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Operational thunderstorm nowcasting in the Alpine region using 3D-radar severe weather parameters and lightning data

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1 Introduction

The real-time object-oriented nowcasting tool TRT (Thunderstorms Radar Tracking), is used operationally at MeteoSwiss since 3 years, as a part of its nowcasting, warning and information system, for the automatic detection, tracking and characterisation of intense convective cells.

TRT is a multiple-radars nowcasting system that uses heuristic and centroid-based methods derived from the RDT algorithm (Hering et al., 2004, 2005). In order to explore the capability of the tool to assess the severe weather potential of thunderstorms, the new version of TRT fully exploits 3D-radar data and has been expanded to a multiple-sensors system including cloud-to-ground lightning data.

The characteristics of the cell-objects describing the 3D storm structure and attributes as well as the accompanying time series, are computed from the volumetric radar data and CG-flashes. These recently introduced attributes include cell-based (Johnson et al., 1998) and grid-based VIL (Vertically Integrated Liquid), 15/45 dBZ Echo Tops, as well as the altitude of the maximum storm reflectivity.

This paper reports first results on how these 3D cell- and grid-based radar derived storm properties will help to assess the severity of thunderstorms in rather complex orography like the pre-Alpine and Alpine region (Fig. 1). By means of a case study of a severe hailstorm over Switzerland on 18 July 2005, we investigate the potential of the new 3D severe storm detection parameters, not yet available to forecasters at that time, to better assess the severity of thunderstorms.

During summer 2005, based on the TRT, MeteoSwiss started the diffusion, by local and national radio stations, of heavy thunderstorms warnings in whole Switzerland for the general public as well as to civil protection authorities, with simple flash-news, with a lead time of 30-120 min. The operational use of the new 3D attributes is expected to enhance the reliability of severe convection warnings, especially concerning heavy rain, hail, and wind gusts.

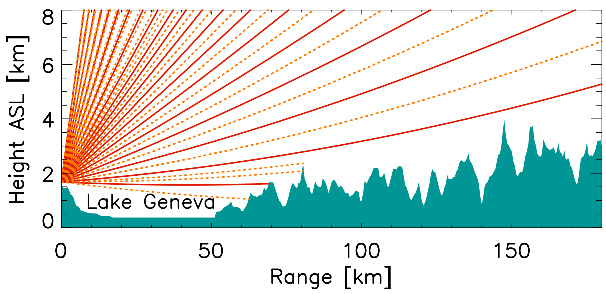

Fig. 1. Scan geometry of Swiss radar La Dôle situated on a mountain top (1680 m a.s.l.) near Geneva, with orography in the direction of azimuth 84°. This is roughly the direction of the hail swath on 18 July 2005.

2 Overview of the TRT algorithm

TRT is based on a dynamic thresholding scheme applied on the reflectivity data of multiple-radar composites. The dynamic scheme is able to identify each storm object at individual thresholds, depending on the stage of its life cycle. This permits an early detection of potentially severe thunderstorms, as well as the uninterrupted tracking of mature systems and of multicells agglomerations. For each cell the algorithm selects the lowest reflectivity threshold that allows to distinguish it from nearby cells (Morel et al., 2003).

A detected storm cell is tracked in successive images using the method of the geographical overlapping of cells. It is then possible to create the time history of cell displacement, and tracks are created from a sequence of radar images.

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Since TRT is tuned to identify individual cells rather than storm systems, the evolution of cell-based characteristics is available to the forecasters. Complex cases with several cells, splits and merges are also taken into account. A more detailed description of the algorithms is given in Hering et al. (2004, 2005).

To ensure a successful detection and tracking even in complex orography, a qualitatively good radar network with effective clutter elimination algorithms is necessary. The input reflectivity values for TRT have already passed a sophisticated 7-step clutter elimination algorithm and an extensive quality control program (Germann et al., 2006; Germann and Joss, 2004). No additional filtering of the row data is performed.

To compute the new multiple-radar severe storms detection products TRT uses the 3D Cartesian composite image (mosaic) of the 3 identical C-band Doppler radars of the Swiss network. Operationally a 20-elevation volume scan between -0.3° and 40° is performed every 5 minutes (Fig. 1). The Cartesian dataset consists of 12 CAPPI's between 1 and 12 km height.

The cell-based attributes (VIL, Echo Tops, maximum storm reflectivity altitude) are calculated inside the 2D foot print of the maximum extent of the cell projected to the ground. Cell-based VIL, as defined in Johnson et al. (1998), is computed integrating vertically the maximum reflectivity of each horizontal storm level. This method accounts also for a tilted reflectivity core and leads to a maximization of the VIL values that can typically be higher than the corresponding grid-based VIL.

In addition 2D-gridded fields of VIL and Echo Tops are computed for the composite radar domain. To remove contributions of hail on the VIL computation, all values above 55 dBZ are set to 57 dBZ. Supplementary information for the storm objects is provided from the Météorage network which supplies cloud-to-ground (CG) lightning data with both polarities.

3 The severe hailstorm on 18 July 2005

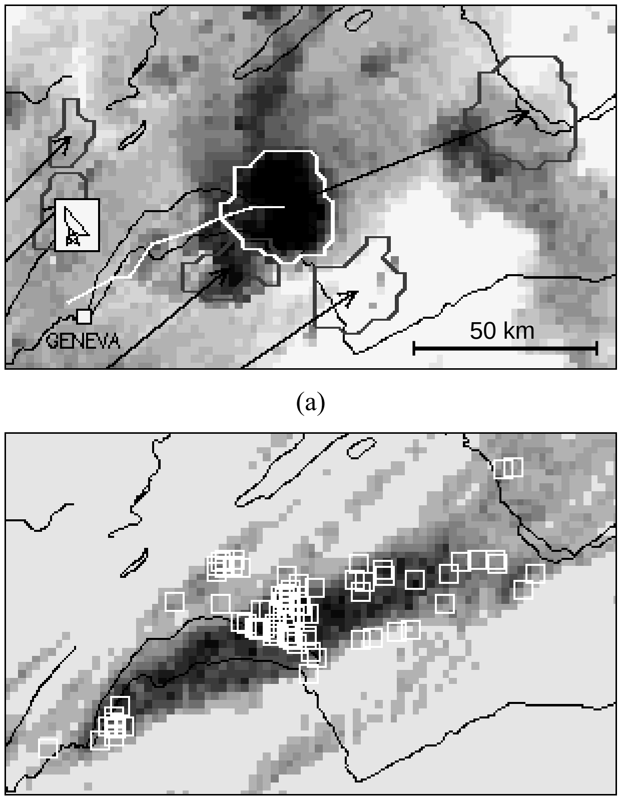
On 18 July 2005 at 13:16 UTC the following message was broadcasted to the public: “Thunderstorm flash of MeteoSwiss: a violent storm being able to cause hail as well as wind gusts of more than 75 km/h is located in this moment in Evian and will probably touch the area of Vevey-Montreux in half an hour”.

The severe convective storm over Switzerland was caused by a cold front approaching from France. One of its cells, starting from Lyon (eastern France) around 11:00 UTC developed into a major supercell hailstorm moving north-eastwards over Lake Geneva to western Switzerland (Fig. 2a). The 250 km track produced a “hail swath” of nearly 1200 km^2 (Fig. 2b) and considerable damage. At least eight people were injured, 15'000 cars damaged, and several vineyards destroyed. Insured claims from this hailstorm were more than €65 millions.

Cloud top temperatures around -60°C were measured by Meteosat-8 (not shown). The severe weather phenomena produced by this supercell included also 2 recorded tornados near Geneva and near the east lakeside.

3.1 Spatial distribution of hail

Fig. 2a shows a detail of the main TRT window with a superimposition of the detected convective objects, onto the radar image. The severe hailstorm is located in the centre and an arrow shows the individual cell displacement velocity and the 1h position forecast. The track indicates the displacement of the supercell passing over Geneva, Lake Geneva and the actual position of the cell centre in the Vevey-Montreux area.



(a)

(b)

Fig. 2. 18 July 2005: (a) Visualisation detail of the real-time TRT-product (13:40 UTC) over Lake Geneva and the Alpine region. Superimposition of the Swiss composite radar image (vertical maximum projection), detected cells (white contours), trajectories (white lines), estimated velocities (black vectors), and extrapolated cells positions (+ 1h; dark grey contours). Levels of shading correspond to reflectivity ranging from 13 dBZ (light grey) to >55 dBZ (dark grey). Note that this is the “extreme events” mode of TRT characterized by an adaptive detection threshold ≥48 dBZ. The location of La Dôle radar is indicated by the symbol. (b) Maximum grid-VIL map (10:30-17:00 UTC) for the same area as in (a). Squares represent locations (communities) where hail was reported at least once by the Swiss Hail Insurance. Levels of shading correspond to VIL classes ranging from 10-15 kg/m^2 (light grey) to 70-75 kg/m^2 (dark grey).

VIL is one of the most widely used parameters as indicator for hail in conventional radars. Nevertheless, some studies investigating its skill (e.g. Edwards and Thompson, 1998) have shown that VIL thresholds have a strong regional and seasonal dependence, and thus show a high variability depending on air mass characteristics.

At present no published VIL thresholds for the occurrence of hail exists for the Alpine area. To perform a first verification for this region a daily maximum VIL map was created by recording the maximum grid-VIL measured at each pixel of the composite radar domain. Fig. 2b represents a detail of a maximum VIL map on 18 July 2005, between 10:30-17:00 UTC. The swath shows the maximum VIL that occurred at each point as the thunderstorm passed over. A computed VIL "hail swath" well centred along the hailstorm track can clearly be identified, when comparing with Fig. 2a.

As verification data we use the hail damage claims collected by the Swiss Hail Insurance, the only insurance in whole Switzerland that insures crop damages. The data indicate on a given day, for every Swiss community, if at least one hail-damage claim has been registered. An exact time assignation of the hail occurrence is thus not possible. The coordinates of the community centres are used as "ground truth". The crop hail-damage locations in Fig. 2b correspond relatively well with areas of elevated radar-derived maximum VIL values. (Note that no crop damages were collected neither over the lake, nor over France to the south of the lake, nor over the more mountainous region passed over by the track). However, there are some locations where damage claims do not correspond to particularly elevated VIL values. On the other hand, areas with locally increased VIL values could also be used to indicate the potential for hail over more remote mountainous regions, where no or only sparse cultivations are present.

3.2 Temporal evolution of severe storms attributes

To investigate the temporal evolution of the hailstorm the time series of the cell-based severe storms detection products are used (Fig. 3). The cell passed over Geneva at approximately 12:55 UTC (vertical lines in Fig. 3), where the cell-based VIL was 60.8 kg/m^2, both 15/45 dBZ Echo Tops reached the maximum measurable altitude of 12 km, and the height of the maximum storm reflectivity increased to a value of 11 km indicating that the cell was still in the development phase. This is supported by the high negative CG flash rate of 31 / 5min at that time, vs. only 1 positive flash (Fig. 3c). At around this time a F1 tornado was recorded near Geneva.

At 13:16 UTC the warning for the region of Vevey-Montreux on the north-east lakeside was broadcasted. The thunderstorm was situated over Lake Geneva and moved at a speed of 65-70 km/h and a direction of about 240° towards Vevey-Montreux (trajectory in Fig. 2b). For the whole period 13:15-14:15 UTC, Cell-VIL was between 70-75 kg/m^2, both Echo Tops at 12 km height and the maximum storm reflectivity (>55 dBZ) between 11-12 km height. The supercell reached its mature stage in this area.

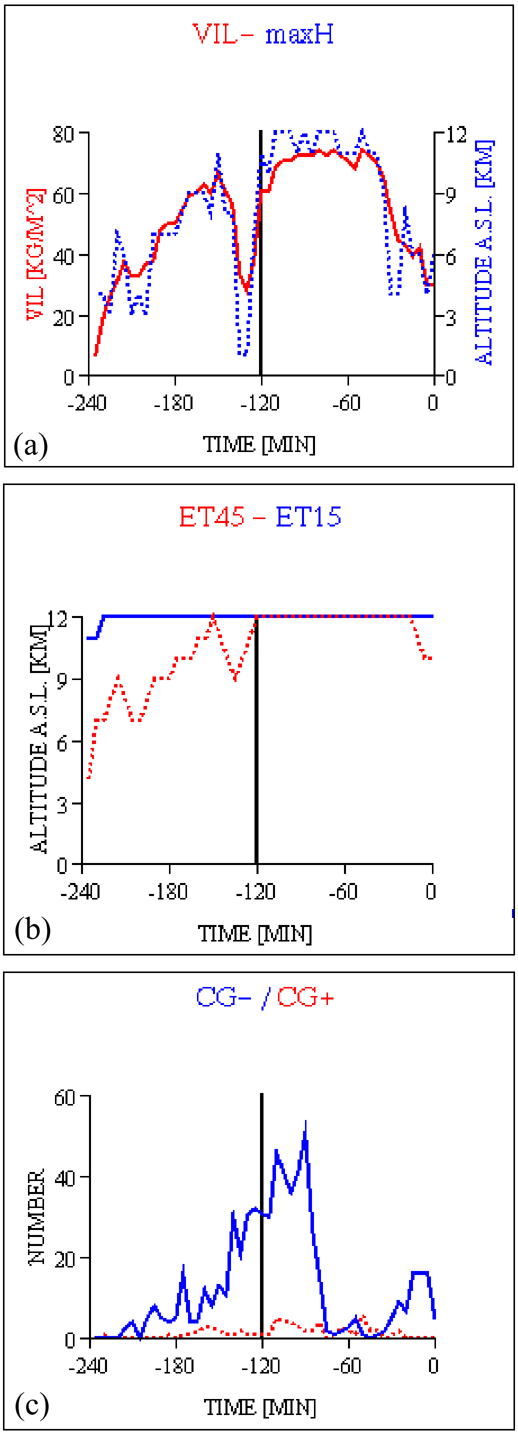


Fig. 3. Cell-based multiple-radar time series and CG lightning flashes evolution for the hailcell from Fig. 2a on 18 July 2005, 14:55 UTC. (a): VIL (solid curve) and altitude of the maximum storm reflectivity (dotted curve). (b): Maximum Echo Top at 45 (dotted curve) and 15 (solid curve) dBZ. (c): Trend of the negative (solid curve) and positive (dotted curve) CG flash rate [#/5min] inside or within 4 km from the cell outline. Vertical lines: cell over Geneva (about 12:55 UTC).

Golfball-sized hail was also observed during this period. A second tornado (F2) was recorded near the east lakeside and a maximum wind gust of 161 km/h was observed by the nearby mesonet station at 13:40 UTC.

The negative CG flash rate rapidly decreased after 13:30 UTC showing a remarkable anticipation of the decay phase of the storm. After 14:15 UTC the decrease of VIL and of the height of maximum reflectivity indicate the begin of the storm decay, although the 45 dBZ Echo Top decreased only after 14:40 UTC.

A detailed observation of maximum grid-VIL in Fig. 2b shows that only a few pixels are in the intensity class 65-70 kg/m^2 and none is in the maximum measurable class 70-75 kg/m^2. On the other hand cell-VIL values above 70 kg/m^2 were measured for at least one hour (Fig. 3a). The cell-based method provides higher values than the grid-based one, because it integrates the maximum reflectivity from each vertical level, taking automatically into account the tilt of the storm core. For nowcasting purposes the combination of both information from a sequence showing the grid-based spatial extent of VIL as well as the cell-based time trends is probably the best.

It can be assumed that most of the damage claims collected by the Swiss Hail Insurance on 18 July 2005 around Lake Geneva were due to the discussed hailstorm since it was the only very severe cell passing over the lake this day. As shown in Fig. 2b by the "VIL hail swath" and overlaid insurance claims, several hail damages occurred in the area stroke by the supercell and denoting relatively high maximum VIL values. However some differences in location between the damage claims and "VIL swath" maxima are also visible. On the other hand it has to be considered that the interpretation of hail damage data in complex orography is sometimes not an easy task because of highly variable agriculture and population density.

4 Conclusions and outlook

First results indicate that the use of 3D multiple-radar severe storm detection products like cell- and grid-based VIL, 15/45 dBZ Echo Tops, and maximum storm reflectivity altitude, as well as CG lightning flash rates, show a potential benefit for assessing the severe weather potential of thunderstorms also in complex orography. In the Alpine area no reliable thunderstorms identification, tracking and 3D characterisation is possible without a sufficient resolution in height and time, here 20-elevations between -0.3° and 40° in 5 minutes.

Further improvements could be: First, the extension of the time series analysis (Fig. 3) to a forecast of the future development of a thunderstorm, i.e. to assess the stage in its life cycle. Second, to benefit from the strong orographic forcing existing in the mountains to improve the early detection of thunderstorms.

VIL shows some skill when used as a hail predictor also on a small spatial scale. Of course this first case study is not sufficient to establish VIL thresholds indicating the probability of hail at the ground. However, as could be expected from the literature, there is a first hint that values above 60 kg/m^2 are a good predictor for severe hail at the ground in the summer high hail season (15.6-15.8.). On the other hand damage locations in Fig. 2b indicate the occurrence of hail also at much lower values. This has to be further investigated by additional case studies.

Some open questions remain to be addressed, specifically concerning the vertical extension of the storms above 12 km height, which actually limits the use of VIL density, and the influence of radar beam shielding by the mountains on the VIL computation. Possible VIL thresholds indicating the probability of hail remain to be established for the Alpine area.

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