TEMPORAL EVOLUTION OF TOTAL LIGHTNING AND RADAR PARAMETERS OF THUNDERSTORMS IN SOUTHERN GERMANY AND ITS BENEFIT FOR NOWCASTING

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I. INTRODUCTION

Improved nowcasting of thunderstorm related hazards like lightning, hail or heavy rain would be of high benefit for weather related industries. A better understanding of the driving processes and the extreme non-linear behaviour of thunderstorms would help to improve the short-term nowcasting.

The new cell tracking algorithm ec-TRAM (tracking and monitoring of electrically charged cells) (Meyer, 2009) was developed to identify, track, and record electrically active cells by combining the information of separately tracked lightning cells and high reflectivity fields. Based on three-dimensional lightning information and conventional two-dimensional radar information the algorithm assesses the actual cell state and records the temporal evolution of the cell parameters. Spatial nowcasts for cell position and cell shape are calculated for the next 20 to 30 minutes.

In this study, which is part of the DLR project RegioExAKT, several selected thunderstorm life cycles recorded by ec-TRAM were complemented with volumetric polarimetric radar information and investigated in terms of the underlying microphysical processes.

As demonstrated in the example of a thunderstorm cell from 25 June 2008 the combination of radar and lightning data has features capable to assess trend nowcasts for thunderstorms. Especially the information about graupel and hail formation in the mixed phase layer as warning parameter for future electrical activity and the evolution of total lightning for cell trend prognoses are promising correlations which still have to be tested.

II. METHOD

The new thunderstorm tracking algorithm ec-TRAM was developed at the DLR (German Aerospace Centre) in Oberpfaffenhofen to combine the information of independently tracked radar and lightning cells. In every time step the two cell types are assigned via spatial overlap to one single object called ec-cell (electrically charged cell). Ec-cells are tracked in a hierarchical order. This approach guarantees the highest information content for the hybrid cells. Because every cell type is closely and independently tracked the combined cell parameters complement but do not affect each other.

The radar cell tracker is a further development of the radar cell tracker Rad-TRAM (Kober, 2009). Radar cells are identified based on the two dimensional low-level precipitation fields of the DWD C-band Radar in Fürholzen. The DWD provides the low level scan operationally every 5 minutes on a 1 km x 1 km grid. The high spatial and temporal resolution of the data allows a closed cell tracking which is especially advantageous to investigate the usually extremely non-linear evolution of thunderstorms. Radar cells are identified and tracked based on the rad-TRAM Algorithm (Kober, 2009) with a reflectivity threshold of 33 dBZ. Spatial nowcasts for cell position and cell shape are calculated for the next 30 minutes by applying a pixel based displacement vector field.

Lightning cells are identified based on spatially and temporally clustered lightning frequency maps. Total lightning data are provided by the European lightning detection network LINET (Betz, 2008). The network uses a three-dimensional time of arrival (TOA) method to triangulate lightning sferics in the VLF/LF regime. Besides the discharge time and amplitude the emission height is calculated for every discharge event, so that in-cloud (IC) and cloud-to-ground (CG) events are consequently discriminated. To remove local sensitivity variations due to non-uniform sensor spacing a minimum value of 2.5 kA for the discharge amplitude is used for the cell tracking. To obtain a net insensitive emission height statistic an additional height threshold of at least 5 km is applied on IC emission heights. While the amplitude threshold is used for the cell tracking and the total lightning analyses the height threshold is used only for the emission height statistics and does not affect the other cell parameters such as discharge count or discharge density. Total lightning data of three minutes are accumulated and mapped on a discharge map. Events are then clustered to a lightning cell if the spatial distance to the closest event is less than 3 km. Because electrical discharge is not only a hint but the direct prove of electrical cloud activity, lightning cells are identified with a threshold of one event. Lightning cells are tracked using a temporal overlap instead of the ‘first-guess’ method used for the radar cell tracking. Every 2.5 minutes discharge events of the last three minutes are clustered. So every actual cell includes events, which are also used to identify the previous cell. Now cells can be tracked via simple spatial overlap of previous and actual cells. Spatial nowcasts for cell position and cell shape are calculated in the same way as for radar cells.

The cell clustering and cell identification parameters for both cell types are selected with the focus to achieve on the one hand the most efficient cell assignment between radar and lightning cells and on the other hand reasonable and comparable cell areas.

Ec-cells emerge from a spatial overlap of actual radar and lightning cells and are tracked in a hierarchical order. Because of the tracking method the tracks of lightning cells are considered to be more reliable than the radar cell tracks. So first it is looked for tracked lightning cells to pass on the ec-cell number of a previous ec-cell to the actual ec-cell complex. In case of any ambiguity, the largest area is the determining factor for cell association. If there is no lightning cell track available in the actual time step it is looked for tracked radar cells to pass on an ec-cell number, again with the largest area as determining factor. FIG.1 shows a snapshot of an ec-TRAM map detail. The radar reflectivities are illustrated in blue shades, actual electrical discharge events, both IC and CG events, are indicated by green crosses. White contours enclose actual radar cells, the red contour an actual lightning cell. White lines are radar cell tracks. The spatial cell prognoses for 10 and 20 minutes are drawn as black and grey contours, respectively. The yellow sign indicates Munich airport.

FIG.1: ec-TRAM snapshot of an ec-cell with actual lightning and radar cells, the radar cell track and radar cell prognoses.

For the selected events the C-band dual-polarization Doppler radar POLDIRAD of the DLR in Oberpfaffenhofen, Germany, provides additional polarimetric radar quantities such as reflectivity, linear depolarization ratio (LDR) and differential reflectivity (ZDR), which allow a hydrometeor classification (Höller, 1994). Volumetric and cross section scans give information about the vertical structure and the hydrometeor distribution of the storm and are used to interpret the ec-cell evolution in terms of the underlying dynamic and microphysical processes.

III. RESULTS AND CONCLUSIONS

FIG.2 shows the temporal evolution of radar and lightning parameters of a thunderstorm cell recorded on 25 June 2008 near Munich. The upper diagram shows the cell areas in km² as a function of time. The black line represents the lightning cell area, the grey line the radar cell area. The lower time diagram shows the evolution of the electrical activity in counts per cell cluster of the storm. The black line indicates the total discharge activity, the red line the IC and the green line the CG discharge activity. The volumetric radar information is investigated but not shown in the FIG.2.

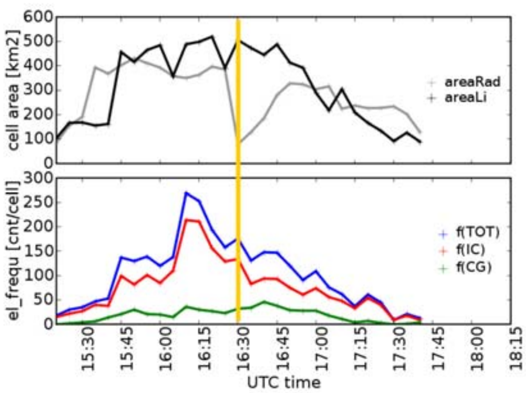

FIG.2: Life cycle of a thunderstorm cell recorded on 25 June 2008

The first reflectivity core with a maximum reflectivity of 33 dBZ was detected at 15:04 UTC in the volumetric radar scan at 4 km height. 15 minutes later at 15:20 UTC ec-TRAM recorded the cell for the first time as the precipitation field at the ground exceeds the threshold of 33 dBZ and lightning activity starts. Graupel and hail were recorded in the mixed-phase layer at 4 km height five minutes prior to the first obvious electrical activity. The electrical activity of the storm starts with IC events during an enhanced cell growth. The first CG event was recorded 5 minutes after the first IC event. The ratio of IC and CG events ranges between 2 and 40 during the whole lifecycle. At 15:25 UTC hail is observed near the ground. At 16.30 UTC both the ground precipitation field and in the volumetric radar data indicate a cell splitting marked as yellow line in FIG.2. 15 minutes prior to the cell splitting total lightning frequency increases significantly by a factor of two. After the cell splitting the main electrical activity shifts to the right moving cell and then diminishes while the precipitation rate of the cell increases significantly. At 16:35 UTC the hail at the ground changes into heavy rain. Lightning activity finally stops after 140 minutes. The radar cell persists until it merges at 16:45 UTC.

The synoptic conditions with high CAPE and low directional but high absolute wind shear are considered supportive to real cell splitting processes according to theory (Klemp, 1978). Interpreted in terms of the cell splitting theory the increase of total lightning just before the cell splits might be due to an updraft intensification. While the cell splits, the downdraft increases intensifying the precipitation at the ground and indicating cell dissipation as the cell core is ‘washed out’.

The example of the thunderstorm of 25 June 2008 suggests several warning parameters. Hail and graupel formation in the mixed phase layer can be an indicator for ongoing charge separation in the cloud and therefore be used as warning parameter for electrical activity in the near future. This is also supported by the current theory for charge separation in thunderstorms with ice phase (Dash, 2001). Beginning IC activity could be used as warning parameter for subsequent CG events. And finally the change of hail to rain and an increasing rain rate at the ground can be an indicator for cell dissipation.

The next steps will be to identify more life cycle patterns, which either support the actual warning parameters or can lead to new warning parameters for trend prognoses. The warning parameters will then be used to add trend prognoses to the spatial prognoses which build on the individually recorded cell histories. Finally the quality of the trend prognoses must be tested.

V. REFERENCES

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