2.14 # NOWCASTING THUNDERSTORMS IN COMPLEX CASES USING RADAR DATA

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1. INTRODUCTION

Nowcasting of convection in the mountains is a challenging task because of the additional difficulties caused by the complex orography. In the Alpine region even relatively small but intense thunderstorms can produce local flash floods causing severe consequences (e.g. canyoning accidents, landslides) and damages. In densely populated areas the complex terrain requires thus the tracking and monitoring of individual, even relatively small thunderstorms. Moreover in the pre-Alpine and plateau region convective cells can organize at the meso-beta scale and must also be considered.

In the Alpine region the use of expert systems is limited by the restricted availability of some of the required input data (e.g. radar beam blocked at low altitudes not allowing the detection of convergence lines, Roberts and Rutledge (2003)). Since convective storms are still difficult to predict by operational numerical models, national weather services often use automatic systems based on the analysis of present weather and the extrapolation of already initiated phenomena. Operational nowcasting systems are mainly based on the use of radar echoes for the detection, tracking and extrapolation of precipitation events. An overview of actual convective storms nowcasting can be found in Wilson et al. (1998, 2004).

MeteoSwiss and Météo-France cooperate on the development and evaluation of an automated radar echo detection and tracking method based on a dynamic thresholding scheme applied on composite images. MeteoSwiss has introduced the scheme in 2003 under the name TRT (Thunderstorms Radar Tracking) as a part of its nowcasting, warning and information system (Hering et al., 2004). The forecaster receives automated information in real-time about cells activity, which he can use as a decision-making aid for convection warning. Météo-France uses the scheme under the name CONO (COnvection Nowcasting Objects), in SIGOONS (SIGnificant weather Object-Oriented Nowcasting System; Brovelli et al., 2005, in this issue).

The principle of the thresholding scheme is derived from the algorithms developed for the severe thunderstorms satellite nowcasting product RDT by Météo-France, within the framework of EUMETSAT's SAF Nowcasting. This product uses the infrared images of the 10.8 µm channel of geostationary satellites like Meteosat-8 to detect convective systems, from isolated cells up to mesoscale convective complexes (Morel et al., 2000, 2002). To make use of the satellite algorithms also for radar composite images, substantial modifications were required, mainly concerning the data input modules, the cell displacement velocity calculations, the clustering of cells, as well as the creation of a major post-processing of the output data. An overview of the main modifications necessary for the adaptation to radar data and a study of the algorithm parameters, such as the different reflectivity thresholds, as well as detailed description of the algorithms are given in Hering et al. (2004).

2. OVERVIEW OF THE THUNDERSTORMS RADAR TRACKING ALGORITHM

The TRT is a real-time object-oriented nowcasting tool for the identification, tracking and monitoring of intense convective precipitation systems. It consists

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of: i) a detection module for the identification of convective cells in a precipitation system, ii) a tracking module to link objects in consecutive radar images, and iii) a post-processing and a visualisation module to put the algorithms output at forecaster's disposal for real-time nowcasting activity and convection warning.

As input the TRT uses the reflectivity data of the Swiss composite image of 3 volumetric C-Band Doppler radars with a time resolution of 5 minutes. The Cartesian composite images have a spatial resolution of 2 km on 16 reflectivity classes between <13 and >55 dBZ (see Fig. 3). A 20-elevation volume scan between -0.3° and 40° is performed operationally. At present the vertical maximum projection from 12 constant altitude surfaces (CAPPI) between 1 and 12 km, is used for TRT. For a successful detection and tracking of even relatively small convective cells in complex orography it is necessary to have a qualitatively good radar network with effective clutter elimination algorithms. The reflectivity values used as input for the TRT have already passed a sophisticated 7-step clutter elimination algorithm and an extensive quality control program (Germann and Joss, 2004).

2.1 *The cell detection module*

The detection method is based on an adaptive reflectivity thresholding of radar images. This scheme allows the detection of convective cells at individual, cell-specific, thresholds, depending on the stage of their life cycle. Thunderstorms can thus be tracked very early during their growing phase as well as in the mature stage and as multicells agglomerations. For each cell the algorithm selects the lowest reflectivity threshold that allows to distinguish it from nearby cells (see Fig. 1).

It is based on three different reflectivity thresholds: dB_{th}, dB_{min}, and ΔdB_T. A cell is defined as a connected zone of radar pixels larger than a given area threshold (at present ≥ 4 pixels i.e. 16 km^2) and whose reflectivity exceeds an adaptive detection threshold (dB_{th}). This threshold must reach at least a minimum value dB_{min} (at present 36 dBZ, green line in Fig. 1), i.e. the lowest limit to be considered a convective cell. In order to detect only cells with a sufficient vertical extension (dynamic reflectivity range, blue arrows in Fig. 1), the difference between the maximum reflectivity value and the value at the base of a cell

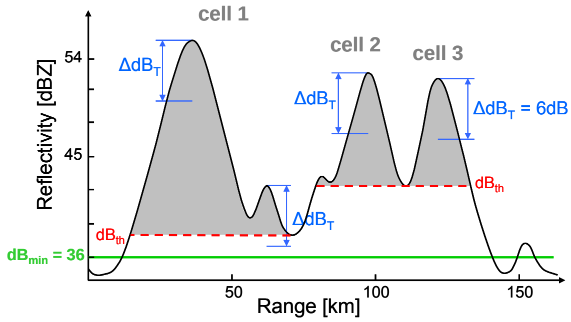


Fig. 1. Schematic illustration of the detection algorithm with a vertical reflectivity cross-section of an idealized precipitation system. Reflectivity thresholds: dB_{th} (detection), dB_{min} (minimum value), and ΔdB_T (vertical extension).

must be larger than a vertical extension threshold ΔdB_T (at present 6 dB). The lowest possible detection threshold (dB_{th}) satisfying these conditions is then chosen (red dashed lines in Fig. 1).

These rules lead to the detection of three cells in Fig. 1. The cells 1 and 2 both include a smaller and less intense cell that does not satisfy the vertical extension threshold ΔdB_T rule. The two small cells are thus incorporated in the larger cell. The cell at a distance of 150 km from the radar does not have a sufficient vertical extension and is rejected.

2.2 *The improved tracking module*

Detected cells are tracked in successive images by the tracking algorithm, based on the method of the geographical overlapping of cells. A detailed description is presented in Morel et al. (2000), Morel and Sénési (2002) and Hering et al. (2004). From a sequence of radar images it is then possible to create the time history of cell displacement and to draw a trajectory.

The principle of the tracking algorithm is to search for an overlapping between a cell C detected at time t and a cell C' detected in the following image at time t+Δt (Fig. 2a). The cell C(t) is first advected according to its displacement velocity (red arrow) to the position C(t+adv) (green cell in Fig. 2a). In case of a sufficient overlapping (grey area in Fig. 2a) between the advected cell and C'(t+Δt), a link (orange line in Fig. 2b) is created between these cells, and their centres are connected by a trajectory. Complex cases with several cells, splits and merges are also taken into account and are handled analogously, linking cells

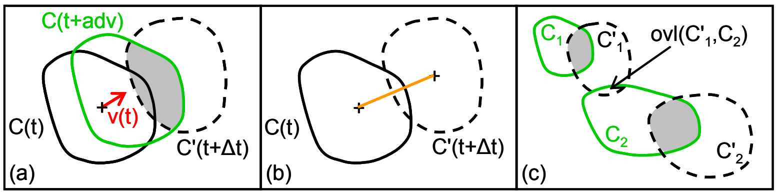


Fig. 2. Principle of the tracking algorithm. A simple overlapping (a) leads to a unique link (b) between cells at time t and t+Δt. A complex case (c) with a rejected secondary link between cell C'_1 and the advected cell C_2 because the overlapping ovl(C'_1,C_2) is less than a fixed percentage of cells area. Centres of gravity are represented by "+". Adapted from Morel and Sénési (2002).

with enough overlapping (Fig. 2c). The trajectories are then continued in the larger cell, whereas the smaller ones die (are born), ending (beginning new) trajectories.

The future storm position is estimated extrapolating the motion of individual cells up to 1 h, using their displacement velocities. Past location and speed is thus used to forecast future position. This linear extrapolation forecast method may be reliable for some tens of minutes, depending on the meteorological situation, the size and intensity of the cells.

The individual cell displacement velocity is thus used first to advect the cell for the overlapping check and then to extrapolate the thunderstorm motion. In the previous version of the tracking module the velocity was calculated based on the displacement of the gravity centre (Fig. 2b). This sometimes caused problems with the reliability of the velocity in complex situations like cells clusters, splits and merges, and significant area changes of a cell. These area changes are mainly due to the large spatial and temporal dynamics of the radar reflectivity field between two consecutive images. The algorithm is robust enough to hardly ever cause the loss of tracking due to an insufficient overlapping, even if the displacement velocity used to advect the cell is inaccurate. However, the limited reliability of the velocity in some complex cases led also to a poor quality of the motion extrapolation of individual cells.

In the improved actual version the cell velocity is calculated using a combination of the displacement of the gravity centre and a cross-correlation technique. If the difference of the cell area in two consecutive images exceeds a pre-defined threshold (at present 30%), the actual velocity is no longer determined by the displacement of the gravity centre, but the cross-correlation technique described in Morel et al. (2000) is used. To this purpose a reference window centred on the actual cell and adapted to its size, is extracted from the complete image. A search window is then extracted from the previous image, centred on the same point, and with the same size but enlarged by a margin to account for a maximum cell speed of 150 km/h. The correlation is calculated for all possible positions moving the reference window inside the search window. The actual velocity is derived from the position with the highest correlation. Using this combination technique it is possible to minimize the mentioned problems in complex situations. Residual noise in the displacement vector of an individual cell is removed with a temporal smoothing filter.

In case of splits and merges of convective cells, the algorithm calculates the displacement velocity using the cross-correlation technique if the cells areas differ more than 30%. Otherwise the centre of gravity of the cells group involved in the split/merge process is computed before and after the process and used for the velocity calculation.

3. VISUALISATION OF THE TRT

At MeteoSwiss the operational real-time visualisation of the TRT-tool is done with a HTML-format using a browser. It consists of a main image (Fig. 3) available as a loop (including zoom capabilities), with a superimposition of the graphical representation of detected and extrapolated convective objects onto the composite radar image. Detected cells are represented by their contours, which delineate the effective detection thresholds (dB_{th}). The trajectories indicate the historical and the actual cell positions. They are computed connecting cells centres. The weighted displacement velocities

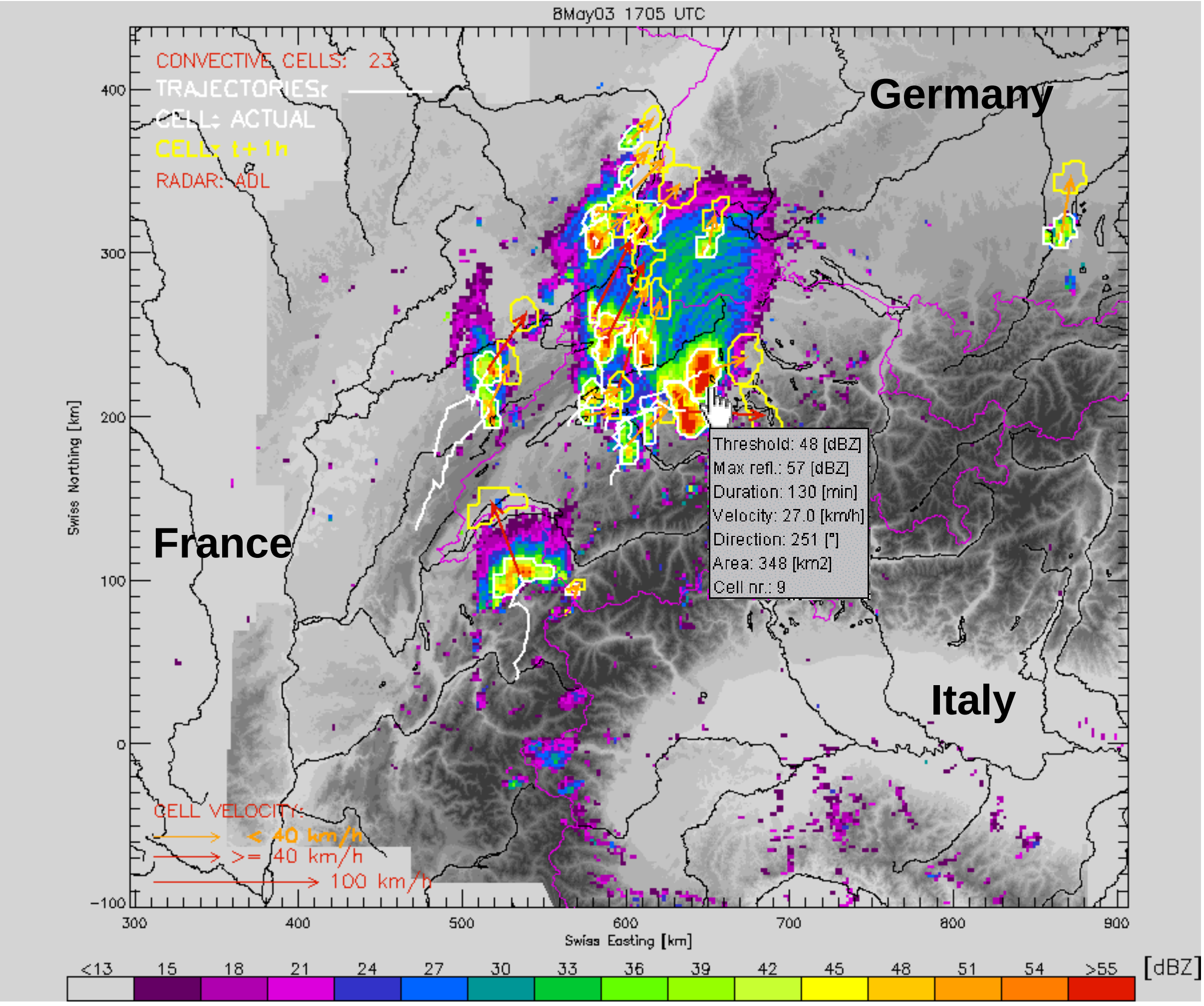


Fig. 3. Operational visualisation of the real-time TRT-product (8 May 2003, 17:05 UTC) over the Alpine region, with the national borders represented in violet. Superimposition of the Swiss composite radar image, detected cells (white contours), trajectories (white lines), estimated velocities (≥40 km/h: red vectors; <40 km/h: orange vectors), and extrapolated cells positions (+ 1h; yellow contours).

(arrows) give an estimate of the future position of the thunderstorm at + 1h (yellow cells).

Moving the mouse inside the contour of a desired cell, a second visualisation level appears in the form of a pop-up window containing additional, cell-specific, actual numerical attributes like detection threshold, maximum reflectivity, trajectory duration, speed, direction and area. Finally clicking inside a cell we can activate the third visualisation level. In a separate window it shows in four diagrams the time histories of the past evolution of different cell attributes like maximum cell reflectivity, detection threshold, cell rain rates and accumulated precipitation, cell area at different reflectivities in 3 dB steps (Fig. 4), and cell velocity and direction (Fig. 5).

The time series of the cell area at different reflectivities is visualised in Fig. 4. The logarithmic area scale puts special emphasis on the highest reflectivities that are also the most relevant for the evaluation of cell severity.

In autumn 2005 the TRT output will be visualized operationally from the new *NinJo* workstation visualisation platform (Joe and Falla, 2004), as part of the storm classification, identification and tracking layer (Joe, 2005). From summer 2005 on, lightning detection data will be ingested into TRT and represented for each cell by time series like in Fig. 4, allowing a further characterisation of the convective objects.

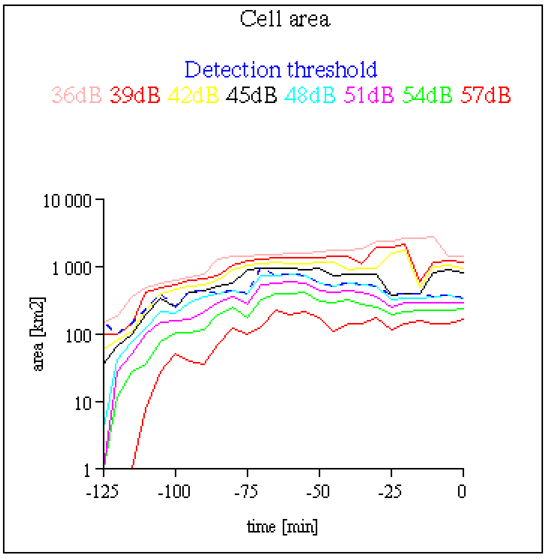


Fig. 4. Real-time operational visualisation of the time series of past evolution of cell area at different reflectivities for the cell in the image in Fig 3 (8 May 2003, 17:05 UTC). The detection threshold is represented by a dashed blue line.

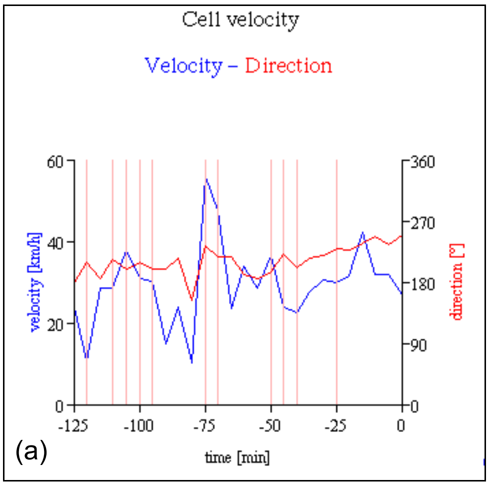
4. TRACKING THUNDERSTORMS IN COMPLEX CASES IN THE ALPINE AREA: A CASE STUDY FROM 8 MAY 2003

We discuss the performance of the actual algorithm for the case study of 8 May 2003. A large convective storm (indicated by the "hand" in Fig. 3) developed from 15:00 UTC on, in the pre-Alpine region of Switzerland and moved to southern Germany lasting until 23:00 UTC. Warm and humid air was advected from the southwest to western Switzerland. This increased the already existing instability of the atmosphere. In the afternoon thunderstorms activity started in this region leading to the formation of several intense convective cells, slowly moving to northeast (as can be seen in Fig. 5b for the storm mentioned above) and accompanied by hail tracks extending to eastern Switzerland.

On the radar image in Fig. 3 one recognizes 23 detected cells of different sizes (from a few pixels up to a size of about 50x20 km) and intensities. The highest reflectivity class in our pictures corresponds to >55 dBZ (indicated as 57 dBZ in Fig. 4), and the maximum reflectivities of the cells are in the range 42 dBZ to >55 dBZ. Pixels ≥54 dBZ indicate also a hail probability at the ground.

The complex situation is caused by several consecutive cell merges and splits (vertical lines in Fig. 5), influenced by the orography. This permits to assess the improvements in the quality of the cell speeds and directions calculations discussed in section 2.2. The improvements of the actual version lead to a considerable increase of the regularity of the cells velocity evolution (blue curve in Fig. 5b) and also of the cells direction (red curve in Fig. 5b) compared to the previous algorithm (Fig. 5a). These attributes are now much less influenced by cells splits and merges.

The quality of the position forecast depends on the reliability of the velocity vectors. A regular evolution in the latest time steps, as in Fig. 5b, indicates a useful extrapolation for some tens of minutes. On the other hand vectors strongly varying in direction and speed,



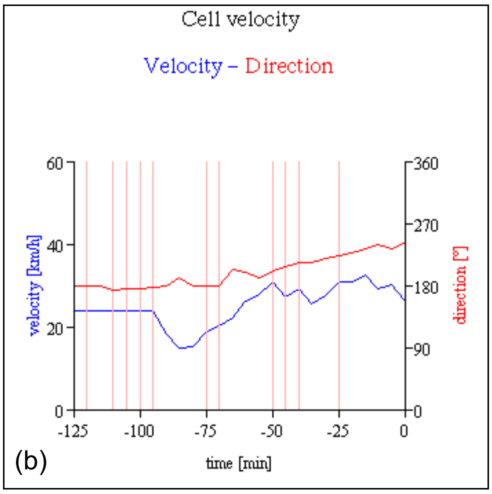


Fig. 5. Time series of past evolution of cell velocity and direction using the previous (a) versus the improved actual (b) algorithm for the cell in the image in Fig. 3 and Fig. 4 (8 May 2003, 17:05 UTC). Vertical lines indicate past cell splits and merges.

as in Fig. 5a for speed, indicate an unreliable forecast and the future cell position is thus inaccurate. The time series of past evolution of cell velocity and direction are thus very useful to assess the quality of the position extrapolation.

From these velocity diagrams no statements are possible concerning the formation of new cells or the decay of an existing cell. For that purpose the evolution of the cell area at different reflectivities (Fig. 4) can give a hint on the development phase of a thunderstorm. Especially the evolution of the curves of the higher reflectivities is useful in this context. The thunderstorm in Fig. 4 is well in his mature phase.

To asses the convective phase the forecaster can also use the variation of the accumulated precipitation of a single cell, calculated simply adding the values of all cell pixels transformed to precipitation rates. The lightning activity will also be included in the phase estimate. These various types of cell characteristics combined with experience from the past, will help to better evaluate the development phase of the storm.

5. FIRST OPERATIONAL RESULTS AT METEOSWISS

Based on the improved TRT version, during summer 2005 MeteoSwiss will start 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. Usually the thunderstorm warning is broadcasted in probabilistic form. On the very short time scale users require deterministic information: where, when and which effects are expected. The TRT is the main tool to track the cells, estimating the future path and severity (i.e. hail or wind gust), as well as the phase of the convection (along with other data like satellite and ground stations). At the conference first results of the real time validation of the warnings will be presented.

6. SUMMARY AND OUTLOOK

The TRT-tool is used operationally with success at MeteoSwiss for the real-time automatic identification, tracking and monitoring of intense convective cells, based on radar composites. It uses an adaptive thresholding scheme, allowing the detection of cells at individual thresholds, depending on the stage of their life cycle. This permits an early detection of potentially severe cells, as well as the tracking of mature systems. Once the cells are detected, they are tracked in successive images based on the method of geographical overlapping. Splits and merges are also taken into account and cells tracks are created from a sequence of radar images. The actual version of the algorithm uses a substantially improved velocity calculation module, based on a combination of cross-correlation and displacement of gravity centres, as well as a temporal smoothing function, to determine cells displacement velocities also for complex splits/merges situations. To estimate future storm position, the motion of individual cells is extrapolated up to 1 h, using their displacement velocities. The improved TRT version will be used as a decision-making aid to diffuse thunderstorms warnings in whole Switzerland by local and national radio stations in summer 2005.

Time histories of several cell attributes are also calculated by TRT allowing the forecaster to assess the development phase of a thunderstorm for nowcasting purposes. The ingest of lightning data will be a further improvement in this context, allowing the discrimination of convective systems and giving an additional hint at the phase. The visualisation in the new *NinJo* platform will open additional possibilities to directly compare cells attributes with several cell views available from the radar layer products, like any kind of vertical and horizontal cross-sections.

At present we use the vertical maximum projection of reflectivity as input for TRT. The planed more extensive use of 3D reflectivity data to derive additional cell properties (e.g. height of max reflectivity, echo top, VIL, probability of hail,...) will allow a comprehensive characterisation of convective cells, as well as a further characterization of their development.

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7. REFERENCES

Brovelli, P., S. Sénési, E. Arbogast, Ph. Cau, S. Cazabat, M. Bouzom, J. Reynaud, 2005: Nowcasting thunderstorms with SIGOONS, a significant weather object oriented nowcasting system. In this issue.

Germann, U., and Joss, J., 2004: Operational measurement of precipitation in mountainous terrain. In P. Meischner, editor, *Weather Radar: Principles and Advanced Applications*, vol. XVII of *Physics of Earth and Space Environment*, chap. 2, pp. 52-77, Springer-Verlag.

Hering, A. M., C. Morel, G. Galli, S. Sénési, P. Ambrosetti, and M. Boscacci, 2004: Nowcasting thunderstorms in the alpine region using a radar based adaptive thresholding scheme. Proceedings, *Third ERAD Conference*, Visby, Sweden, 206-211.

Joe, P., and M. Falla, 2004: Radar visualization in the NinJo project. Proceedings, *Third ERAD Conference*, Visby, Sweden, 550-555.

Joe, P., 2005: Severe weather forecasting tools in the NinJo workstation. In this issue.

Morel, C., S. Sénési, F. Autones, and L. Labatut, 2000: The Rapid Developing Thunderstorms (RDT) product of the nowcasting SAF. Prototyping activities and quality assessment using GOES images. Proceedings, *The 2000 Meteorological Satellite Data Users' Conference,* Eumetsat and CNR, Bologna, Italy, 698-705.

Morel, C., S. Sénési, and F. Autones, 2002: Building upon SAF-NWC products: Use of the Rapid Developing Thunderstorms (RDT) product in Météo-France nowcasting tools. Proceedings, *The 2002 Meteorological Satellite Data Users' Conference,* Eumetsat and Met Eirean, Dublin, Ireland, 248-255.

Morel, C., and S. Sénési, 2002: A climatology of mesoscale convective systems over Europe using satellite infrared imagery. Part I: Methodology. *Q. J. R. Meteorol. Soc.*, **128**, 1953-1971.

Roberts, R., and S. Rutledge, 2003: Nowcasting storm initiation and growth using GOES-8 and WSR-88D data. *Wea. Forecasting,* **18**, 562-584.

Wilson, J. W., N. A. Crook, C. K. Mueller, J. Sun, and M. Dixon, 1998: Nowcasting thunderstorms: a status report. *Bull. Amer. Meteor. Soc.,* **79**, 2079-2099.

Wilson, J. W., E. E. Ebert, T. R. Saxen, R. D. Roberts, C. K. Mueller, M. Sleigh, C. E. Pierce, and A. Seed, 2004: Sydney 2000 forecast demonstration project: convective storm nowcasting. *Wea. Forecasting,* **19**, 131-150.