as reflectivity cores, but none of them is 100 % successful in interpreting these reflectivity cores as convective cells. We primarily try to find high reflectivity cores applicable for severe storm nowcasting rather than 'physically based cells'.

In the CHMI is recently being tested reflectivity cores identification method using single threshold 44 dBZ. Reflectivity threshold 44 dBZ was final choice after testing values 36 dBZ, 40 dBZ, 44 dBZ and 48 dBZ. Main reason for choosing 44 dBZ reflectivity threshold was a compromise between lower values (in order to indentify also weaker cells) and higher values, which better distinguish individual reflectivity peaks in clusters of convective cells.

We also tested an algorithm, that comes out of identification used in TRACE3D algorithm. As input it uses reflectivity cores obtained by identification utilizing single threshold of 44 dBZ. Then it finds a local maximum in each reflectivity core and removes all values lower than the local maximum reflectivity value - 10 dBZ.

TRACE3D based algorithm is more suitable to find individual cells especially in clusters of convective cells. Different quantities of peak reflectivity within the reflectivity core can be tracked. However, this algorithm is not suitable for monitoring of storm volume development and other quantities, as reflectivity threshold of the reflectivity core varies during its lifetime. This problem is removed when a reflectivity core is defined by single reflectivity threshold. Justification for this method lies in operational utilization, where is important to predict movement of areas of high reflectivity instead of only reflectivity peaks. Furthermore, according to preliminary results, CELLTRACK tracking skill is slightly better for single threshold algorithm reflectivity cores rather than for TRACE3D identification algorithm reflectivity cores.

2.2 Reflectivity cores assignment

Assignment algorithm uses two consecutive files of 2D objects identified by one of the above mentioned algorithms as input data. Like other cell tracking algorithms this algorithm uses first guess of reflectivity core movement. For this purpose we use output from COTREC, which is being presently operationally calculated in CHMI. For performance of CELLTRACK this approach is better than use of movement vectors derived from previously assigned reflectivity cores. Probably the most important reason for this fact is splitting and merging of reflectivity cores, that can happen as artefact of identification algorithm. In such case resulting vector, which connects geometrical centres of subsequent reflectivity cores, is quite inaccurate. After calculating first guess, distances and shape similarity between all shifted reflectivity cores and all real reflectivity cores in subsequent image are calculated.

To calculate shape similarity the shifted reflectivity core from the first image is overlayed by reflectivity core from the subsequent image. Values of maxima and minima in x and y direction determine a rectangle drawn to this area. Shape similarity is calculated as $(YY + NN)/(YY + NN + YN + NY)$, where YY is equal to the number of pixels occupied by both reflectivity cores, NN is equal to the number of unoccupied pixels in the rectangle and finaly YN and NY are pixels occupied by only one reflectivity core. Another possible quantity could be the root mean square error or the mean absolute error, but the calculation would be more difficult without any significant improvement. Any reflectivity core which is closer than certain radius is marked as possible *child* core (hereafter "child" only). Moreover each child is tested the same way to have another *parent* core (hereafter "parent" only). Threshold value grows with increasing mean wind speed and it's values lie between 7 and 13 kilometres.

In a next step, algorithm tries to assign reflectivity cores. Clusters (i.e. at least one child and one parent) are processed at first. By tracking a cluster of closely spaced objects on a time serie of images there is an increased requirement for shape similarity. Determining a child using criterion of smallest distance is unsufficient because of frequent splitting and merging of reflectivity cores as artefact of their identification. The algorithm therefore looks for most similar reflectivity cores in the first step. Their similarity must be higher then minimum of 0.85. If their distance is smaller than threshold mentioned above, they are coupled together (assigned as parent and child) and because of high similarity they are eliminated from further processing of given cluster. After all pairs of similar cells are found, the program

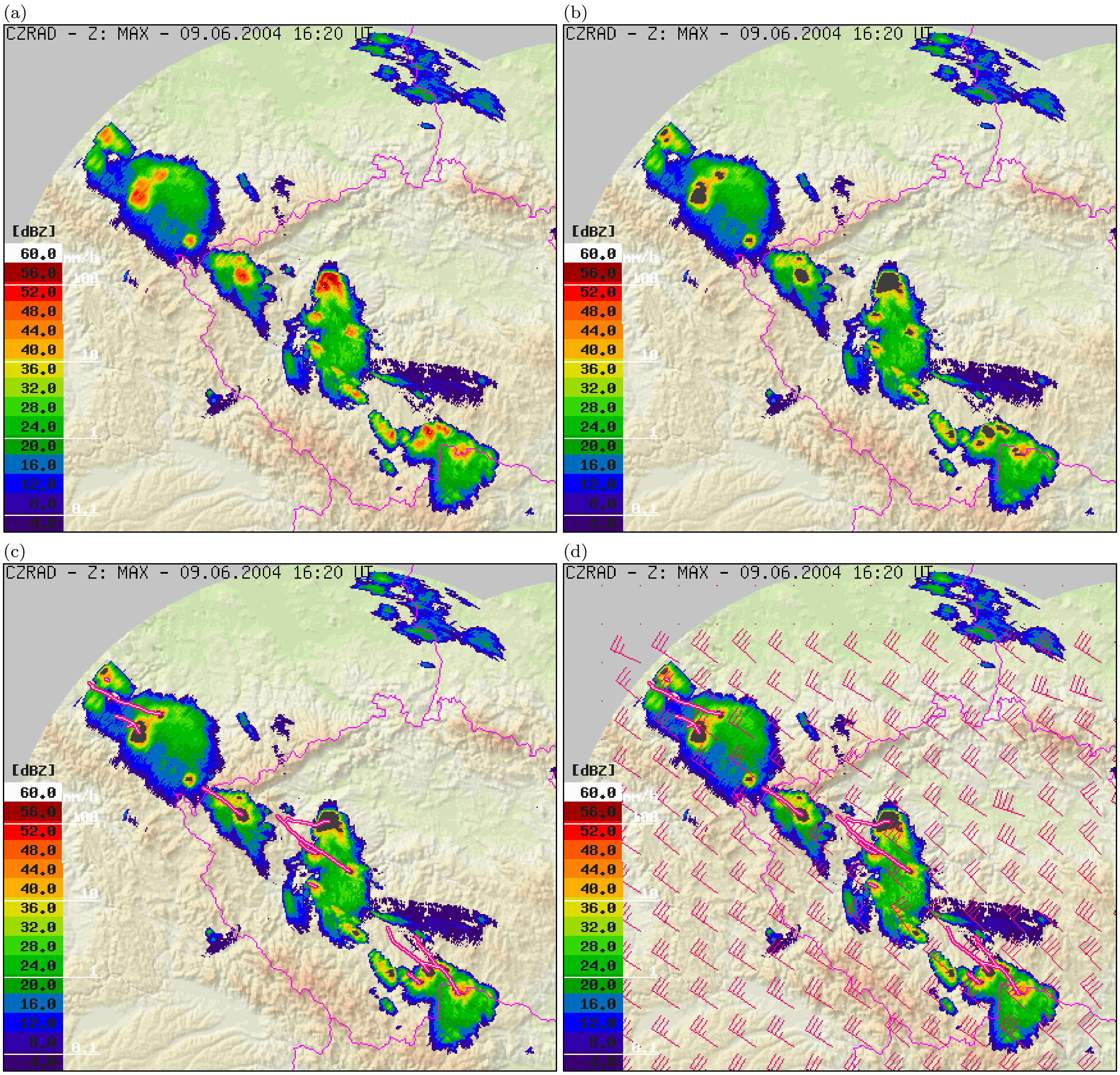

Fig. 1. June 9, 2004 16:20 UTC. (a) Reflectivity scan at 16:20 UTC; (b) the same as (a), but overlayed by appropriate reflectivity cores identified by single threshold algorithm; (c) paths of reflectivity cores drawn back in time, but no more than to 14:50 UTC; (d) same as (c) but overlayed by wind field obtained from COTREC at 15:20 UTC.

seeks for closest cells. Such a pair must fulfil a criterion of minimal similarity 0.80. If this criterion is not fulfiled the algorithm tries to find other child or parent (i.e. splitting if child is too small or merging if parent is too small). In case of splitting a new child is found if its center lies in the body of first guess reflectivity core or at most two kilometres apart from its edge. The same procedure is applied for merging.

After all clusters are processed the algorithm looks for unassigned cores. A reflectivity core can be unassigned if it has no child or parent or because of splitting and merging. If a sufficiently large core is splitted or it forms from more smaller cores, it may not be assigned to the same cluster, as their centres are too far from each other. Thus, as the last step, assignment algorithm attempts to correct this flaw by searching for splitting and merging of unassigned reflectivity cores. However criteria are somewhat more strict, since centers of smaller reflectivity cores should be inside the body of the larger one. This requirement prevents assigning small distant reflectivity cores, because large reflectivity cores fulfil this criterion very well. The algorithm has no upper limit of number of children and parents.

2.3 Extrapolation of reflectivity core movement

Position of reflectivity core is determined by position of its center, however simple extrapolation of the center of reflectivity core doesn't give satisfactory forecast. Main reason for this poor performance is splitting and merging of reflectivity cores – in most cases artificial product of reflectivity core identification.

Therefore CELLTRACK tries to find best fitting overlay of parents and children in each cluster of reflectivity cores assigned as parents and children. To calculate this overlay true reflectivity values in first image (parents) Z_p are subtracted from true reflectivity values in second image (children) Z_{ch} and quantity *sum* is calculated using formula

$$sum = n(\sum_{n \in X} |Z_p(n) - Z_{ch}(n)|)$$

where X is area covered by united parents and children areas and n is number of pixels covered in X area. CELLTRACK tries to find smallest value of the *sum*.

If a reflectivity core has no parent, mean motion vector of reflectivity cores with at least one parent is used. If there is no reflectivity core with at least one parent, no prediction is made. This typically occurs with onset of first detectable reflectivity core. Prediction is made up to 90 minutes with 10 minutes time step.

3 Evaluation of performance

Evaluation of CELLTRACK performance was carried out in next two ways. Firstly, CELLTRACK performance was evaluated during assignment of reflectivity cores in consecutive images. Secondly, we tested the skill of CELLTRACK in forecasting a convective situation and made comparison with COTREC and persistence forecast.

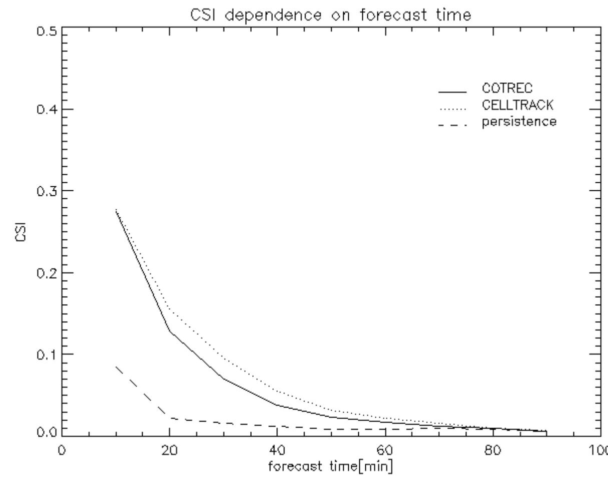

Fig. 2. June 9, 2004. Daily averaged CSI dependence on forecast time for reflectivity value threshold 44 dBZ. Full line represents COTREC, dotted line represents CELLTRACK and dashed line persistence forecast.

During evaluation of reflectivity cores assignment skill, assignments obtained from the CELLTRACK algorithm were compared with those obtained from manual inspection (i.e. manual reflectivity cores assignment). In case of difference between them, assignment from manual inspection was labeled as correct, and assignment by CELLTRACK was labeled as false. This means if CELLTRACK assigns child and parent incorrectly, both number of misses and wrong assignments are increased. Table 1 plots values of hits, misses and wrong assignments for reflectivity cores identification by single threshold algorithm. The same quantities in the same situations for reflectivity cores identification by algorithm based on TRACE3D identification are in Table 2. Four convective situations with various amounts of reflectivity cores and various wind speeds were chosen.

	hits	misses	wrong assignments	CSI
2001-05-31	369	32	22	0.87
2003-06-08	198	3	5	0.96
2004-06-09	270	19	17	0.88
2004-08-07	181	22	15	0.83
total	1018	76	59	0.88

Table 1. Hits, misses, wrong assignments and CSI for four different convective situations and their totals for identification by single threshold algorithm.

Values of CSI in Table 1 are 96 % for 2003-06-08 – a situation with few (not more than 10) reflectivity cores in each image and 83 % for situation 2004-08-07 with higher number (between 25 and 30) of reflectivity cores in each image and very slow wind. Remaining two sit-

	hits	misses	wrong assignments	CSI
2001-05-31	386	34	22	0.85
2003-06-08	181	7	15	0.89
2004-06-09	290	35	29	0.82
2004-08-07	178	26	23	0.78
total	1035	102	99	0.84

Table 2. Hits, misses, wrong assignments and CSI for four different convective situations and their totals for identification algorithm based on TRACE3D identification.

uations have also relatively high number (about 20) of reflectivity cores in each image, however the wind speed is considerably higher. Similar conclusions can be made for Table 2 but here the values of CSI are lower.

Forecasting skill and comparison with COTREC were evaluated only for reflectivity cores identification by simple threshold algorithm. We focused on convective situation with presence of deviating storms. Figure 2 displays CSI for forecast up to 90 minutes for COTREC, CELLTRACK and persistence forecast on 9th June 2004. It can be seen that CELLTRACK gives slightly better results than COTREC. Performance of persistence forecast is worse than both CELLTRACK and COTREC.

Figure 1 shows a case from 9th June 2004 depicting situation with deviating storm. All the figures depict situation at 16:20 UTC. In Figures 1a resp. 1b there are reflectivities of convective cells resp. reflectivities of convective cells overlayed by appropriate reflectivity cores calculated by single threshold algorithm with 44 dBZ threshold value. Paths of reflectivity cores, that were presented on the 16:20 UTC scan are drawn back in time but no more than to 14:50 UTC. In the center of the Figure 1c we can see path of storm deviating from the mean wind direction to the left. Figure 1d is the same as 1c overlayed by wind field as calculated by COTREC at 15:20 UTC. As can be seen, COTREC smooths wind field in the area of deviating storm.

4 Conclusions and outlook

CELLTRACK algorithm was developed and tested in the CHMI. Preliminary results indicate that in convective situations this algorithm is able to give forecast comparable with that of COTREC and better than persistence forecast. Therefore it seems to be a suitable complement for COTREC in convective situations. CELLTRACK could be improvement of COTREC especially during occurrence of strong deviating storms (typically supercells). Further improvement of the CELLTRACK forecast can be achieved by means of incorporating lifecycle characteristics derived from volume radar data and other remote sensing methods.

Acknowledgement

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References

Johnson, J.T. et al. (1998): The Storm Cell Identification and Tracking Algorithm: An Enhanced WSR-88D Algorithm, Weather and Forecasting 13, 1998, p. 263 – 276

Handwerker, J. (2002): Cell tracking with TRACE3D – a new algorithm, Atmospheric Research 61, 2002, p. 15 – 34

Mecklenburg S., Schmid W., Joss J. (1998): COTREC - a simple and reliable method for nowcasting complex radar pattern over complex orography, In: Final Seminar of COST-75: "Advanced Weather Radar Systems" - Locarno, 23.-27. 3. 1998, European Commission, Luxembourg, 1999, p. 441-450

Novak P., Kracmar J. (2002): New data processing in the Czech weather radar network, In: Second European conference on Radar Meteorology, Delft, 18.-22. 11. 2002, p. 328-330

Novak P., Walder J., Kracmar J. (2002): The first attempts at the radar echo prediction in the Czech weather radar network, In: Second European conference on Radar Meteorology, Delft, 18.-22. 11. 2002, p. 55-58

Novak P. (2004): Czech weather radar data utilization for precipitation nowcasting, In: ERAD 2004 proceedings, ERAD publication series, Vol. 2, p. 459-463.

Zgonc A., Rakovec J. (1998): Time Extrapolation of Radar Echo Patterns, In: Final Seminar of COST-75: "Advanced Weather Radar Systems" - Locarno, 23.-27. 3. 1998, European Commission, Luxembourg, 1999, p. 229-238

`http://www.chmi.cz/meteo/rad/`
- Czech Hydrometeorological Institute, Radar Department

`http://www.cnrm.meteo.fr/aladin/`
- NWP model ALADIN