Statistical analysis of convective storm tracks using volume reflectivity measurements from a C-band radar

E. Goudenhoofdt, M. Reyniers, and L. Delobbe
Royal Meteorological Institute of Belgium (RMI)
(Dated: September 15, 2009)

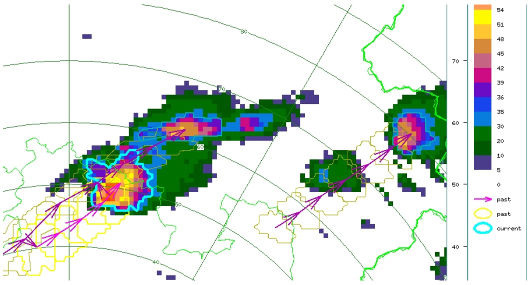
I. INTRODUCTION

The analysis and prediction of convective storms is not straightforward due to the complexity of the processes involved and the multiple scales at which they occur. Nowcasting of thunderstorms is generally based on radar images extrapolation. Unfortunately, this technique is not able to predict the evolution of the storm intensity or the initiation of new storms. A better insight of the characteristics of convective storms is required. Weather radars are best suited to observe this phenomenon at high spatial and temporal resolution. The radar volume data archived at RMI since 2003 provide a wealth of information for statistical studies on storm properties. The cell tracking system TITAN has been used to retrieve convective storm tracks from the radar data. Preliminary results obtained for the period 2006-2008 are presented here. Empirical distributions of different storm properties such as duration, maximum reflectivity or echo-top have been generated. Spatial characteristics of the storm tracks are also derived like the mean direction of displacement and a map of the storm initiation density.

II. RADAR DATA AND TITAN CELL TRACKER

The Royal Meteorological Institute of Belgium (RMI) operates a single-polarisation C-band weather radar. It provides a good coverage of the southern part of Belgium and also Luxembourg and part of France, Germany and the Netherlands. The radar performs a 5-elevation scan every 5 minutes with reflectivity measurements up to 240 km. The beam width is 1 degree. The resolution of the radar polar data is 250 m in range and 1 degree in azimuth. A time-domain Doppler filtering is applied for ground clutter removal.

The cell identification, tracking and analysis system TITAN has been installed at RMI. It is a comprehensive software package which can handle data from various radar types. It also supports data from satellite, lightning sensors, surface observations and numerical models. The algorithm TITAN itself (Dixon, 94) is a relatively simple but powerful method based on centroid tracking. In a first step, the polar data from the Wideumont radar are transformed into Cartesian data using nearest neighbour principle with no interpolation. Storms are then identified as three-dimensional objects with reflectivity above a given threshold. The ensemble of storms detected on 2 consecutive scans are logically matched by combinatorial optimisation with a maximum speed constraint. An additional algorithm handles for splits and mergers. TITAN is in constant development and it has been updated several times. A new detection algorithm based on dual thresholding has been implemented and a new overlapping technique is applied before the existing combinatorial optimisation method.



III. TRACKS ANALYSIS

In the cell tracker TITAN, the main parameter for the identification of an individual cell is the reflectivity threshold. Following previous similar studies, a value of 35 dBz has been chosen. The dual threshold is fixed at 45 dBz. Another important parameter is the minimum storm volume which is fixed at 50 km^3.

A side application of the TITAN system allows generating ASCII tables of storm track properties. Two categories of properties are produced :

- Instantaneous storm properties such as position, echo-top or volume.
- Aggregate track properties such as duration, mean echo-top or direction of displacement.

The tracks are sorted into two categories : simple and complex tracks. A complex track refers to a track for which splitting and/or merging occurs. For a complex track, the properties are aggregated amongst all cells belonging to the track. The storm track tables generated by the TITAN system can be processed by an appropriate statistical tool.

Some parameters allow selecting a subset of the storms detected by Titan. The minimum duration is fixed at 900 sec which corresponds to 3 consecutive scans. The maximum study area is defined by the detection range of the radar. It is however preferable to reduce the size of the study area for several reasons. It is well known that the quality of the radar observations decreases with the distance from the radar. Attenuation, overshooting and beam broadening may lead to lower storm detection at long range. In this study, a maximum range of 180 km has been chosen. If one part of the storm track lies outside the range limit, the track is removed.

IV. RESULTS

The volume data of the Wideumont radar have been processed by the Titan cell tracker and storm tracks obtained from 2006 to 2008 have been analysed. The results for the different years are relatively similar. Therefore we will show here the results for the year 2008 only. It appears that convective storms mainly occur between May and August.

Frequency distributions of several properties of the storm tracks have been computed. The results are presented for the simple and complex tracks together.

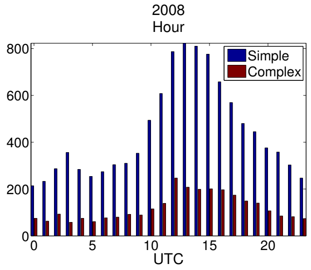


FIG. 1: Diurnal cycle of convective storms in 2008

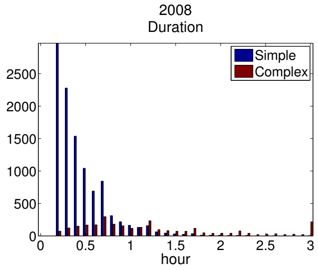


FIG. 2: Convective storm duration in 2008

In Fig. 1, the effect of the diurnal cycle is highlighted for both simple and complex tracks. As expected, there is a significant maximum between 12 and 16 UTC. The frequency distribution of the duration of the storm tracks is showed in Fig. 2. The distribution seems exponential for simple tracks and short-lived storms are predominant. The distribution for the complex tracks are close to a log normal model with a non negligible amount of complex tracks living more than 3 hours.

We also derived frequency distribution of the maximum reflectivity and the maximum height of the 35-dBZ threshold (echo-top 35 dBz). Both properties exhibit log-normal distributions.

The study of the storm kinematic (positions, speeds) should be less affected by the uncertainty of the radar observations. Figure 3 shows the repartition of the mean displacement of the storms. It is clear that there is a maximum in the North-North-East direction. This is consistent with the dominant wind recorded in the study area for convective situations. The same behaviour (not shown) appears for the complex tracks.

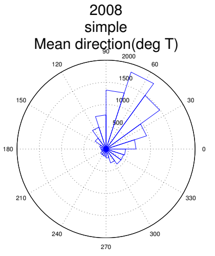


FIG. 3: Mean displacement direction of simple storm tracks in 2008

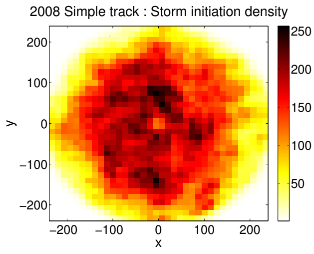


FIG. 4: Density of storm initiation location in 2008 (simple tracks only)

The density of the storm initiation is presented in Fig. 4. We can clearly see the effect of the range. The density tends to decrease at more than 100 km from the radar while it is also relatively low near the radar due to the cone of silence. The density is not uniform over the study area. It is however dangerous to conclude that there are preferred areas for convection initiation. This question should be further investigated to be sure that this is not induced by radar artifacts. An analysis based on observations from a second radar would be helpful for that purpose.

V. CONCLUSIONS AND PERSPECTIVES

A 3 year dataset from a C-band radar has been analysed to get a better insight of the convective activity in Belgium. The capabilities of the tracking and analysis system TITAN to produce information about convective storms have been showed. Promising preliminary results have been obtained from this long-term dataset. Realistic empirical distributions of some storms properties have been obtained. Simple cells are mostly short lived while about half of the complex cells last more than 1 hour. The distribution of the maximum reflectivity exhibits a log-normal behaviour. A few spatial statistics have also been computed. The mean direction of the storms is consistent with the dominant wind. The storm initiation density map suggests that there are preferred regions of convection although this observation must be verified.

It is worth pointing out that the methodology needs to be improved to get more robust results. The effect of the radar data quality needs to be further investigated. For example, ground clutter is present on some radar images. It would be also interesting to study the influence of the reflectivity thresholds on the storm tracking and the derived statistics. A more extended analysis of the spatial characteristic of the storms (size, cluster organisation) will be performed as well. A multivariate analysis will be carried out to find a possible relation between storm evolution and properties of storm tracks. In a latter stage, other types of observations (lightning, satellite, GPS) and NWP models output will be used. Finally the use of a second radar could be very valuable in order to compare the results.

VI. ACKNOWLEDGMENTS

We would like to thank Jaqueline Murakami Kokitsu (IPMet, Brazil), Karel de Waal (South African Weather Service) and Mike Dixon (UCAR, U.S.A.) for their support concerning the installation of TITAN. This research is supported by the Belgian Federal Science Policy.

VII. REFERENCES

Dixon, M., and G. Wiener, 1993: TITAN: Thunderstorm Identification, Tracking, Analysis, and Nowcasting–A Radar-based Methodology. J. Atmos. Oceanic Technol., 10, 785797